

**HOW MANIPULABILITY (GRASPABILITY AND FUNCTIONAL USAGE)
INFLUENCES OBJECT IDENTIFICATION**

by

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DALHOUSIE UNIVERSITY
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DEDICATION PAGE

This degree, and the content of this dissertation is dedicated, first and foremost to my wife, Marsha, who stayed by my side and supported my endeavors for 12 years now, the majority of which have been spent working towards this degree. Any stress and strain brought on by this degree we endured together, and I am forever grateful for her continued love and patience.

I would also like to dedicate a portion of this work to my late grandmother, Kay Paul, a sweet and nurturing soul who passed from this life quite unexpectedly two years ago. Too soon to see my cousin (William) and I graduate, but I know she was proud of both of us.

Finally, I would like to dedicate this work to my son, Theodore, who will be about a year old at the time I graduate. He does not yet understand why his father spends so much time at the computer, but with time, I hope, he'll come to understand the significance of this work and its meaning for our family.

TABLE OF CONTENTS

LIST OF TABLES	ix
LIST OF FIGURES.....	xi
ABSTRACT.....	xvi
LIST OF ABBREVIATIONS USED.....	xvii
ACKNOWLEDGEMENTS	xix
CHAPTER 1 INTRODUCTION	1
1.1 BRIEF HISTORY OF THEORIES OF VISUAL OBJECT IDENTIFICATION.....	6
1.2 DIFFERENT MODEL ARCHITECTURES OF OBJECT IDENTIFICATION & ACTION SYSTEMS	9
1.3 ARCHITECTURE A. ACTION <i>AFTER</i> SEMANTICS	15
1.4 ARCHITECTURE B. ACTION <i>BEFORE</i> SEMANTICS.....	19
1.5 ARCHITECTURE C. ACTION <i>PARALLEL</i> TO SEMANTICS	25
1.6 ARCHITECTURE D. ACTION REPRESENTATION <i>WITH</i> OR <i>AS</i> SEMANTICS	40
1.7 OTHER ARCHITECTURES: CONSIDERING MULTIPLE ACTION SYSTEMS.....	42
1.8 OUTLINE OF THE CURRENT RESEARCH.....	44
1.9 REFERENCES	46
CHAPTER 2 NORMS FOR TWO TYPES OF MANIPULABILITY (GRASPABILITY AND FUNCTIONAL USAGE), FAMILIARITY, AND AGE OF ACQUISITION FOR 320 PHOTOGRAPHS OF OBJECTS.....	57
2.1 ABSTRACT.....	58
2.2 INTRODUCTION TO THE NORMING STUDY	59
2.3 METHODS.....	65
2.4 RESULTS.....	72
2.5 DISCUSSION	80
2.6 ENDNOTES	83
2.7 REFERENCES	84
2.8 APPENDIX A.	88
2.9 APPENDIX B.....	89

CHAPTER 3	THE INFLUENCE OF OBJECT MANIPULABILITY ON CATEGORIZATION AND NAMING OF BACKWARD-MASKED PHOTOGRAPHS SHOWN FOR BRIEF DURATIONS: A REVERSAL EFFECT FOR OBJECT MANIPULABILITY.....	94
3.1	ABSTRACT.....	95
3.2	INTRODUCTION.....	96
3.3	THE CURRENT STUDY: EARLY VISUAL PROCESSING, BRIEF EXPOSURE AND MASKING	106
3.4	EXPERIMENT 1 – CATEGORIZATION.....	106
3.5	METHODS.....	107
3.6	RESULTS.....	113
3.7	DISCUSSION	116
3.8	EXPERIMENT 2 - NAMING	120
3.9	METHODS.....	121
3.10	RESULTS.....	124
3.11	DISCUSSION	129
3.12	GENERAL DISCUSSION.....	136
3.13	REFERENCES	144
3.14	SUPPLEMENTARY APPENDIX A1. LIST OF OBJECTS USED (AND CORRESPONDING RATINGS)	155
3.15	SUPPLEMENTARY APPENDIX A2. BLOCK 1 (ONLY) ANALYSIS.....	159
3.16	SUPPLEMENTARY APPENDIX A3. SIMILARITY AND RT?	161
CHAPTER 4	MODELING A CATEGORIZATION AND NAMING REVERSAL BASED ON OBJECT MANIPULABILITY: CONSIDERING THE ROLE OF SEMANTIC ORGANIZATION, ACTION, & SIMILARITY	166
4.1	ABSTRACT.....	167
4.2	COMPUTATIONAL MODELING INTRODUCTION	168
4.3	METHODS: THE BASIC ARCHITECTURE OF THE NAMING ACTION MODEL.....	175
4.4	TESTING THE THREE MECHANISMS.....	178
4.5	EXPLORING THE PLAUSIBILITY OF THESE MECHANISMS: BACK TO THE STIMULUS SET	199
4.6	GENERAL DISCUSSION.....	201
4.7	REFERENCES	208

4.8	SUPPLEMENTARY APPENDIX SA1. NAMING ACTION MODEL EXTENSION DETAILS....	215
4.9	SUPPLEMENTARY APPENDIX SA2. MATLAB SYNTAX FOR MODIFIED NAMING ACTION MODEL	221
CHAPTER 5	EFFECTS OF OBJECT MANIPULABILITY (GRASPABILITY AND FUNCTIONAL USAGE) ON MASKED AND UNMASKED OBJECT IDENTIFICATION.....	229
5.1	ABSTRACT.....	230
5.2	INTRODUCTION.....	231
5.3	EXPERIMENT #1: OBJECT NAMING	241
5.4	METHODS.....	243
5.5	RESULTS.....	246
5.6	DISCUSSION	253
5.7	EXPERIMENT #2: PICTURE-WORD MATCHING	255
5.8	METHODS.....	257
5.9	RESULTS.....	260
5.10	DISCUSSION	266
5.11	GENERAL DISCUSSION.....	268
5.12	APPENDIX A – OBJECT AND FOIL LIST	275
5.13	REFERENCES	278
5.14	SUPPLEMENTARY APPENDIX A. RT SCATTERPLOTS.....	284
CHAPTER 6	PHOTOGRAPHS OF MANIPULABLE OBJECTS ARE NAMED MORE QUICKLY THAN THE SAME OBJECTS DEPICTED AS LINE-DRAWINGS: EVIDENCE THAT PHOTOGRAPHS ARE MORE EMBODIED THAN LINE- DRAWINGS?	287
6.1	ABSTRACT.....	288
6.2	INTRODUCTION.....	289
6.3	MATERIALS AND METHODS	293
6.4	DATA ANALYSIS	295
6.5	RESULTS.....	298
6.6	RESULTS SUMMARY (ACROSS ANALYSES).....	302
6.7	DISCUSSION	303
6.8	CONCLUSIONS.....	305
6.9	REFERENCES	306

6.10	APPENDIX A. (A LIST OF THE 222 OBJECTS/ITEMS USED)	309
6.11	APPENDIX B – NEW LINE DRAWINGS (BY ANDREA RANKIN)	311
CHAPTER 7	GENERAL DISCUSSION	312
7.1	CHAPTER 2: THE VALUE OF A GOOD STIMULUS SET (AND RATINGS).....	313
7.2	CHAPTER 3: SHOWING EFFECTS OF MANIPULABILITY ON IDENTIFICATION TASKS...	316
7.3	CHAPTER 4: MODELING SEMANTIC IMBALANCE/ORGANIZATION OF THE SYSTEM .	320
7.4	CHAPTER 5: GRASPABILITY VERSUS FUNCTIONAL USE, IS THERE REALLY A DIFFERENCE?.....	326
7.5	CHAPTER 6: PHOTOGRAPHS VERSUS LINE DRAWINGS – TYING UP LOOSE ENDS	330
7.6	RELATING OUR GRASPABILITY AND FUNCTIONAL USE RATINGS TO THE BIGGER PICTURE	333
7.7	HOW DO THESE RESULTS RELATE TO EMBODIMENT?.....	341
7.8	CONCLUDING REMARKS	352
7.9	FUTURE DIRECTIONS	353
7.10	REFERENCES	355
7.11	APPENDIX A – UNREPORTED / UNPUBLISHED RESEARCH.....	363
	BIBLIOGRAPHY.....	368
	APPENDIX: COPYRIGHT PERMISSIONS	392

LIST OF TABLES

Table 2.1.	Examples of object categories expected to fall in each cell of the factorial design.	64
Table 2.2.	Familiarity norm correlations across studies. *** $p < .001$	75
Table 2.3.	Age of Acquisition (AoA) norm correlations across studies. *** $p < .001$ ^a based on an N = 184. ^b based on an N = 83. ^c based on an N = 61.....	76
Table 2.4.	Manipulability correlations to Magnie ratings. *** $p < .001$, * $p < .05$, ^a smallest N = 178 for these, ^b for these correlations N as low as 36 to 43 items.....	78
Table 2.5.	Differences between current and Magnie et al. (2003) ratings on Manipulability. Columns show current classification (as either manipulable/non-manipulable). Rows show Magnie et al. (2003) classification (MM Index). Items in bold indicate objects classified differently, underlined objects represent those classified similarly.	79
Table 2.6.	Inter-item correlations, familiarity, AoA and Manipulability. N = 320 for all items except those correlated to Manip2 (N=178 in this case).	80
Table 3.1.	Average ratings for objects in each group. Each group consisted of 60 objects (that is 60 manipulable and 60 non-manipulable objects). Note, Age of Acquisition (AoA) was on a 7-point Likert scale (1=young AoA, 7=old AoA), Familiarity (Fam) on a 5-point scale (1=low Fam, 5=high Fam), and Manipulability (Manip) on 5-point scale (1=low Manip, 5=high Manip).	109
Table 3.2.	List of significant main effects and interactions (underlined) and key effects that were not significant (grey). Partial Eta-Squared (η^2).	114
Table 3.3.	Subject Analysis repeated measures ANOVAs effects and interactions. Partial Eta-Squared (η^2). One participant was excluded from the RT analysis because of very high error rates at short EDs compared to other participants (less than 10% of objects in category correct, i.e. over 90% error in one of the cells of the design).	126
Table 3.4.	Abbreviations for the eight reaction times (left), and the five measures of visual similarity explored.....	163
Table 3.5.	Summary of results from the eight multiple regression analyses. The “OVERALL” column summarizes the significance of the overall regression. The other columns summarize whether each individual measure of visual similarity was significant in the analysis. Note that the degrees of freedom vary since analysis was done at the item level, and not all items were identified equally accurately in each condition. Further note that significance was evaluated at the $\alpha_{CRIT} = .05 / 8 = .006$, with * to indicate the results that were significant, although values below .05 were marked with a t.	164
Table 4.1.	Language around semantic organization mechanism and predictions.....	191
Table 4.2.	Average number of categories generated for 30 objects.	200
Table 5.1.	Linear Mixed-Effects Regression effect sizes for model including Manip1 (Model 1.1), $n = 320$	249
Table 5.2.	Linear Mixed-Effects Regression effect sizes for including Manip2 (Model 1.2), $n = 178$	249
Table 5.3.	Linear Mixed-Effects Regression effect sizes for model including Manip1 (Model 2.1).....	262

Table 5.4.	Linear Mixed-Effects Regression effect sizes for model including Manip2 (Model 2.2)	262
Table 5.5.	A comparison between the tasks used in the current research to those used by Salmon, McMullen and Matheson (submitted), and the results. The cells matching characteristics of the Picture-Word matching task are highlighted in grey. Notably, although the picture-word matching task requires the same type of response as the categorization task (two button on the keyboard), the level at which the object is identified is more equivalent to a naming task and so are the corresponding results.	268
Table 7.1.	Average number of (super-ordinate level) categories generated for 30 objects of the following types.....	350

LIST OF FIGURES

Figure 1.1.	Simple Box-and-Arrow models of visual object identification. (A) Some visual input gets passed through some unknown cognitive process ‘???’ to arrive at an appropriate output. (B) Example, a picture of an dog gets labeled with a person speaking the word “dog”. (C) “Semantics”, an amodal store of the representation of known objects thought to be at least part of the necessary steps involved in translating a visual representation of object into a verbal one. (D) Examples of the layers or levels of representation that can exist for a single object. In this example, most participants naturally label the photograph “dog” at the basic level. But the same stimuli could appropriately be labeled “animal” (superordinate) or “golden retriever” (subordinate). 12
Figure 1.2.	Building “Action” into our current input-semantics-output model of identification there are a number of possibilities about where the “action” can be represented. In panel D, the * beside semantics denotes that it a proper embodied cognition model with action representation as a part of distributed representation of the entire object, the term “semantics” may no longer be appropriate. 13
Figure 1.3.	Examples of poorly delineated and novel objects all affording some action. A & B represent two ways of putting together “geons” to make manipulable objects. C. Represents a poorly delineated tool like a mallet or hammer. D & E represent novel but still graspable/manipulable objects, reprinted from Cant and Goodale (2007) with permission. 20
Figure 1.4.	(A) Direct and indirect routes to action through the structural description system. Reprinted from Yoon, Heinke, and Humphreys (2002) with permission from the publisher as originally cited from Riddoch, et al. (1989). (B) The Naming-Action model (NAM), reprinted from Yoon, Heinke, and Humphreys (2002), with permission. 29
Figure 2.1.	An example of two trials during the rating experiment. “♪” indicates where a warning tone was played to alert participants (and the experimenter) that a new trial was about to start. Words in the bubbles indicate numbers being said by experimenter. 70
Figure 3.1	Example objects in each category. Each of the four cells was comprised of 30 objects, for a total object set of 120 objects. See Supplementary Appendix A1 for a complete list of the 120 objects.	... 108
Figure 3.2	General method employed. (Show Experiment #1 Categorization & Experiment #2 Naming).	... 111
Figure 3.3	Bars show average reaction times (RT) in milliseconds for Categorization of Manipulable (black) versus Non-Manipulable (grey) objects. Percent error is shown with the solid and dashed line. X-axis indicates exposure duration or ED (short-35ms, or long-105ms). Note, smaller bars indicate faster RTs, and lower lines indicate fewer errors. Error bars indicate the standard error.	... 115

Figure 3.4.	(A) Reaction time (RT) and error rates for Manipulability by Exposure Duration (ED). Bars show average reaction times (RT) in milliseconds for Naming of Manipulable (black) versus Non-Manipulable (grey) objects. Percent error is shown with the solid and dashed line. Error bars indicate the standard error. (B) Error rates (% error) for the Manipulability by ED by block 3-way interaction. Block 1 represented by solid lines, and block 2 represented by dashed lines. Note: Task was naming, so there was no “chance” level – the only correct reply was the correct name of the object, meaning chance guessing accuracy would be close to 0%. X-axis indicates exposure duration or ED (short-35ms, or long-105ms). Note, smaller bars indicate faster RTs, and lower lines indicate fewer errors.	... 127
Figure 3.5.	Reaction time (RT) for the Task (across experiments) by Manipulability interaction. Note that the same manipulable objects (dark grey) are named more quickly despite being categorized more slowly compared to non-manipulable objects (light grey). Error bars indicate the standard error.	... 135
Figure 3.6.	Examples of flips and rotations that were done to the stimulus set to align features of the objects for subsequent similarity analyses.	... 161
Figure 4.1.	Basic schema of the Naming Action model (NAM) as shown in Yoon, Heinke & Humphreys (2002).	... 174
Figure 4.2.	Basic dynamics of the Naming Action Model (NAM) in response to a picture (input to structural description system). The black horizontal line represents a threshold set at 0.9. The blue line represents average activity of the winning node in the Action module. The red line represents average activity in the winning node of the Naming module. Vertical lines indicate the amount of time (number of iterations) it took the network before a winner was chosen (equivalent to estimation of reaction time for a human participant). The above figure was generated in MATLAB as a reproduction of the original dynamics of Yoon et al.’s (2002) NAM.	... 177
Figure 4.3.	Depiction of the dynamics of the action module (each line represents activity within one of the nodes) when shown a manipulable object (A) versus and non-manipulable object (B). Notice that when the action module is shown a manipulable object (A), that over time, one of the nodes will reach a maximum firing rate as the system correctly identifies the action associated with that object. On the other hand, when the action module is shown a non-manipulable object (B) none of its nodes reach maximal firing, regardless of time (although the module retains a base level of low activity that has minimal impact on the other modules of the system).	... 180
Figure 4.4.	The new model architecture with (B) and without (A) the action output module. Note how adding the action output module (B) creates an asymmetry in the model (in the case where only pictures are considered as input).	... 181
Figure 4.5.	Results from the symmetric model show no effect of manipulability (left), the Action Added model shows a manipulability effect for naming (centre), and the original behavioural data shows a cross-over interaction (reversal effect) between manipulability and task (right). Note that these results represent the average of 10 runs for each model with new random ‘stimuli’ generated for each run (to ensure that final results were not artefactually based on one anomalous randomization of input to the model).	... 182

Figure 4.6.	A depiction of how similarity appears as input to the model (a vector of random numbers for each unique item). Each number would represent some feature of an object and some associated value. For example, the first number could represent the number of curved lines in an object, the second number could represent number of vertices, etc. Note that for these similarity simulations, non-manipulable objects were set to have more within-category similarity by setting these numbers to be equal. In the example above, note, the two Non-manipulable objects (A & B) begin with the same two values (4, 10) which will make them appear more similar to the model (in this case, the vectors have a length of four, so these objects are 50% similar, or half their features are shared). On the other hand, Manipulable objects C & D have no shared values and therefore have 0% similarity.	... 186
Figure 4.7.	Results from Similarity simulations that varied in degree of similarity.	... 187
Figure 4.8.	The left panel shows a representation of non-manipulable (blue) and manipulable (red) objects with equal/balanced semantic organization between the two categories of objects. The right panel shows an unbalanced mapping, with manipulable (red) objects mapping to more super-ordinate semantic categories than non-manipulable (blue) objects. This results in more low-ratio mappings (or super-ordinate categories) for the same number of manipulable objects.	... 193
Figure 4.9.	Another depiction of the semantic organization differences hypothesis is shown in the context of the overall model where the circles in the super-ordinate knowledge represent nodes that fire maximally for manipulable categories of objects (dark grey) or non-manipulable categories of objects (light grey). Circles in the item-specific knowledge represent nodes that fire maximally to the presentation of an object. Notice, to test the semantic organization differences hypothesis, there are more super-ordinate manipulable categories for the same number of manipulable objects (but each of those categories would contain fewer items – i.e. a greater number of sparse categories).	... 194
Figure 4.10.	Results from semantic organization differences of different strengths. Note: Larger effects of manipulability reversal when differences in organization are more pronounced.	... 195
Figure 4.11.	A depiction of semantic organization differences that can lead to super-ordinate category-based reversals.	... 197
Figure 5.1.	Masked and Unmasked versions of some of the objects.	... 244
Figure 5.2.	Manipulability effect sizes (betas) during object Naming for Masked and non-Masked conditions (simple effects analyses). Note that negative betas are plotted up, and indicate a relationship between higher scores on manipulability and faster RTs, with each beta coming from a different analysis. Also note that masking interrupts these effects in different ways for the two types of manipulability. For Manip1 (graspability), effects are larger for non-masked items, but for Manip2 (functional use), effects are larger for masked items.	... 251

Figure 5.3.	Manipulability effect sizes (betas) during Word-Picture Matching for Masked and non-Masked conditions (simple effects analysis). Note that negative betas are plotted up, and indicate a relationship between higher scores on manipulability and faster RTs. Also note that masking interrupts these effects in different ways for the two types of manipulability. For Manip1 (graspability), effects are larger for non-masked items, but for Manip2 (functional use), effects are larger for masked items. These findings are consistent with those from Experiment #1 (Picture Naming).	... 264
Figure 5.4.	Reaction Time Data for Naming Experiment (each dot represents one of the items). Note: fewer dots for Manip2 data, as fewer items had ratings on this scale. R^2 values represent effect of the predictor in isolation (without the effects of familiarity and AoA).	... 284
Figure 5.5.	Data for Manip1 Masked & Not-Masked. In both cases, a polynomial fit explained more variance than a linear fit. (This fit was significantly better for the masked objects).	... 285
Figure 5.6.	Reaction Time Data for the Matching Experiment (each dot represents one of the items). Note: fewer dots for Manip2 data, as fewer items had ratings on this scale.	... 286
Figure 6.1.	Examples of photographs and line drawings of the same objects, with “manipulable” objects in the left-most columns, and “non-manipulable” objects in the right-most columns.	... 295
Figure 6.2.	The RT means for the two-way interaction between Depiction and Manipulability, showing larger effects of object depiction (photographs versus line drawings) for manipulable than non-manipulable objects. Error bars show the 95% confidence intervals.	... 300
Figure 7.1.	Example photos from the 320 object photograph set we normed on two types of manipulability, familiarity and age of acquisition (AoA). Reprinted from Salmon, McMullen and Filliter (2010).	... 314
Figure 7.2.	A depiction of the manipulability by task reversal observed in chapter 3. Manipulable objects were named more quickly, but categorized more slowly.	... 317
Figure 7.3.	Our model architectures for an extended version Naming Action Model by Yoon, Heinke & Humphreys (2002). Architectures shown with and without a dedicated action output module.	... 321
Figure 7.4.	A depiction of semantic branching/imbalance can lead to super-ordinate category-based reversals. Relative to sparse categories (red) the crowded (blue) categories are faster to categorize because of collective activity in the category building up evidence faster. However, these same categorizes are slower to name because there’s more competition within the category.	... 323
Figure 7.5.	Masked and un-masked versions of the stimuli used in chapter 5. Note, the right panel shows examples of manipulable objects, the left non-manipulable objects. Furthermore, the top panel shows manmade objects, and the bottom panel natural objects.	... 326

Figure 7.6.	Manipulability effect sizes (betas) during object Naming (left-side) and Picture-Word Matching (right-side) for Masked and non-Masked conditions (simple effects analyses) in chapter 5. Note that negative betas are plotted up, and indicate a relationship between higher scores on manipulability and faster RTs, with each beta coming from a different analysis. Also note that masking interrupts these effects in different ways for the two types of manipulability. For Manip1 (graspability), effects were larger for non-masked items, but for Manip2 (functional use), effects are larger for masked items.	... 328
Figure 7.7.	Examples of photographs and line drawings used in chapter 6. Note, this experiment involved the same objects depicted as photographs or line-drawings, as well manipulable (left panel) and non-manipulable (right-panel) objects.	... 330
Figure 7.8.	The RT means for the two-way interaction between Depiction (photograph versus line-drawing) and Manipulability (manipulable versus non-manipulable), showing larger effects of object depiction (photographs versus line drawings) for manipulable than non-manipulable objects.	... 331
Figure 7.9.	Model for multiple action systems presented in the Introduction (left panel). The right panel shows that same model including the two types of manipulability with <i>graspability</i> with its own dedicated module, and <i>functional use</i> as part of semantics.	... 334
Figure 7.10.	Diagram from Buxbaum and Kalenine (2010) mapping function onto neuroanatomic substrate (reprinted with permission from the publisher). Schematic includes the sub-division between the dorsal pathway (red and green arrows), as well as the ventral stream (blue arrow).	... 338
Figure 7.11.	Diagram from Buxbaum and Kalenine (2010) with plausible over-lap from current dissertation added. Specifically, our first manipulability ratings (graspability) likely capture aspects of the dorso-dorsal stream, and are maximally active during fast identification tasks where the complete object is visible (e.g. the non-masked photo of the cell-phone in the top-right corner). Our second type of manipulability ratings (functional use) likely captured aspects involved in both the ventro-dorsal and ventral streams, and are maximally active during slower identification tasks where the object is presented for a brief exposure duration and/or is degraded with a mask (e.g. the masked photo of the cell-phone in the bottom-right corner).	... 341
Figure 7.12.	Results from the 3 orientation study (circa Apr 2007) using line-drawings. Of note, no significant differences between manipulable and non-manipulable objects at any object rotation. Error bars represent standard error.	... 365
Figure 7.13.	Results collected by Dr. McMullen and one of her students prior to my arrival in the lab. Highlighted is the suggested difference between manipulable and non-manipulable objects rotated either 60 degrees or 300 degrees away from the canonical orientation, that we were attempting to replicate. Error bars indicate standard error.	... 365
Figure 7.14.	Results from my attempted replication (circa July 2007) of the study from Figure 7.13. As before, y-axis indicates reaction time, and x-axis indicates object orientation. Of note, no replication of the difference between objects at 60 and 300 degrees. Error bars indicate standard error.	... 366

ABSTRACT

In our environment we do two things with objects: identify them, and act on them. Perhaps not coincidentally, research has shown that the brain appears to have two distinct visual streams, one that is engaged during the identification of objects, and one that is associated with action. Although these visual streams are distinct, there has been increasing interest in how the action and identification systems interact during grasping and identification tasks. In particular, the current research explored the role that previous motor experience with familiar manipulable objects might have on the time it takes healthy participants to identify these objects (relative to non-manipulable objects). Furthermore, previous research has shown that there are multiple, computationally and neuro-anatomically different, action systems. The current research was particularly interested in the action systems involved in 1) grasping, and 2) functionally using an object. Work began by developed a new stimulus set of black & white photographs of manipulable and non-manipulable objects, and collecting 'graspability' and 'functional usage' ratings (chapter 2). This stimulus set was then used to show that high manipulability was related to faster naming but slower categorization (chapter 3). In chapter 4, the nature of these effects was explored by extending a computational model by Yoon, Heinke and Humphreys (2002). Results from chapter 5 indicated independent roles of graspability and functional usage during tasks that required identification of objects presented either with or without a concurrent mask. Specifically, graspability effects were larger for items that were not masked; and functional use effects were larger for items that were masked. Finally, chapter 6 indicated that action effects during identification tasks are partly based on how realistic the depictions of the objects are. That is, results from chapter 6 indicated the manipulability effects are larger for photographs than they are for line-drawings of the same objects. These results have direct implications for the design of future identification tasks, but, more broadly, they speak to the interactive nature of the human mind: Action representations can be invoked and measured during simple identification tasks, even where acting on the object is not required.

LIST OF ABBREVIATIONS USED

AIC	Akaike information criterion
ANOVA	Analysis of Variance
AoA	Age of Acquisition (high value = acquired late in life)
aPID	Average Pixel Intensity Difference
apf	Actual Potency Ratings
ATL	Anterior Temporal Lobes
BOLD	Blood Oxygen Level Depletion
.BMP	Bitmap Image (a type of file extension for photographs)
CD	Compact disc or CD-rom
CRT	Cathode ray tube
ED	Exposure Duration
EEG	Electroencephalogram
Fam	Familiarity
FB	Initials from a patient with visual agnosia
FFA	Fusiform Face Area
FMA, MAF, AFM	Experimental orders for collecting ratings in chapter 2
fMRI	Functional Magnetic Resonance Imaging
GIMP	The GNU Image Manipulation Program
IFG	Inferior Frontal Gyrus
IPL	Inferior Parietal Lobule
LME	Linear Mixed Effects model
lme4	A statistical package in R for conducting linear mixed effects analyses
<i>M</i>	Mean
Manip	Manipubility
Manip1	'Graspability' or grasping rating (higher value = graspable)
Manip2	'Functional usage' rating (high value = functional actions different from grasping actions)
MHz	Mega hertz
MM Index	Magnie et al.'s (2003) manipulability index
MRI	Magnetic Resonance Imaging
ms	Milliseconds
N	Total sample size
NAM	Naming-Action model
ns	Not significant compared to an $\alpha = 0.05$
<i>p</i>	<i>p</i> -value
PACE	Presemantic Account of Category Effects
PC	Personal Computer
PDP	Parallel Distributed Processing
PET	Positron Emission Topography
pg, p	Page number
<i>r</i> ,	Pearson's <i>r</i> correlation coefficient
R	The programming language 'R' used to statistically explore data sets
R ²	R-squared or coefficient of determination
RSVP	Rapid Serial Visual Presentation
RT	Reaction Time

rTMS	Repetitive Transcranial Magnetic Stimulation
SD	Standard deviation
STG	Posterior Superior Temporal Gyrus
T1, T2, T3	Time abbreviations for time 1, time 2, time 3
V1, V2, V3	Labels for areas in the brain that process visual information

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CHAPTER 1 INTRODUCTION

1.0.1 Pre-amble and definitions

This dissertation is about the relationship between the ‘object identification system’ and the ‘action system’ in the adult human brain. By “action system” I am referring to the networks in the human brain that select and coordinate appropriate action to specific objects in the environment. The characterization of the “action system” is overly vague, simplistic, and abstract for the moment, but I will be a little more specific shortly. By “object identification system”, I am referring specifically to the visual system and associated networks and connections in the brain that allow a human brain to view an object presented on a computer and to know, for example, that the object presented is a photograph of a ‘dog’. Of course, it is possible to identify objects based on other senses, such as on the sounds, smell, taste, or feel of an object, but this dissertation is about *visual* object identification, only.

Human visual object identification begins with the human eye. In evolutionary terms, the human eye is quite complex. For example, the earliest eyes in other organisms could only be used to detect the presence or absence of light – information that would then be used to move toward or away from that light source. The human eye, on the other hand, comes equipped with array of complexity including two types of photoreceptors: “Rods” that perform better in low-light conditions and are especially tuned to movement across the retina, and “Cones” that perform better in well illuminated conditions, allow for high visual acuity and perception of color. Furthermore, humans have evolved to have two eyes which, among other things, allows them to have more precise depth perception, which facilitates interpreting and navigating their environment. This greater complexity

of visual information helps enable our species to engage in more complex behavior (and actions), than, for example, organisms with more ‘primitive’ visual systems. One complex behavior that our visual system supports is object identification. That is, in co-operation with a complex language system we have developed “names” for objects in our environment. This, among other things, has allowed our species to develop a very complex culture, and eventually technological development, but at a very simple level “names” allow us to communicate to each other about objects even if those objects are not physically present in the moment. In early infancy, for example, an important milestone in development is learning the appropriate “name” to apply to objects in our visual world. For babies, it can be especially important to learn the names of favorite objects that they wish to interact with such as “doll”, “bottle”, “teddy”, with the implied call to action from the parents [‘bring me the...’]. Notice, that, throughout this section I have implied that the visual system has co-evolved with the language and ‘action’ system to facilitate and support more complex “actions” / behaviors. But, what is this “action” system?

An ‘action’ can be defined by any movement an organism makes. Researchers who study the object identification system, often consider speaking to be an ‘action’; after all, production of the word “dog” requires movement of the jaw, mouth, and tongue. In fact, speaking the word “dog” could be considered a very evolutionarily complex action, since, among other things, it requires the existence of and cooperation from an intact and sophisticated language system. As humans we are, of course, capable of many different types of actions, including automatic or unintentional actions like breathing, sneezing, blinking, hiccupping, as well as reflexive actions. We are also capable of

engaging in a wide-range of actions of purposeful or intentional actions (e.g. running, sitting, clapping, picking up an object), many of which grow more sophisticated and/or efficient, as we develop and practice the skill. For example, reading and typing are examples of two kinds of actions humans engage in that usually become more efficient, and arguably more sophisticated, as a person practices and learns the skill¹. Furthermore, humans are capable of quickly learning and applying new motor/action associations. For example, I can sit a healthy undergraduate in front of a computer in our research laboratory and tell them that every-time they see a “natural” object they should press a button with their index finger, and every-time they see a “manmade” object they should press a button with their middle finger and they can learn to do the task very quickly and efficiently. That is, this type of arbitrary assignment of button-pressing in response to stimuli appearing on a computer-screen is usually very straight forward and simple for a young healthy adult. We actually exploited the simplicity of this arbitrary action assignment in the current research by having some of our tasks be response by button-press tasks.

Therefore, there is a lot that could be implied in the term ‘action’ and ‘action system’. In the current dissertation, however, I will talk about action only in the context of how it relates to identification of objects that are already known to the research participant. Importantly, however, this still means that ‘action’ will be pulling a bit of a double-duty in this dissertation. (1) First, ‘action’ will sometimes be used to refer to the required responses participants were expected to give. In the research data presented in this dissertation, only two types of responses were ever collected: naming responses (in

¹ Another good example is learning to feed yourself. Anyone, like myself, who has recently watched a baby or toddler try to feed themselves, will not need convincing that this is a great example of a skill that improves dramatically with practice, development, and age.

which the participant was required to say out-loud what they thought the object was), and button-press responses (in which participants different buttons on a key-board based on the identity of the perceived object). (2) Second, ‘action’ will sometimes be used to refer to previously learned action-associations with the perceived object, and how those action-associations might facilitate (or interfere with) object identification. Importantly, however, when the second meaning is invoked, participants were never actually required to make the appropriate action-gesture or grasping movement.

Furthermore, this dissertation will focus on the difference between ‘manipulable’ and ‘non-manipulable’ objects, where ‘manipulable’ objects are defined as those you can ‘grasp and use with one hand,’ and assigned based on average ratings provided by healthy undergraduates (cf. chapter 2). Thus, it could be said that our ‘manipulable’ objects are really defined as a set of objects for which humans have learned motor/action-associations (implied in ‘use’ part of that definition) and non-manipulable object are defined as those with less clear motor/action-associations. For example, in our set of objects a ‘banana’ was rated as highly manipulable, but an ‘airplane’ was rated by participants as non-manipulable. Therefore, it could be said that my dissertation is about whether the existence of these action-associations formed from previous experience (i.e. ‘manipulability’) influences object identification during tasks that don’t require those specific actions.

As the title “graspability and functional use” implies, actions appropriate for objects can further be distinguished between actions associated simple grasping movements, and those that are specific to the functional use of objects. This difference has been articulated on largely by Buxbaum and colleagues (e.g. Boronat, et al., 2005;

Buxbaum & Kalenine, 2010; Buxbaum, Kyle, Tang, & Detre, 2006; Buxbaum & Saffran, 2002; Buxbaum, Veramonti, & Schwartz, 2000) and their 2-Action Systems models.

Specifically, they have accumulated and described neuroimaging and neuropsychological evidence of distinct neuro-architecture (i.e. different networks, or connections of brain areas) for these different types of action. Later in this dissertation, I revisit the topic of these differences within the action system, and in fact, this is the topic of the research presented in chapter 5. However, this introduction going forward will present a very simplified view of the action and identification systems, building up to the more complicated models, predictions, and descriptions later on.

1.0.2 Introduction & Overview

When navigating the environment we, as humans, do two things with objects we encounter are: (1) identify them and (2) use them, if they can be used². By ‘use’, I am implying some kind of object appropriate manual action that gets represented, and initiated by, the action system. As was stated in the pre-amble, this dissertation is about the relationship between our identification system (i.e. the networks and systems in the brain that allow us to identify an object) and our action system (i.e. the networks in our brain that co-ordinate actions). It make sense that object form and identity can influence how objects are used and acted on (e.g. Tucker & Ellis, 2004), but, is the reverse true? Can the action-associations of an object aid in its identification? That is, when do action-representations come online relative to representations of object identity? Answering these questions could lead to improved strategies for rehabilitating patients for action-related neurological disorders, as well as contributing to the field of artificial intelligence,

² Using them also requires locating them, but that area of investigation is tangential to the current research question.

specifically the design of systems that can both identify and act on objects in their environment.

This Introduction will begin with a brief history of early object identification models, leading into recent, albeit simplified models of object identification. The rest of this Introduction will then discuss different architectures that could explain where action fits into existing models of identification along with evidence for each architecture, and what predictions could be made from these simplified architectures. Finally, this introduction will conclude with a preview of the research to be presented in subsequent chapters. The goal throughout this dissertation is to gain a better understanding of the role action plays during human object identification, as well as exploring whether or not the role is different for different types of actions (chapters 2 and 5) and different types of tasks (chapters 3, 4 and 5). This research will combine the methods of basic behavioral human research (chapters 2, 3, 5, and 6) along with computational modeling (chapter 4) to address these questions.

1.1 BRIEF HISTORY OF THEORIES OF VISUAL OBJECT IDENTIFICATION

Early models of object identification focused on structural description models, or part-based recognition. For example, Marr and Nishihara (1978) proposed that object parts come to be mentally represented as generalized cones (or cylinders) and objects as hierarchically organized structural representations relating the spatial positions of parts to one another. Their model was later refined by Biederman (1985, 1987) with his recognition by components (RBC) theory. In particular, Biederman's theory involved (1)

a restricted set of three-dimensional volumes to represent part shape (“Geons”) defined by properties, including whether the edge is straight or curved, symmetrical, if the cross-section is a constant size, etc., and (2) a layer dedicated to spatial relations between parts, for example “above” or “below”.

One of the key criticisms of these early structural-description models is that they assumed viewpoint invariance, while growing experimental evidence was showing that objects were slower to be identified in different orientations. For example, Jolicoeur (1985) asked participants to name misoriented line drawings of common objects and found that the time to name was related to how far objects were rotated from upright. Tarr and Pinker (1989) were able to show that this was also true of novel objects, that is, participants were slower to recognize trained shapes in new orientations with the costs systematically related to the distance from a trained view. Tarr (1995) later showed the same effect for objects requiring 3D mental rotation. Thus, the theoretical framework shifted to the idea of viewpoint-dependent (rather than independent or invariant) object recognition. This shift even included computational models (e.g. Poggio & Edelman, 1990) that further reinforced the idea of view-based recognition.

In the last two decades, the wide-spread use of neuroimaging methods, such as functional magnetic resonance imaging (fMRI), has shifted the focus away from general theories of object recognition to a focus on the role of certain cortical areas (for a recent review of this shift, see Peissig & Tarr, 2007). For example, an area on the ventral surface of the temporal lobe on the fusiform gyrus was identified to respond selectively to faces (see fusiform face area, FFA: Kanwisher, McDermott, & Chun, 1997; Sergent, Ohta, & MacDonald, 1992) which raised a long debate about whether this area was a specialized

face-processing area or just an area recruited for expertise (cf. Gauthier & Tarr, 1997; Gauthier, et al., 2000; Gauthier, Williams, Tarr, & Tanaka, 1998; Kanwisher, 2000; Kanwisher, et al., 1997; Kanwisher, Stanley, & Harris, 1999; Kung, 2007; Xu, 2005). Cortical areas elsewhere in the brain have been identified that selectively respond to color and form (e.g. Martin, Haxby, Lalonde, & Wiggs, 1995; Miceli, et al., 2001), places, houses and scenes (see, for example, the parahippocampal place area, PPA, e.g. Bar & Aminoff, 2003; Downing, Chan, Peelen, Dodds, & Kanwisher, 2006; Epstein, Harris, Stanley, & Kanwisher, 1999) faces and animals (see, for example, the Fusiform Face Area, e.g. Chao, Martin, & Haxby, 1999; Kanwisher, et al., 1999), and manipulable objects, such as tools and utensils (Chao, Haxby, & Martin, 1999; Noppeney, Price, Penny, & Friston, 2006).

The focus on mapping networks in the brain, the role of cortical areas, and making full use of the new tools of cognitive neuroscience (fMRI, EEG, etc.) has led to mountains of data, but a dearth of theory (cf. Peissig & Tarr, 2007). Thus, the exact mechanisms whereby object recognition is performed remains unclearly defined, despite recent advances and availability of neuroimaging techniques, and many recent computational models (e.g. Carpenter & Grossberg, 2002; Hinton, 2007; Hummel & Biederman, 2002; Plaut & Farah, 1990; Riesenhuber & Poggio, 2000; Yoon, Heinke, & Humphreys, 2002).

The current research aims to answer at least one question about object identification. Specifically, do associated motor actions play a role? That is, can the action system influence object identification, or are the systems involved in both completely distinguishable? Answering this question is not a trivial matter because, as we

will see in subsequent sections, there a number of different possibilities about where ‘action’ can fit into a model of object identification. In the next section we introduce basic (simplified) models of object identification and then lead into a discussion about where “action” could fit into such models and the implication of such architecture on object identification. The ultimate goal will be to lead toward an understanding of the most plausible architecture underlying object recognition by human brain. Hopefully the data presented in this dissertation will help illuminate the value of certain architectural models over others and lead to stronger theoretical frameworks in the future.

1.2 DIFFERENT MODEL ARCHITECTURES OF OBJECT IDENTIFICATION & ACTION SYSTEMS

In the absence of a full understanding of the specific mechanisms underlying many cognitive processes of the brain, box and arrow diagrams/models have a long tradition of outlining at least the general sequence of processing events. For example, the most basic, cognitive model involves some input (i.e. sensation) and some output (i.e. action) (see Panel A in Figure 1.1). In the case of object identification, the input could be some kind of photograph, and the output could be a verbal response, such as naming the object, e.g. “dog” (see Panel B in Figure 1.1). Early cognitive psychologists recognized that any input (or stimulus) that generated output (behavior) had to necessarily be translated by some intermediate process or middle step inside the organism, although by some this middle-step was treated as unknowable (hence the “???” in Panels A and B of Figure 1.1).

Attempts made to characterize this middle step, in the case of object identification, named this step “**semantics**”, derived from the Greek *sēmantikos* or “having significance”. The basic idea of semantics was that somewhere in the brain all “things” *known* to the organism were stored (for future recognition). This storage place was called the “semantic store”. It was also called “semantic memory”, “semantic knowledge” or simply “semantics”. Semantics was first characterized as an *amodal* store of information, meaning that regardless of the sense used (e.g. taste, touch, or sight) one could still activate the same representation of the object (e.g. “apple”).

In contrast, recent and emerging theories of *embodied cognition* suggest that representations are more distributed over the areas used in perception of the object. That is, the theory suggests that representation of the object comes as a result of re-activation of the same brain areas involved in its perception (cf. Allport, 1985, who was one of the first to clearly define theories of embodiment). However, even though theories of embodied cognition have been gaining in popularity, the tradition has always been to assume an amodal ‘semantic’ store, and that will be the starting point of models explored in the current research. More will be said about embodied cognition later.

So, in a simple object identification model, semantics has become the term denoting the “*what*” of what must become activated to perform an appropriate response to a presented object. This response could be a verbal response, such as in an identification task where the correct response could be saying the word “apple” (e.g. Panel C in Figure 1.1). But it could theoretically involve any appropriate response (output) to the object such as a manual response like a button press, or in the case of manipulable objects, some kind of grasping or object-appropriate action.

Rosch (1975) further distinguished different levels of semantics (basic, superordinate & subordinate). For example, identification at the “basic” level is, identification at the level which is most inclusive at which there are attributes common to all or most members of that category (e.g. “car”, “chair”, or “dog” as shown in Panel D of Figure 1.1). This “basic” level has also been referred to as the “entry” level since it is the first level named and understood by children, and the first level to enter the lexicon of a language (cf. Jolicoeur, Gluck, & Kosslyn, 1984; Tanaka & Taylor, 1991).

“Superordinate” level semantics was any level above the basic level, such as “animal” or “living” in the example above. Superordinate levels are more abstract, contain more members, and members share few attributes among each other. “Subordinate” level semantics are any level below basic/entry level semantics such as the name of a specific dog breed (e.g. “golden retriever” in the example above, Panel D of Figure 1.1). This language of “basic”, “superordinate” and “subordinate” level semantics was useful for delineating semantics during object identification at different levels, for example a task involving “Naming” the object was usually done at the **basic** level, where a categorization task such as natural versus manmade was semantics at a **superordinate** level. The significance of these different levels of identification of an object will become more evident, and expanded on in subsequent chapters. For now, when discussing identification of, or ‘Naming’ a specific object, it will be assumed that this is being done at the basic (or entry level), unless stated otherwise.

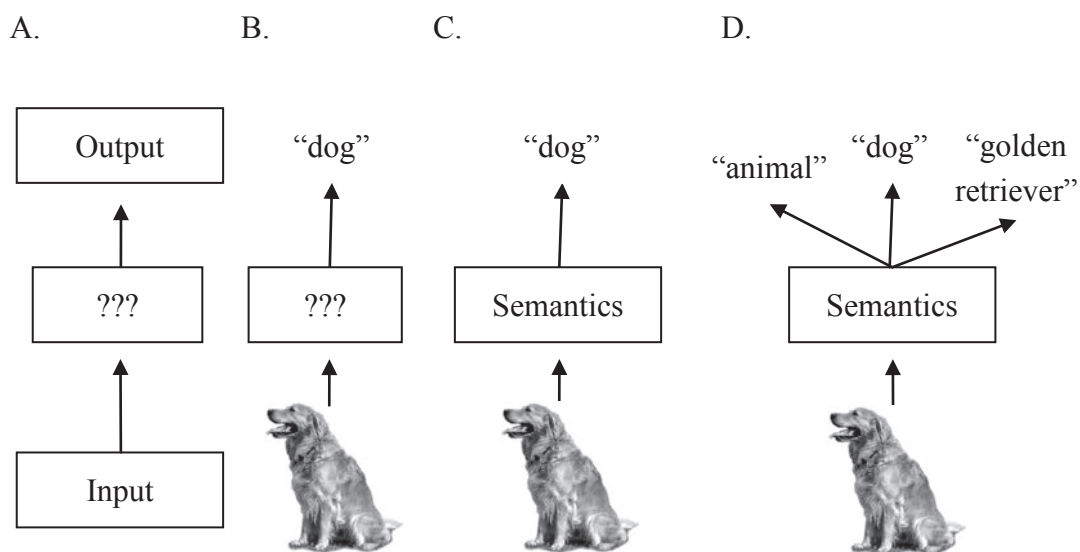


Figure 1.1. Simple Box-and-Arrow models of visual object identification. (A) Some visual input gets passed through some unknown cognitive process ‘???’ to arrive at an appropriate output. (B) Example, a picture of an dog gets labeled with a person speaking the word “dog”. (C) “Semantics”, an amodal store of the representation of known objects thought to be at least part of the necessary steps involved in translating a visual representation of object into a verbal one. (D) Examples of the layers or levels of representation that can exist for a single object. In this example, most participants naturally label the photograph “dog” at the basic level. But the same stimuli could appropriately be labeled “animal” (superordinate) or “golden retriever” (subordinate).

1.2.1 Fitting Action into a Object Identification Models

The models above (Figure 1.1) focus on object identification (via semantics), but where does action fit into these models? Specifically, how does the identification system deal with “manipulable” objects? As stated in the pre-amble, we can formally define manipulable objects as those that are “capable of being grasped and manipulated [or used] by one hand” (Grezes & Decety, 2002, p. 214). Where is that object-specific action stored for manipulable objects, and how is it accessed? One possibility is that action is selected as a part of the output process, in other words, action is always downstream or

post-semantics (Architecture A in Figure 1.2). Conversely, one could consider the possibility that action information is accessed prior to semantics, and the action information helps build the appropriate semantic representation (for example, architecture B in Figure 1.2). Another possibility is a dedicated action processor that runs in parallel to semantics, and interacts for certain kinds of tasks (this architecture is depicted in panel C of Figure 1.2). Finally, it's possible that the action representations of objects are built directly into the semantic representation of the object such that both are activated as a part of the same process (panel D of Figure 1.2). This last possibility is similar to an embodied cognition approach – although researchers in this area may avoid the term “semantics”³.

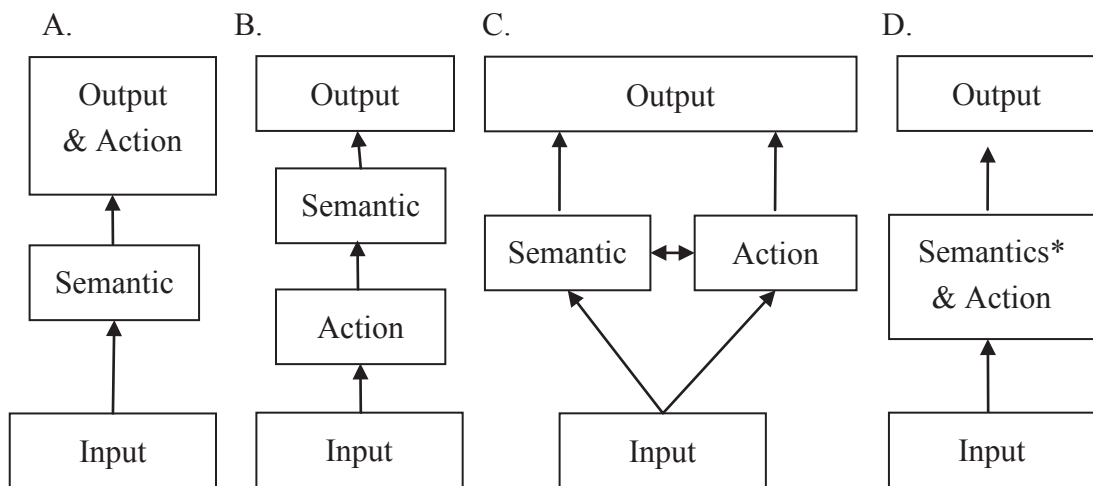


Figure 1.2. Building “Action” into our current input-semantics-output model of identification there are a number of possibilities about where the “action” can be represented. In panel D, the * beside semantics denotes that in a proper embodied cognition model with action representation as a part of distributed representation of the entire object, the term “semantics” may no longer be appropriate.

³ Note, all of these models assume *one* type of ‘input’, but it’s true that in order to identify objects we make use of multiple senses (e.g. touch, audition). Furthermore, even within the visual domain it’s possible that processing of visual information is sub-divided for different types of visual stimuli (for example, a specialized reading-processor). There is even evidence that the goals directed towards an object (identifying versus acting on) can influence the visual streams involved.

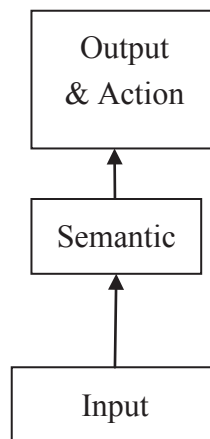
It is important to note critical distinctions in the four architectures presented in Figure 1.2. First architectures A and B could be considered **serial** models because things happen in a pre-defined sequence. That is, they predict that between action and semantics one always precedes and influences the other (but not the other way around). On the other hand, architectures C and D could be considered **parallel** models because activation of semantics and action can be happening at the same time (i.e. not in sequence as in architectures A and B). Critically, however, architecture C predicts that the two modules (semantics and action) can be activated independently, although interactions can occur, as indicated by the bidirectional arrow between them. Architecture D, on the other hand, predicts that the two always become active together, as the action representation is part of the semantic-representation (or as a part of the representation of the identity) of manipulable objects. Thus, in summary, there are at least 4 different architectures that could represent how object action is situated relative to semantics and identification:

- A. Action representation after Semantics
- B. Action representation before Semantics
- C. Action representation as a parallel specialized processor
- D. Action representation represented as a part of semantics

The following sections will explore each of these possibilities in more detail, including what effects the architectures would predict when identifying manipulable objects (objects to which action is possible), and what research has been done in the past to support these architectures.

Note, for the next few sections, this Introduction will discuss object manipulability and action as if there is only *one* type of manipulability. However, as will be elaborated on in sections “*Reconciling Architecture A with B*” and “*Manipulability and TWO types of Action,*” and mentioned in the pre-amble, there has been growing evidence that the action system can be sub-divided into two or three different types (e.g. Boronat, et al., 2005; Bub & Masson, 2012; Bub, Masson, & Cree, 2008; Buxbaum & Kalenine, 2010; Buxbaum, et al., 2006; Buxbaum & Saffran, 2002; Buxbaum, et al., 2000; McNair & Harris, 2012; Spunt, Falk, & Lieberman, 2010). The importance of distinguishing between these different types of action will become more evident as results from different experiments need to be reconciled. However, we delve into this issue in more detail after first exploring the evidence for the simple architectures A and B. Considering these simple architectures first, will help us understand why they are not sufficient, and why more complex models are required.

1.3 ARCHITECTURE A. ACTION *AFTER* SEMANTICS



Numerous studies have shown that perceiving an object can influence later action on that object implying that architecture A is possible (action after semantics). For example, Tucker and Ellis (2004) showed that object identity can prime object action. Specifically they had participants make superordinate-level identification (natural or manmade) about objects presented one at a time by responding with either precision or whole-hand grasps. They found a congruency effect between semantic categorization and grasp-type: objects were categorized more quickly when the response-grasp was appropriate to a grasp that would be made to use the object. Further, Tucker and Ellis (2004) showed that these congruency effects were also present for words, and not just for visually presented depictions of objects. These results provide evidence that semantic information (knowledge of what the object is and/or its form) can influence action-related responses. Specifically they provide support that action has an influence post-semantically.

Other examples of object identity influencing action come from Bub, Masson and colleagues (2003; 2008). For example, Bub, Masson, and Bukach (2003) trained participants to make mime specific gestures (e.g. a poke gesture) in response to different colors (e.g. the color green). After these color-gesture associations were learned, they had participants switch between a task that required them to gesture towards the color, or give the appropriate gesture to the visually presented object. They found a congruency effect in both the gesturing to color, and gesturing to the object condition, with faster gesturing times when the presented object and presenting color required congruent gestures, than when the gestures were incongruent/different. Notably this object processing effect on carrying out the gesture was not observed in another of their experiments in which

participants saw the objects but were only required to respond to the color (i.e. passive viewing). This suggests that it was necessary for participants to encode (process) the visually presented objects on at least some of the trials for the action associated with the object to become activated and lead to congruency effects during the carrying out of the action.

In a follow-up experiment Bub, Masson and Cree (2008) developed a device in which specific actions could be carried out to (they called the device the ‘Grasasaurus’), and again measured the role exposure to familiar manmade manipulable primes played during the execution of grasping behavior. Again, across multiple experiments they found congruency effects suggesting that semantic processing of a manipulable object either facilitates grasp actions congruent with the object being processed, or interferes with grasp actions that are incongruent with the object being processed, or both (leading to the observed congruency effects). In other words, attending to well-known manipulable objects has an effect on planned or carried out actions, even when those actions are not being carried out on the object themselves, but on another object, such as the response ‘elements’ on the grasasaurus (for other examples of action congruency effects, see Lindemann, Stenneken, van Schie, & Bekkering, 2006; Riddoch, Edwards, Humphreys, West, & Heafield, 1998; Wühr & Elsner, 2007).

In addition, taxing the semantic system has been shown to influence object grasping. For example, Creem and Proffitt (2001) showed that during a dual semantic and grasping task, participants made more grasping errors (grasping objects ‘in inappropriate ways’) compared to doing a dual visuo-spatial and grasping task. That is, participants were presented with real objects and asked to them pick up and move them to a new

location. When objects were presented with no concurrent task, participants naturally picked up objects with a grasp *appropriate to object use* implying that object identity was influencing action-selection even though the instructions did not explicitly specify anything about ‘appropriate’ grasps or identity. Creem and Proffitt (2001) also had participants perform this same task (moving objects one at a time) while performing either a concurrent visuo-spatial or semantic task. When participants performed the concurrent semantic task (which involved recalling previously memorized paired-associate words) participants rarely picked up the objects appropriately. When the participants performed a concurrent visuo-spatial task (which involved a spatial imagery task involving characterizing the corners of blocked letters) there was only a small decrement in performance. This result suggested that action, in particular, the simple task of grasping and moving an object, was influenced by the semantic system (ergo, action after semantics). That is, when semantics is taxed by a concurrent semantic task the nature/accuracy of the action changes.

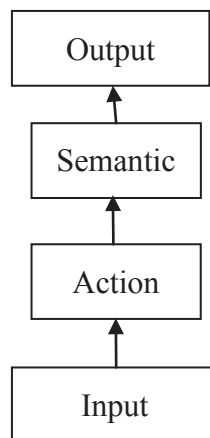
Taken together, this body of evidence provides strong support that semantic representations influence actions performed on objects. In a strictly linear, serial, non-parallel architecture, this would imply that action representations and action selection occur *after* object representation in semantics.

1.3.1 Architecture (A) Implications

In a strictly linear (sequentially serial) interpretation of models, ‘action after semantics’ would imply that ‘action’ properties of objects have no bearing during

identification. That is, these models imply action does and *can* only matter after the object has been appropriately identified in semantics. Even more specifically, it implies that any identification tasks such as having participants *name an object* (naming task) should not be influenced by action, unless object associated-actions interfere with appropriate response-selection. That is, this architecture suggests that either (1) object action-associations will not affect the time it takes to identify manipulable versus non-manipulable objects or (2) the only place where action information could influence object identification are during post-semantic stages during identification, such as response-selection (i.e. the last stage of object identification). This architecture has been about semantics before action; however, as we will see in the next section, there *is* evidence to support the opposite pattern (action *before* semantics).

1.4 ARCHITECTURE B. ACTION *BEFORE* SEMANTICS



One example of ‘*action before semantics*’ is the ability to imagine actions from nonsense objects. That is, consider the objects shown in Figure 1.3 A-E. It is probably easy to imagine a use and appropriate grasp for the first two objects (A & B). In fact,

most individuals would probably label Figure 1.3A as “cup” and Figure 1.3B as a “bucket”. Figure 1.3C is intentionally more ambiguous, although it may appear to some as “hammer” or a “paint-roller,” most would agree that it would be more appropriately grasped by the longer cylindrical part, or what many would call its “handle”. Finally, Figures 1.3D & E (reprinted from Cant & Goodale, 2007 with permission from the publisher) are very ambiguous about what they *are* (in terms of identity), yet most individuals can imagine both (A) an appropriate way to grasp the object and even (B) a possible use for the object. Thus, these figures, taken together, illustrate that action can be implied or extracted from a nonsense or novel object. That is, action independent of a known identity (i.e. independent of semantics).

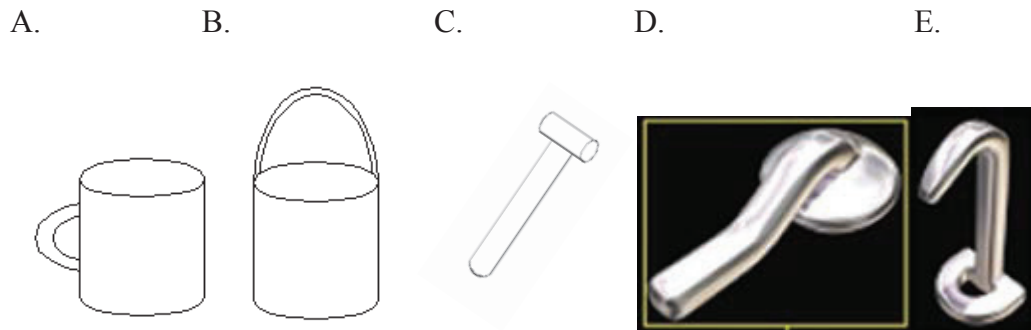


Figure 1.3. Examples of poorly delineated and novel objects all affording some action. A & B represent two ways of putting together “geons” to make manipulable objects. C. Represents a poorly delineated tool like a mallet or hammer. D & E represent novel but still graspable/manipulable objects, reprinted from Cant and Goodale (2007) with permission.

This idea of implied action in objects was dubbed action “affordances”, and has been defined as the possibilities for action ‘afforded’ by objects (cf. Gibson, 1979; Humphreys, 2001), and is a little different than the object-appropriate actions discussed

in the previous model. For example, a knife “affords” cutting, and a bucket “affords” carrying water. Further, the same object can afford different uses depending on the size and motivation of the actor (e.g. an upside-down bucket can be used as a seat, or stepping stool for a child). Importantly, affordances imply a route to action independent of or *preceding* semantics. That is action information can be present independent of previous knowledge or experience with the object.

1.4.1 Experimental Evidence of a Direct route to Action

Experimental evidence for a direct route to action information without semantics comes largely from neuropsychological research with patients suffering from ‘optic aphasia’. These optic aphasics have been characterized by an intact ability to gesture towards objects despite not being able to identify the object (Pilgrim & Humphreys, 1991; Riddoch & Humphreys, 1987). Other patients have been shown to execute ‘utilization errors’, or errors that include repeating the same action (e.g. putting on multiple spectacles) or grabbing objects by the handle when the task requests otherwise (Lhermitte, 1983; Riddoch, et al., 1998). These types of errors are typically associated with lesions to the frontal lobes, and are further evidence of a direct route to action.

Even healthy participants have been shown to execute action errors under speeded response conditions (Rumiati & Humphreys, 1998). Rumiati and Humphreys (1998) had participants make gestures towards visually presented objects under deadline conditions, and found that most gesturing errors were visually related to the target (e.g. making a hammering gesture to the picture of razor), with proportionally fewer semantic errors

(e.g. making a lathering gesture to the face when a razor was presented). In contrast, when words were presented instead of pictures of objects, only semantic errors arose.

Consistent with this idea, Adamo and Ferber (2009) enhanced processing of two sequentially presented items with similar actions when the objects were presented as pictures but not words. Specifically, in their experiment participants viewed multiple objects presented rapidly and sequentially in what is known as a rapid serial visual presentation (RSVP) design. They were told to attend to stimuli that were presented in a green color, but sometimes two green objects would appear back-to-back. Typically, in these experiments, when two targets are presented back-to-back, or after a very short delay, the ability to encode (and later label) the second target is impaired, this effect has been labeled an “attentional blink”. However, Adamo and Ferber (2009) showed a reduced attentional blink, or greater processing of the second target when both targets were pictures of the object, but not when the objects were presented as words. Adamo and Ferber (2009) interpreted this result as this first picture of an object eliciting an ‘action affordance’ that would enhance processing of objects that afforded a similar action.

This priming of specific actions for pictures of objects but not for words have also been reported by other researchers (cf. Helbig, Graf, & Kiefer, 2006; Kiefer, Sim, Helbig, & Graf, 2011). These results suggest that visually presented objects get action priority, with semantics only being activated later (or by words). Taken with the neuropsychological evidence, the implication is of an action module independent of semantics, or, in a strictly serial and linear interpretation, action before semantics.

1.4.2 Reconciling Architecture A with B

There are two possibilities that could explain the seemingly contrary evidence for action both *before* and *after* semantics. Possibility 1: The architecture for object identification is not purely sequential, and is instead organized in a more parallel way. This possibility will be explored in subsequent sections. Possibility 2: There are at least two types of action, one with its influence before semantics and another with its influence afterward. This latter possibility has found support in research by Buxbaum and colleagues (e.g. Boronat, et al., 2005; Buxbaum & Kalenine, 2010; Buxbaum, et al., 2006; Buxbaum & Saffran, 2002; Buxbaum, et al., 2000). This latter possibility will now be explored.

1.4.3 Manipulability and TWO types of Action

It is possible that there is both an early and a late influence of action during object identification. This, in the context of a strictly serial model, implies two separate action modules – one early and one late. Buxbaum and colleagues (e.g. Boronat, et al., 2005; Buxbaum & Kalenine, 2010; Buxbaum, et al., 2006; Buxbaum & Saffran, 2002; Buxbaum, et al., 2000) have attempted to characterize the nature of these two action systems by defining two different types of manipulability: grasping and functional use⁴. These are thought to be different because grasping an object appears to rely strongly on calculations of current object location, whereas shaping an hand for object use requires access to stored knowledge about the skilled manipulation specific to a given object (Buxbaum, et al., 2006). Thus, grasping could be thought of as early pre-semantic kind of

⁴ Buxbaum (2006) further delineated two types of functional use: prehensile and non-prehensile, but those distinctions are not explored in the current research.

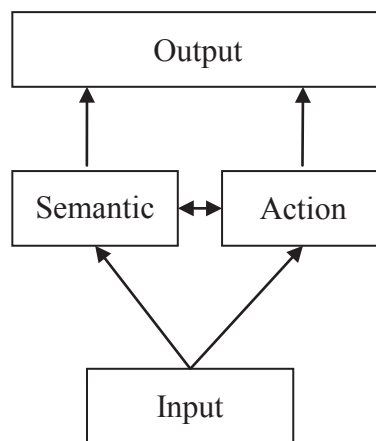
action, and functional use, by definition would be the object-specific (semantic-dependent) or post-semantic action. Much of the evidence for the distinction between “grasping” and “functional use” has come from neuropsychology and neuroimaging research, which, to discuss fully, requires a more full understanding of the brain and its anatomy. Thus, the next section (architecture C) will first introduce neuropsychological research historically before discussing evidence presented by Buxbaum and colleagues.

1.4.4 Architecture (B) implications

Whereas architecture A would predict action-specific information about an object would only be processed after the object had been identified through semantics, architecture B would instead predict that some action-related aspects of the object could be processed before or independent of object semantics. Specifically architecture B would predict “manipulable” objects to be named /semantically accessed differently than “non-manipulable” objects (by virtue of the action-representations for objects that were already active). However this architecture is mute as to the nature of that difference, specifically whether activating action-associations with an object would speed up (facilitate), slow down (inhibit) identification of those objects. It could be that the ‘action information’ available at the time of semantics would speed up the naming of manipulable objects (relative to non-manipulable objects). On the other hand, object-specific action activity (related to grasping or functional use) might interfere with response-related action such as naming or button-pressing in response to the identity, leading to slower identification of manipulable objects. Again, the architectures explored above were an attempt to describe models in which processing was assumed to happen in

sequence (aka, serially). However, it is possible, and, as will be discussed in the next section, more biologically *plausible* that aspects of the identification and action system are active in the brain at the same time (aka, in parallel).

1.5 ARCHITECTURE C. ACTION *PARALLEL* TO SEMANTICS



1.5.1 The Brain and Parallel Architecture

Up until this point, I have been talking about the object identification system in very abstract box-arrow terms. Of course, how these systems work depends a great deal on the underlying biology of the brain. Neuroimaging techniques such as magnetic resonance imaging (MRI) and functional MRI (fMRI) have been particularly useful for determining the neuro-architecture involved in processing of visual information, generally, and what networks are involved in the processing of certain types objects and object-related action. To use a computer analogy, we could refer to the brain neuro-architecture (or anatomy) and object identification ‘networks’ as the ‘**hardware**’ in the

brain. What the brain is doing in different regions, or the modular box-and-arrow models we've been presenting to this point, we could refer to as the 'software' of the brain. Let's take a moment to examine what is known about the hardware of the visual system in the brain.

It is now commonly accepted that visual information, after being processed in the occipital cortex (or V1) and secondary association areas (V2, V3), gets split along two primary visual pathways. The **ventral** ("what") pathway projects from the striate to inferotemporal cortex and plays a role in perceptual identification of objects. The **dorsal** ("where" or "how") pathway projects from the striate to posterior parietal cortex and mediates sensorimotor transformations for actions directed at objects (Goodale & Milner, 1992, 1994). These two pathways operate in parallel: the dorsal pathway is typically thought to represent grasping and localization of objects, while the ventral pathway is dedicated to object recognition. This distinction between the two pathways suggests a dedicated action module in the dorsal pathway that is separate from object recognition or semantics in the ventral pathway. It further suggests that any representation of object-specific action or "functional use" would (1) require accessing both pathways simultaneously, or (2) suggest a second object-specific action module located either in semantics or somewhere between the two pathways. That is, the question remains: Is action representation in both or just one of these two visual pathways?

1.5.2 Neuropsychological Support for Separate Modules

Neuropsychological research offers a window into the extent to which these two visual pathways are independent or dependent of one another. With neuropsychological research, it is possible to study how the object identification system responds when it is

damaged. As discussed above, patients have been identified who suffer from ‘utilization errors’ (errors that include repeating the same action) and ‘optic aphasia’ (inability to name an object despite being able to correctly gesture its use). Another disorder manifests as an inability to correctly gesture towards an object despite being able to name it (Coslett & Saffran, 1992; DeRenzi, Faglioni, & Sorgato, 1982; Hillis & Caramazza, 1995; Riddoch, Humphreys, & Price, 1989). This complementary disorder, known as ‘visual apraxia’ demonstrates a double-dissociation between gesturing and object identification and indicates separate processing modules for naming and gesturing in the brain. This double dissociation provides strong support for parallel, independent processors for object identification and action-selection.

In addition to support for separate, parallel, semantic & action modules, there is also support for a bidirectional link between these two processes. That is, the two separate systems do influence each other (as suggested by the double-headed arrow between action & semantics in the opening figure). Again, neuropsychological research supports this bidirectional link between semantics and action. For example, Humphreys and Riddoch (2001) identified patients with unilateral neglect who were better able to detect objects when cued with an action (“find the object to drink from”) than when cued with the object’s name (“find the cup”), indicating that cuing through action was helping the identification system to correctly identify the object. Wolk et al. (2005) also showed that objects with high manipulability ratings (based on ratings by Magnié, Besson, Poncet, & Dolisi, 2003) were more likely to be recognized by a patient with mild visual agnosia. Thus, these studies provide evidence that when the regular route to semantics is

damaged, accessing action can be used as a way of facilitating recognition (i.e. compensating for the damage by getting to semantics via a different route).

1.5.3 Computational Modeling of Neuropsychological Disorders

Yoon, Heinke and Humphreys (2002) designed a computational model based on the premises of: (1) an action module that is independent of semantics, (2) bidirectional links between action and semantics, and (3) a direct pathway to action that bypasses semantics. In addition to modeling naming and action responses to pictures of objects, their ‘Naming-Action Model’ (NAM) also included modeling responses to objects’ names presented as words. Words have long-known to be able to bypass semantics based on the ability to sound-out the word, aka “grapheme to phoneme conversion” (hence a direct connection between the “input lexicon” and the “phonological name output” in the model). Naming objects, on the other hand, necessarily must be done using the semantic system, since there is nothing inherent in an object that dictates its name (hence the only route from the “structural description system” to naming output is through semantics) (see Smith & Magee, 1980).

A further feature of the Naming-Action model (NAM) is that it differentiates between two levels of semantics: item-specific semantics and superordinate semantics (akin to the different levels of semantics described by Rosch, 1975). Their model was laid out similarly to more simplified models presented by Riddoch, et al. (1989) (see Figure 1.4A), but included bidirectional links simulating integration and communication between the semantic, action, and phonological name output over time (see Figure 1.4B for a depiction of their model as taken from their original work Yoon, et al., 2002).

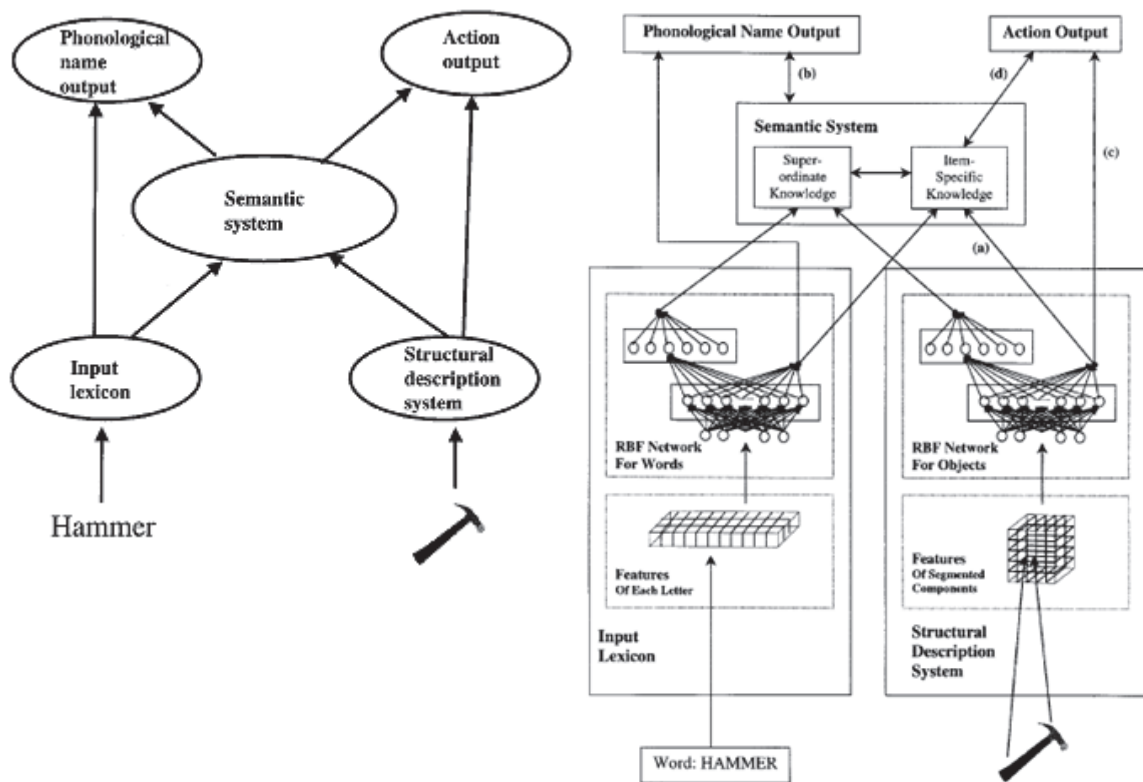


Figure 1.4 (A) Direct and indirect routes to action through the structural description system. Reprinted from Yoon, Heinke, and Humphreys (2002) with permission from the publisher as originally cited from Riddoch, et al. (1989).
 (B) The Naming-Action model (NAM), reprinted from Yoon, Heinke, and Humphreys (2002), with permission.

1.5.4 Evidence for a Direct Route to an Independent Action

Module

Experimental evidence for a direct route to action comes, in part, from Rumiati and Humphreys (1998) who showed different error patterns in identification and gesture tasks. That is, they induced errors by imposing response deadlines (responses within 800 ms of seeing the target) and found that when pictures were shown for naming, participants made relatively high numbers of visual errors rather than semantically related

errors (an example of a visual error would be a writing gesture to a toothbrush which is visually similar but semantically unrelated to a pen). In contrast, when words were shown, almost all errors were semantic, not visual ones. Thus, pictures, and not words, appeared to support direct access to actions.

Further evidence for a direct pathway from vision to action comes from research by Chainay and Humphreys (2002) who had participants make action judgments to objects, words and non-objects (e.g. “would you make a twist or pouring response with this particular stimulus?”). For comparison, a task involving semantic categorization or contextual knowledge was used (e.g. “is this object typically used in the kitchen?”). Chainay and Humphreys (2002) found that while semantic decisions did not differ in latency for objects and words, action judgments were faster for objects than for words. This benefit for action judgment was not due to the presence of simple features in objects, since action judgments were slow to non-objects which contained similar features. Thus, Chainay and Humphreys concluded that there was privileged access to action knowledge from visual objects due to learned associations between objects and actions (i.e. the direct pathway from “structural description system” to “action output” in Figure 1.4).

Priming experiments have also shown privileged access to action directly from visual objects. For example, Helbig, Graf, and Kiefer (2006) conducted two experiments in which participants were instructed to name two objects that were presented back-to-back (the first object was shown 167 ms – 250 ms, and then removed, and the next object was shown 112 ms later). The critical manipulation in their experiment was whether or not the first object (i.e. the “prime”) matched the second object (i.e. the “target”) in terms of the type of action that would normally be associated with the object. The target was

always a black & white photograph of a familiar manmade manipulable object, but the prime was either a photograph (experiment #1) or a word written on the screen (experiment #2). Their results indicated congruency effects for when targets were preceded by photographs but not by words. This suggests that objects presented visually (i.e. as photographs) activate the specific actions associated with those objects in a way that is not done by the 'word' depiction of the same object. Furthermore, this suggests privileged access to action by visually presented objects, relative to words.

Other evidence comes from repetition priming studies. For example, the speed of object naming was primed (facilitated) by previous grasping or naming of the object, but grasping responses were not primed by previous grasping or naming (Garofeanu, Króliczak, Goodale, & Humphrey, 2004). This suggested that visuomotor processing for grasping depended on the instant transmission of visual information to the motor system that was independent of memory. Object naming, in contrast, was reliant on the memory (visual structural or semantic) system (consistent with the model shown in Figure 1.4a).

1.5.5 Evidence that the link between Semantics & Action is Bidirectional

Partial evidence for a bidirectional link between semantics and action comes, in part, from evidence that previous grasping of an object facilitates naming it (cf. Cant & Goodale, 2007; Garofeanu, et al., 2004). Other evidence of a link from action back to semantics comes from Helbig et al.'s (2006) research where objects with associated action primed each other during an object identification task also demonstrated that action representations associated with one object (the prime) could then be used to facilitate identification of a second object (the target) if that second object shared a

similar action. That is, primed action-associations can facilitate object identification for objects compatible with that action (an influence of action on identification).

On the other hand, results from Craighero, Fadiga, Rizzolatti, & Umiltà (1999) indicated that preparing to grasp an object (action) is influenced by the perception of a similarly shaped and oriented objects (identification) (see also Craighero, Fadiga, Rizzolatti, & Umiltà, 1998). Specifically, in Craighero et al.'s (1999) task participants were given a task where on each trial they were shown the word "right" or "left" which would instruct them to make a pincer-grasp to a concealed bar rotated either 45 degrees clockwise or 45 degrees counter-clockwise. The instruction "right" or "left" was informative but participants were instructed to not initiate the grasp response until the fixation cross was replaced with a picture. Critically, across different experiments the "go" picture shown was different objects that were either rotated in a congruent or incongruent way and where shaped in some experiments to be very similar to the bar in which they would be carrying out the action, and in other experiments, less similarly shaped. Finally, in some experiments the cue would indicate for them to abandon the prepared response in favor of responding with another effector (i.e. the foot or the eyelids). Their results indicated that preparing a grasping movement to a specific object is facilitated by the presentation of a visual object with "intrinsic properties", such as object orientation, that "match those of the object to be grasped" (Craighero, et al., 1998, p. 1689). In other words, grasping (action) was influenced by the perception of similarly shaped and rotated objects, indicating that perceiving objects (even when these are not the actual objects being acting on) affects the speed of the action to be carried out when the object presented affords a similar action.

Furthermore, Yoon and Humphreys (2007) found evidence that the speed of action judgments on objects was influenced by how the object's handles were oriented (with handles oriented away from participant's right hand disrupting the action judgments). Similar findings of the importance of the orientation of handles during priming effects have been reported more recently by Bub, Masson and colleagues (Bub & Masson, 2010; Masson, Bub, & Breuer, 2011). These results, taken together, represent evidence not only of semantics influencing action, but of action influencing semantics. Thus, collectively, accumulated evidence across various labs have shown that action can influence identification, and identification or perception of objects can influence action. That is, the link between semantics and action is bidirectional.

1.5.6 Using NAM to simulate behavioural effects

Yoon, Heinke and Humphreys' (2002) Naming-Action Model (NAM) was designed to simulate specific neuropsychological deficits through lesioning (damaging) the connections between the modules. For example, they showed that their model could simulate a deficit in object naming with intact action (optic aphasia) when the connection between the structural description system and semantics (in particular item-specific semantics) was lesioned. Likewise, their model was used to simulate two types of apraxia: (1) a deficit in demonstrating actions to pictures despite intact actions through words/semantics (visual apraxia), which corresponded to a lesion to the direct pathway from input to action, and (2) a deficit in an ability to gesture action (apraxia due to a damaged semantic route), corresponding to a lesion to the indirect pathway to action – damage to the connection between semantics and action output. Finally, their model demonstrated impaired ability to name objects despite intact ability to gesture use of the

objects (anomia), corresponding to a lesion between semantics and the phonological name output system.

In addition to simulating the damaged brain, NAM was also used to simulate some behavioural effects in the healthy brain. Specifically, NAM was used to (1) explain why healthy adults name words faster than objects, but gesture to objects faster than to words, and (2) why healthy adults gesturing to deadlines make proportionally higher numbers of visual than semantic errors, while naming to deadlines produces the reversed pattern of effects. Thus, Yoon, Heinke and Humphreys' (2002) NAM was able to show that their architecture of dedicated but interconnected parallel modules was sufficient to explain many naming and action output effects in both the healthy and damaged/lesioned brain.

Despite offering a clear model of naming and action selection for manipulable objects, NAM fails to explain where non-manipulable objects fit into their model. Implementation of NAM is such that every 'object' presented to the model has a clear and correct action associated with it that is represented in the 'action module'. Presumably this would mean that non-manipulable objects would have no action representation in the action module. One might then predict that this lack of representation (in the healthy brain) would lead to slower naming times for non-manipulable objects compared to manipulable objects, because non-manipulable would not have representations in the action module to help them identify the object more quickly. But future research should test this prediction (and the current dissertation will, see chapter 4).

1.5.7 NAM's Action Module: Dorsal or Ventral?

Another question the NAM model fails to answer is whether the neural substrate for the dedicated “action module” is subserved in the dorsal or ventral pathway. Yoon, Heinke and Humphreys (2002) acknowledge that although prehensile action has been typically considered a dorsal-pathway function (cf. reviews by Jeannerod, 1997; Milner & Goodale, 1995), the kind of action described in NAM is more of the type relating to correct selection of an action associated with an object (which has typically been more associated with ventral regions). That is NAM's ‘action module’ in this case, may describe a more ventral substrate, or at least one mediated by both dorsal and ventral parts of the cortex. The fact that NAM is completely agnostic to the existence of action modules based purely on prehensile grasping of objects (in particular the grasping of novel objects) suggests that there may very well be two distinct types of action represented in the brain. In fact, this is the very idea that Buxbaum and colleagues (2006; 2002; 2000), among others, have been advocating for the last decade (see next section).

1.5.8 Even Finer Lines of Manipulability: Grasping versus Functional Use

The Naming-Action Model demonstrated support for an independent “action module” that coded specific actions associated with specific objects. Buxbaum and colleagues (2006; 2002; 2000), have argued that ‘action’ can be further sub-divided into at least two different modules: one for functional usage and one for grasping (or ‘volumetric’ gestures). The key difference here is that ‘grasping’ has simply to do with the prehensile calculating and parsing of the motion vectors needed to reach for, grasp and then carry the object; function usage, on the other hand is about the correct usage of

the tool/object. Note that functional usage implies previous experience with an object (e.g. learning correct usage), while the grasping mechanism can be involved with almost any object regardless of its familiarity – even novel objects. In this way, this latter type of action could be used as a definition for manipulability. That is, ‘manipulable’ objects can be defined as those objects capable of being “grasped and used” or more specifically “grasped and used with one hand”(cf. Grezes & Decety, 2002).⁵ Given what we know about the kinds of information processed in the dorsal and ventral streams of the brain this type of manipulability (grasping) would correspond to activity in the dorsal stream (cf. Chao & Martin, 2000; Grèzes, Tucker, Armony, Ellis, & Passingham, 2003; Westwood & Goodale, 2011), while functional usage action information would correspond to either purely ventral activity, or a combination of both ventral and dorsal activity.

1.5.9 Support for Dissociable Action Systems

Support for dissociable action systems comes from neurological evidence of double-dissociations between knowledge of object manipulation and object function in apraxic and agnosic patients. That is, agnosic patient, FB, reported by Sirigu, Duhamel, and Poncet (1991) was able to demonstrate (mime) actions associated with using objects whose function he did not recognize, while Buxbaum, et al (2000) reported two severely apraxic patients with impaired manipulation knowledge with relatively intact function knowledge. For example when FB, who could demonstrate how to manipulate objects, when asked to identify an iron, responded “You hold it in one hand, and move it back and

⁵ Other definitions for manipulability ratings include Magnié, Besson, Poncet, and Dolisi’s(2003) pantomime manipulability ratings, and Wolk, Coslett, and Glosser’s (2005) form-manipulation ratings. Both of these are discussed in detail in chapter 2.

forth (mimes the action). Maybe you can spread glue evenly with it' (Sirigu et al., 1991, p. 2566). In contrast, Buxbaum, et al.'s (2000) patients were significantly impaired at manipulation knowledge despite preserved functional knowledge. Specifically, they were impaired at selecting two objects 'similar in their manner of manipulation' from a triad of three objects (e.g. a calculator and telephone would match because they both involve pressing numbers). From this double-dissociation, Buxbaum, et al. (2000) posited that manipulable objects are represented in terms of 'how' knowledge concerned with how objects are held and moved (manipulated). This 'manipulation knowledge' can be separate from semantic knowledge including knowledge about how the object is used (functional knowledge).

More recently, Buxbaum et al. (2006) have used neuroimaging techniques to further study neural substrates underlying knowledge of hand postures for grasping and functional use. They had participants view pictures of manipulable objects and determine whether they would be grasped with a pinch or clench (Grasp condition), functionally used with a pinch or clench (Prehensile Use condition), or functionally used with a palm or poke hand gesture (Non-prehensile Use condition). fMRI results indicated greater activity in the left inferior frontal gyrus (IFG), posterior superior temporal gyrus (STG), and inferior parietal lobule (IPL) in Non-prehensile Use trials as compared to Grasp trials. These results suggested greater recruitment of areas in both the dorsal and ventral processing streams for a functional usage task as compared a simple grasp decision. Comparison of Non-prehensile Use and Prehensile Use activations revealed significant differences only in the left IPL, confirming the importance of this area in storing knowledge of hand postures for functional use.

The role of left IPL was further investigated in a recent publication by Ishibashi, Lambon Ralph, Saito, and Pobric (2011) using repetitive transcranial magnetic stimulation (rTMS). rTMS is a method of periodically disabling a specific area of the brain (usually of a healthy participant) through magnetic stimulation. The technique of rTMS has allowed researchers to better understand the role of specific brain areas by temporarily disrupting them. Ishibashi, et al. (2011) used rTMS to temporarily disable the anterior temporal lobes (ATL) – part of the ventral stream, and left IPL – part of the dorsal stream, during participant semantic decision tasks. Participants were asked to make either semantic (what for) or manipulation (how) judgements of tools in daily life. They found that stimulation of the ATL resulted in longer function judgements, while stimulation of the IPL lead to longer responses for “manipulation” judgments. Since their “manipulation” judgments had a semantic component, this corroborated the involvement of the dorsal stream during some action & semantic decisions, as well as the role of the ventral stream (ATL) during other action decisions.

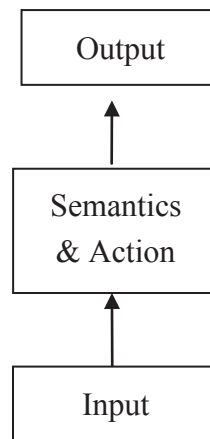
1.5.10 Summary

In summary, there is evidence for more than one important action module. There is also evidence, and computational support (most specifically – NAM), for independent brain areas (modules) that process action, and interact with semantic areas in a parallel (non-serial) way. That is, there is support for a dynamic and interactive parallel architecture.

1.5.11 Architecture (C) implications

The implications of a purely parallel and independent (but linked) action module suggest that not only can semantics influence action, but action can influence semantics. That is, the parallel architecture predicts a much more complex relationship between action and semantics, with the two capable of influencing each other. Note here, that ‘capable of influencing’ does not imply that these systems always interact. Depending on the task demands or time-course of activity in both these regions the effect of one area on another may be easily observable in some research designs, and yet completely unnoticeable in others. Thus, a brain with this architecture would predict interactive effects that only appear under certain experimental conditions. Further, the Naming Action Model (NAM), despite its success at characterizing many observable behavioural results only expounded on a single action module, while research, particularly that of Buxbaum and colleagues has been emphasizing the role of multiple action systems. Thus, a correct model of the human identification and action system may require more than one ‘action module’.

1.6 ARCHITECTURE D. ACTION REPRESENTATION *WITH OR AS* SEMANTICS



1.6.1 What does Action representation with Semantics Mean?

The evidence presented so far, especially in the previous section, seems quite compelling for the existence of an action processor separate and distinct from ‘semantics’. However, given the recent surge and popularity of the “embodied cognition” movement in psychology, this Introduction would be incomplete without at least considering the possibility that action is represented as part of the semantics system.

“Embodied cognition” can be defined many ways, but perhaps the simplest definition is that the same substrate used in perception of an object is always used in the representation (semantics) of the object. That is the representation for an object/process is embodied in its perceptual substrate (e.g. Buxbaum & Kalenine, 2010; Garbarini & Adenzato, 2004; Proffitt, 2006; Zwann, 1999). Mirror neurons – cells that fire both when observing and performing an action – are an example of embodiment. Specifically, mirror

neurons represent cells active when both perceiving and doing (cf. Cheng, Meltzoff, & Decety, 2007; Ferrari, Gallese, Rizzolatti, & Fogassi, 2003; Pezzulo, Barca, Bocconi, & Borghi, 2010; Rizzolatti & Craighero, 2004). Another example from the reading and fMRI literature comes from work by Hauk, Johnsrude, and Pulvermüller (2000) that showed that passive reading of action words (e.g. to *lick*, *pick*, or *kick*) differentially activates areas of the motor strip that were adjacent or overlapping with areas activated by actual movement of the tongue, fingers or feet. This view of embodied cognition suggests that action representation should be part of semantics (linked and not separate).

1.6.2 The difference between Architecture C & D

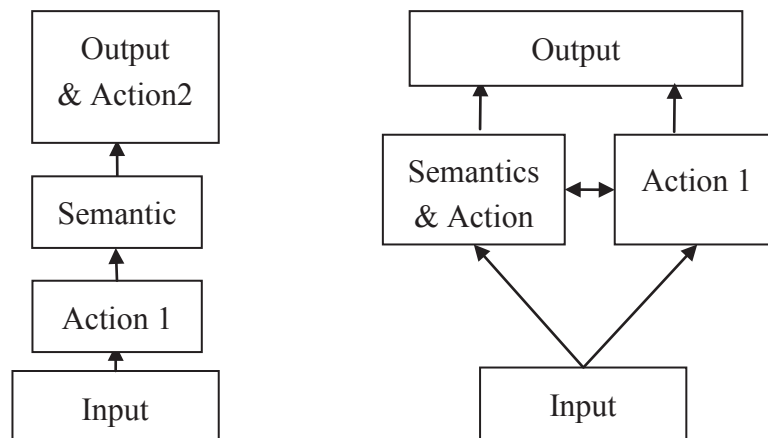
This embodied view of cognition at first appears quite at odds with the parallel, and separate modules presented earlier. However, one growing view of semantics is that of distributed representations of objects with representation based in the modality for which the object is most commonly associated. For example, fruits and vegetables would have heavy representation in sensory areas associated with taste and color, stuffed animals in the sensory areas for touch, and all tools in areas associated with action. That is, one could say non-manipulable objects would be characterized by the absence of action representation in the brain (cf. Chao, Haxby, et al., 1999; Noppeney, et al., 2006). This view of distributed embodied representation does not rule out the possibility that certain kinds of action information could be represented together in a common substrate. That is, this approach does not preclude that information about grasping objects could all be represented in a common area of the brain. Note, moreover, that that kind of representation could also be described as a dedicated ‘action area’. Thus, the separate modules presented in architecture C and the embodied approach may not be mutually

exclusive, but merely a representation of a continuum, or different ways of describing the same organization in the brain.

1.6.3 Summary & Architecture (D) implications

The view of embodied cognition as represented by the simple box-and-arrow chart at the beginning of this chapter oversimplified the complexity of the human identification system. It also implied that an embodied cognitive view is distinct and separate from Yoon, Heinke and Humphrey's (2002) dedicated (separate) action module view. However, as argued in this section, the two are not mutually exclusive, and a distributed embodied view of cognition can still include areas of the brain focused on action (i.e. areas that others would describe as dedicated actions areas). Therefore, the embodied view may best be thought of as another way describing the representation in the brain, and not a completely novel architecture.

1.7 OTHER ARCHITECTURES: CONSIDERING MULTIPLE ACTION SYSTEMS



1.7.1 New Architectures

The architectures presented so far have differed with respect to where a single action module might be located. However, as suggested in previous sections there is evidence for at least two distinct types of action systems. One involved more in computing vectors for grasping objects, and another for the functional usage of objects. One could imagine a serial setup in which grasping (Action 1) occurs directly in response to visual input, and then functional usage (Action 2) occurs either with semantics or as a part of output generation (left Panel above). However, the evidence is quite clear that the brain processes this kind of information in a parallel way, and thus the parallel architecture depicted in the right panel is more plausible (right Panel above). However, it is easier to imagine other possible architectures, for example (1) Action 2 as a dedicated module, (2) action linked with output instead of semantics, etc. In principle, it is possible to imagine many different model architectures once multiple action systems are considered. One goal of the current research is to explore the influence of different types of manipulability on object identification to help inform future theory about how the brain organizes this information.

This dissertation will attempt to document the role of two types of manipulability in human visual object identification: grasping and functional usage. The ultimate goal will be to gain a better understanding of how this information is organized in the brain – data that will be useful in future basic research, rehabilitation of patients with visual agnosia and apraxia, as well building of intelligent action systems (biological and artificial).

1.8 OUTLINE OF THE CURRENT RESEARCH

In order to expand our knowledge of how action influences object identification, two types of action will be explored in this dissertation: (1) grasping and (2) functional usage. The definitions employed in this dissertation were similar to those used by Grezes and Decety (2002) and Buxbaum and colleagues (e.g. 2006) where manipulable or ‘graspable’ objects were defined as those objects that participants could ‘grasp and use with one hand’. Functional Usage ratings were defined as those for which the action for using the object was very different than the action for grasping the object. In this way, an ‘apple’ got a low functional usage rating because its grasping and functional use actions are similar, whereas a ‘calculator’ got a high one because its grasping and functional use actions are very dissimilar.

A comprehensive database containing ‘grasping’ and ‘functional usage’ ratings for a large number of objects was not available to us, and therefore, we developed one (presented in chapter 2). This new database also included ratings for two of the main object identification confounds: familiarity and age of acquisition. This database was then used to generate a balanced list of manipulable and non-manipulable objects for testing during naming and categorization experiments (chapter 3). The results from these experiments were then modeled using an extension to Yoon, Heinke and Humphreys (2002) NAM model (chapter 4), in order to develop a better understanding of the meaning of the results.

Chapter 5 more fully explores the difference in the role between grasping and functional usage during tasks in which objects were shown with a concurrent mask. Chapter 6 considers the role of visual representation: photograph versus line drawing.

Finally, chapter 7 concludes by summarizing all the results and how they fit into the context of the architectures presented in this introduction. The goal throughout is to gain a better understanding of how the action system(s) influence object identification in a healthy brain.

1.9 REFERENCES

- Adamo, M., & Ferber, S. (2009). A picture says more than a thousand words: Behavioural and ERP evidence for attentional enhancements due to action affordances. *Neuropsychologia*, *47*(6), 1600-1608.
- Allport, D. A. (1985). Distributed memory, modular subsystems and dysphasia. In S. K. Newman & R. Epstein (Eds.), *Current Perspectives in Dysphasia* (pp. 32-60). Edinburgh: Churchill Livingstone.
- Bar, M., & Aminoff, E. (2003). Cortical analysis of visual context. [Article]. *Neuron*, *38*(2), 347-358.
- Biederman, I. (1985). Human image understanding: Recent research and a theory *Computer Vision, Graphics, and Image Processing*, *32*(1), 29-73.
- Biederman, I. (1987). Recognition-by-components: A theory of human image understanding. *Psychological Review*, *94*(2), 115-147.
- Boronat, C. B., Buxbaum, L. J., Coslett, H. B., Tang, K., Saffran, E. M., Kimberg, D. Y., et al. (2005). Distinctions between manipulation and function knowledge of objects: Evidence from functional magnetic resonance imaging. *Cognitive Brain Research*, *23*(2-3), 361-373.
- Bub, D. N., & Masson, M. E. J. (2010). Grasping beer mugs: On the dynamics of alignment effects induced by handled objects. *Journal of Experimental Psychology: Human Perception and Performance*, *36*, 341-358.
- Bub, D. N., & Masson, M. E. J. (2012). On the dynamics of action representations evoked by names of manipulable objects. *Journal of Experimental Psychology: General*, *141*, 502-517.

- Bub, D. N., Masson, M. E. J., & Bukach, C. M. (2003). Gesturing and naming: The use of functional knowledge in object identification. *Psychological Science, 14*(5), 467-472.
- Bub, D. N., Masson, M. E. J., & Cree, G. S. (2008). Evocation of functional and volumetric gestural knowledge by objects and words. *Cognition, 106*(1), 27-58.
- Buxbaum, L. J., & Kalenine, S. (2010). Action knowledge, visuomotor activation, and embodiment, in the two action systems. *Annals of the New York Academy of Sciences, 1191*, 201-218.
- Buxbaum, L. J., Kyle, K. M., Tang, K., & Detre, J. A. (2006). Neural substrates of knowledge of hand postures for object grasping and functional object use: Evidence from fMRI. *Brain Research, 1117*, 175-185.
- Buxbaum, L. J., & Saffran, E. M. (2002). Knowledge of object manipulation and object function: Dissociations in apraxic and nonapraxic subjects. *Brain and Language, 82*(2), 179-199.
- Buxbaum, L. J., Veramonti, T., & Schwartz, M. F. (2000). Function and manipulation tool knowledge in apraxia: Knowing 'what for' but not 'how.'. *Neurocase, 6*(2), 83-97.
- Cant, J. S., & Goodale, M. A. (2007). Attention to form or surface properties modulates different regions of human occipitotemporal cortex. *Cerebral Cortex, 17*(3), 713-731.
- Carpenter, G. A., & Grossberg, S. (2002). A self-organizing neural network for supervised learning, recognition, and prediction. In T. A. Polk & C. M. Seifert (Eds.), *Cognitive modeling*. (pp. 289-314). Cambridge, MA US: MIT Press.

- Chainay, H., & Humphreys, G. W. (2002). Privileged access to action for objects relative to words. *Psychonomic Bulletin & Review*, *9*(2), 348-355.
- Chao, L. L., Haxby, J. V., & Martin, A. (1999). Attribute-based neural substrates in temporal cortex for perceiving and knowing about objects. *Nature Neuroscience*, *2*(10), 913-919.
- Chao, L. L., & Martin, A. (2000). Representation of manipulable manmade objects in the dorsal stream. *NeuroImage*, *12*, 478-484.
- Chao, L. L., Martin, A., & Haxby, J. V. (1999). Are face-responsive regions selective only for faces? *NeuroReport: For Rapid Communication of Neuroscience Research*, *10*(14), 2945-2950.
- Cheng, Y., Meltzoff, A. N., & Decety, J. (2007). Motivation modulates the activity of the human mirror-neuron system. *Cerebral Cortex*, *17*(8), 1979-1986.
- Coslett, H. B., & Saffran, E. M. (1992). Optic aphasia and the right hemisphere: A replication and extension. *Brain and Language*, *43*(1), 148-161.
- Craighero, L., Fadiga, L., Rizzolatti, G., & Umiltà, C. (1998). Visuomotor priming. *Visual Cognition*, *5*(1-2), 109-125.
- Craighero, L., Fadiga, L., Rizzolatti, G., & Umiltà, C. (1999). Action for perception: A motor-visual attentional effect. *Journal of Experimental Psychology: Human Perception and Performance*, *25*(6), 1673-1692.
- Creem, S. H., & Proffitt, D. R. (2001). Grasping objects by their handles: A necessary interaction between cognition and action. *Journal of Experimental Psychology: Human Perception and Performance*, *27*(1), 218-228.

- DeRenzi, E., Faglioni, P., & Sorgato, P. (1982). Modality-specific and supramodal mechanisms of apraxia. *Brain*, *105*, 301-312.
- Downing, P. E., Chan, A. W. Y., Peelen, M. V., Dodds, C. M., & Kanwisher, N. (2006). Domain specificity in visual cortex. [Article]. *Cerebral Cortex*, *16*(10), 1453-1461.
- Epstein, R., Harris, A., Stanley, D., & Kanwisher, N. (1999). The parahippocampal place area: Recognition, navigation, or encoding? *Neuron*, *23*, 115-125.
- Ferrari, P. F., Gallese, V., Rizzolatti, G., & Fogassi, L. (2003). Mirror neurons responding to the observation of ingestive and communicative mouth actions in the monkey ventral premotor cortex. *European Journal of Neuroscience*, *17*(8), 1703-1714.
- Garbarini, F., & Adenzato, M. (2004). At the root of embodied cognition: Cognitive science meets neurophysiology. *Brain and Cognition*, *56*(1), 100-106.
- Garofeanu, C., Króliczak, G., Goodale, M. A., & Humphrey, G. K. (2004). Naming and grasping common objects: A priming study. *Experimental Brain Research*, *159*(1), 55-64.
- Gauthier, I., & Tarr, M. J. (1997). Becoming a 'greeble' expert: Exploring mechanisms for face recognition. *Vision Research*, *37*(12), 1673-1682.
- Gauthier, I., Tarr, M. J., Moylan, J., Skudlarski, P., Gore, J. C., & Anderson, A. W. (2000). The fusiform 'face area' is part of a network that processes faces at the individual level. *Journal of Cognitive Neuroscience*, *12*(3), 495-504.

- Gauthier, I., Williams, P., Tarr, M. J., & Tanaka, J. (1998). Training 'greeble' experts: A framework for studying expert object recognition processes. *Vision Research*, 38(15-16), 2401-2428.
- Gibson, J. J. (1979). *The ecological approach to visual perception*. Boston: Houghton-Mifflin.
- Goodale, M. A., & Milner, A. D. (1992). Separate visual pathways for perception and action. *Trends in Neurosciences*, 15(1), 20-25.
- Goodale, M. A., & Milner, A. D. (1994). Separate visual pathways for perception and action. In H. Gutfreund & G. Toulouse (Eds.), *Biology and computation: A physicist's choice*. (pp. 606-611). River Edge, NJ US: World Scientific Publishing Co.
- Grezes, J., & Decety, J. (2002). Does visual perception of object afford action? Evidence from a neuroimaging study. *Neuropsychologia*, 40, 212-222.
- Grèzes, J., Tucker, M., Armony, J., Ellis, R., & Passingham, R. E. (2003). Objects automatically potentiate action: An fMRI study of implicit processing. *European Journal of Neuroscience*, 17(12), 2735-2740.
- Hauk, O., Johnsrude, I., & Pulvermüller, F. (2000). Somatotopic representation of action words in human motor and premotor cortex. *Neuron*, 41(2), 301-307.
- Helbig, H., Graf, M., & Kiefer, M. (2006). The role of action representations in visual object recognition. *Experimental Brain Research*, 174, 221-228.
- Hillis, A. E., & Caramazza, A. (1995). Cognitive and neural mechanisms underlying visual and semantic processing: Implications from 'optic aphasia.'. *Journal of Cognitive Neuroscience*, 7(4), 457-478.

- Hinton, G. E. (2007). Learning multiple layers of representation. *Trends in Cognitive Sciences, 11*(10), 428-434.
- Hummel, J. E., & Biederman, I. (2002). Dynamic binding in a neural network for shape recognition. In T. A. Polk & C. M. Seifert (Eds.), *Cognitive modeling*. (pp. 337-374). Cambridge, MA US: MIT Press.
- Humphreys, G. W. (2001). Objects, affordances...action! *The Psychologist, 14*(8), 408-412.
- Humphreys, G. W., & Riddoch, M. J. (2001). Detection by action: neuropsychological evidence for action-defined templates in search. . *Nature Neuroscience, 4*, 84-88.
- Ishibashi, R., Lambon Ralph, M. A., Saito, S., & Pobric, G. (2011). Different roles of lateral anterior temporal lobe and inferior parietal lobule in coding function and manipulation tool knowledge: Evidence from an rtms study. *Neuropsychologia*.
- Jeannerod, M. (1997). *The cognitive neuroscience of action*. Malden: Blackwell Publishing.
- Jolicoeur, P. (1985). The time to name disoriented natural objects. *Memory & Cognition, 13*(4), 289-303.
- Jolicoeur, P., Gluck, M. A., & Kosslyn, S. M. (1984). Pictures and names: Making the connection. *Cognitive Psychology, 16*(2), 243-275.
- Kanwisher, N. (2000). Domain specificity in face perception. *Nature Neuroscience, 3*(8), 759-763.
- Kanwisher, N., McDermott, J., & Chun, M. M. (1997). The fusiform face area: A module in human extrastriate cortex specialized for face perception. *The Journal of Neuroscience, 17*(11), 4302-4311.

- Kanwisher, N., Stanley, D., & Harris, A. (1999). The fusiform face area is selective for faces not animals. *NeuroReport: For Rapid Communication of Neuroscience Research*, 10(1), 183-187.
- Kiefer, M., Sim, E.-J., Helbig, H., & Graf, M. (2011). Tracking the time course of action priming on object recognition: Evidence for fast and slow influences of action on perception. *Journal of Cognitive Neuroscience*, 23(8), 1864-1874.
- Kung, C.-C. (2007). *Expanding the FFA debate: A reevaluation of recent studies and evidence for the multimodal and dynamic fusiform gyrus*. ProQuest Information & Learning, US.
- Lhermitte, F. (1983). 'Utilization behaviour' and its relation to lesions of the frontal lobes. *Brain*, 106, 237-255.
- Lindemann, O., Stenneken, P., van Schie, H. T., & Bekkering, H. (2006). Semantic activation in action planning. *Journal of Experimental Psychology: Human Perception and Performance*, 32(3), 633-643.
- Magnié, M. N., Besson, M., Poncet, M., & Dolisi, C. (2003). The Snodgrass and Vanderwart set revisited: Norms for object manipulability and for pictorial ambiguity of objects, chimeric objects, and nonobjects. *Journal of Clinical and Experimental Neuropsychology*, 25(4), 521-560.
- Marr, D., & Nishihara, H. K. (1978). Representation and recognition of the spatial organization of three-dimensional shapes. *Proc. R. Soc. Lond. B Biol. Sci.*, 200, 269-294.

- Martin, A., Haxby, J. V., Lalonde, F. M., & Wiggs, C. L. (1995). Discrete cortical regions associated with knowledge of color and knowledge of action. *Science*, *270*(5233), 102-105.
- Masson, M. E. J., Bub, D. N., & Breuer, A. T. (2011). Priming of reach and grasp actions by handled objects. *Journal of Experimental Psychology: Human Perception and Performance*, *37*(5), 1470-1484.
- McNair, N. A., & Harris, I. M. (2012). Disentangling the contributions of grasp and action representations in the recognition of manipulable objects. *Experimental Brain Research*, *220*(1), 71-77.
- Miceli, G., Fouch, E., Capasso, R., Shelton, J. R., Tamaiuolo, F., & Caramazza, A. (2001). The dissociation of color from form and function knowledge. *Nature Neuroscience*, *4*(6), 662-667.
- Milner, A. D., & Goodale, M. A. (1995). *The visual brain in action*. New York, NY US: Oxford University Press.
- Noppeney, U., Price, C. J., Penny, W. D., & Friston, K. J. (2006). Two Distinct Neural Mechanisms for Category-selective Responses. *Cerebral Cortex*, *16*(3), 437-445.
- Peissig, J. J., & Tarr, M. J. (2007). Visual Object Recognition: Do We Know More Now Than We Did 20 Years Ago? *Annual Review of Psychology*, *58*, 75-96.
- Pezzulo, G., Barca, L., Bocconi, A. L., & Borghi, A. M. (2010). When affordances climb into your mind: Advantages of motor simulation in a memory task performed by novice and expert rock climbers. *Brain and Cognition*, *73*(1), 68-73.
- Pilgrim, E., & Humphreys, G. W. (1991). Impairment of action to visual objects in a case of ideomotor apraxia. *Cognitive Neuropsychology*, *8*(6), 459-473.

- Plaut, D. C., & Farah, M. J. (1990). Visual object representation: Interpreting neurophysiological data within a computational framework. *Journal of Cognitive Neuroscience*, 2(4), 320-343.
- Poggio, T., & Edelman, S. (1990). A network that learns to recognize three-dimensional objects. *Nature*, 343, 263-266.
- Proffitt, D. R. (2006). Embodied perception and the economy of action. *Perspectives on Psychological Science*, 1(2), 110-122.
- Riddoch, M. J., Edwards, M. G., Humphreys, G. W., West, R., & Heafield, T. (1998). Visual affordances direct action: Neuropsychological evidence from manual interference. *Cognitive Neuropsychology*, 15(6/7/8), 645-683.
- Riddoch, M. J., & Humphreys, G. W. (1987). Visual object processing in optic aphasia: A case of semantic access agnosia. *Cognitive Neuropsychology*, 4(2), 131-185.
- Riddoch, M. J., Humphreys, G. W., & Price, C. J. (1989). Routes to action: Evidence from apraxia. *Cognitive Neuropsychology*, 6(5), 437-454.
- Riesenhuber, M., & Poggio, T. (2000). Models of object recognition. *Nature Neuroscience*, 3(Suppl), 1199-1204.
- Rizzolatti, G., & Craighero, L. (2004). The Mirror-Neuron System. *Annual Review of Neuroscience*, 27, 169-192.
- Rosch, E. (1975). Cognitive representations of semantic categories. *Journal of Experimental Psychology: General*, 104(3), 192-233.
- Rumiati, R. I., & Humphreys, G. W. (1998). Recognition by action: Dissociating visual and semantic routes to action in normal observers. *Journal of Experimental Psychology: Human Perception and Performance*, 24(2), 631-647.

- Sergent, J., Ohta, S., & MacDonald, B. (1992). Functional neuroanatomy of face and object processing: a positron emission tomography study. *Brain, 115*, 15–36.
- Sirigu, A., Duhamel, J., & Poncet, M. (1991). The role of sensorimotor experience in object recognition. A case of multimodal agnosia. *Brain, 114*, 2555-2573.
- Smith, M. C., & Magee, L. E. (1980). Tracing the time course of picture–word processing. *Journal of Experimental Psychology: General, 109*(4), 373-392.
- Spunt, R. P., Falk, E. B., & Lieberman, M. D. (2010). Dissociable neural systems support retrieval of how and why action knowledge. *Psychological Science, 21*(11), 1593-1598.
- Tanaka, J. W., & Taylor, M. (1991). Object categories and expertise: Is the basic level in the eye of the beholder? *Cognitive Psychology, 23*(3), 457-482.
- Tarr, M. J. (1995). Rotating objects to recognize them: A case study on the role of viewpoint dependency in the recognition of three-dimensional objects. *Psychonomic Bulletin & Review, 2*(1), 55-82.
- Tarr, M. J., & Pinker, S. (1989). Mental rotation and orientation-dependence in shape recognition. *Cognitive Psychology, 21*(2), 233-282.
- Tucker, M., & Ellis, R. (2004). Action priming by briefly presented objects. *Acta Psychologica, 116*(2), 185-203.
- Westwood, D. A., & Goodale, M. A. (2011). Converging evidence for diverging pathways: Neuropsychology and psychophysics tell the same story. *Vision Research, 51*(8), 804-811.

- Wolk, D. A., Coslett, H. B., & Glosser, G. (2005). The role of sensory-motor information in object recognition: Evidence from the category-specific visual agnosia. *Brain and Language, 94*, 131-146.
- Wühr, P., & Elsner, B. (2007). Effects of irrelevant stimulus orientation on visually guided grasping movements. *Behavioral Neuroscience, 121*(2), 301-309.
- Xu, Y. (2005). Revisiting the Role of the Fusiform Face Area in Visual Expertise. *Cerebral Cortex, 15*(8), 1234-1242.
- Yoon, E. Y., Heinke, D., & Humphreys, G. W. (2002). Modelling direct perceptual constraints on action selection: The Naming and Action Model (NAM). *Visual Cognition, 9*(4-5), 615-661.
- Yoon, E. Y., & Humphreys, G. W. (2007). Dissociative effects of viewpoint and semantic priming on action and semantic decisions: Evidence for dual routes to action from vision. *The Quarterly Journal of Experimental Psychology, 60*(4), 601-623.
- Zwann, R. A. (1999). Embodied cognition, perceptual symbols, and situation models. *Discourse Processes, 28*(1), 81-88.

**CHAPTER 2 NORMS FOR TWO TYPES OF MANIPULABILITY
(GRASPABILITY AND FUNCTIONAL USAGE), FAMILIARITY,
AND AGE OF ACQUISITION FOR 320 PHOTOGRAPHS OF
OBJECTS**

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2.1 ABSTRACT

There is increasing interest in the role that manipulability plays in processing objects. To date, Magnié et al.'s (2003) manipulability ratings, based on the degree to which objects can be uniquely pantomimed, have been the reference point for many studies. However, these ratings do not fully capture some relevant dimensions of manipulability, including 1) whether an object is graspable and 2) the extent to which functional motor associations above and beyond graspability are present. To address this, the current study collected ratings of these dimensions, in addition to ratings of familiarity and age of acquisition (AoA), for a set of 320 black and white photographs of objects. Familiarity and AoA ratings were highly correlated with previously reported ratings of the same dimensions ($r = .853, p < .001$; and $r = .771, p < .001$, respectively) validating the current norms. Grasping and functional use ratings, in contrast, were more moderately correlated with Magnié et al.'s (2003) pantomime manipulability ratings ($r = .507, p < .001$). These results were taken as evidence that the new manipulability ratings collected in this research capture distinct aspects of object manipulability.

Keywords: manipulability, grasping, familiarity, age of acquisition, ratings

2.2 INTRODUCTION TO THE NORMING STUDY

There has been increasing interest in the role “manipulability” and object action play in object recognition (where manipulability is defined as *the extent to which an object can be picked up or grasped and then used*). Yoon, Heinke and Humphreys (2002) have proposed a direct route from early visual (structural) descriptions to action that does not require the semantic system. This direct route parallels the direct route from the input lexicon to the phonological name (naming) output, and helps explain why participants are faster to name the word “hammer” than a picture of the hammer, but faster to gesture at the picture than they are at the word. These two direct routes in Yoon, et al.’s (2002) Naming Action Model interact at the level of semantics, and may explain why manipulability influences object recognition in participants (cf. Filliter, McMullen, & Westwood, 2005; *see also* McMullen et al., in press, and Humphreys, 2001).

Research on brain-damaged patients has also pointed to a role for manipulability in visual object recognition. Early work with individuals with visual object agnosia focused on impairments in visual object recognition that were specific to the objects’ living or non-living category status (cf. Farah, McMullen, & Meyer, 1991; Farah, Meyer, McMullen, 1996; Gaffan & Heywood, 1993; Warrington & Shallice, 1984.). More recently there has been interest in the notion that the relevant object dimension underlying this deficit may, in fact, be object manipulability (see Borgo & Shallice, 2003; Humphreys & Riddoch, 2001). Wolk, Coslett, and Glosser (2005) were able to show that object manipulability can be an important predictor of a visual object agnostic’s ability to identify objects, with patients being more likely to accurately recognize highly manipulable objects. Some patients with visual agnosia retain the ability to gesture the

functional use of objects and are termed optic aphasics. This supports the direct route to action proposed by Yoon et al. (2002). In a double dissociation, patients with apraxia are known to have deficits in functionally using objects while still retaining the ability to identify those objects (Riddoch, Humphreys, & Price 1989).

A common reference point for manipulability ratings has been Magnié, Besson, Poncet, and Dolisi's (2003) ratings, which were based on the ability to unambiguously pantomime an object. Wolk et al. (2005) also proposed "form-manipulation" ratings based on the extent to which the form predicts how object should be used. Magnié et al.'s (2003) ratings appear to suffer from face validity issues because their ratings seem to be more about pantomiming than about manipulability (grasping and using objects). Wolk et al.'s (2005) ratings suffer from a low N (only ratings for a few items were published).

The current research set out to collect ratings of other aspects of manipulability not captured by existing ratings for a set of 320 objects. Objects were chosen from a variety of categories, including animals, fruits, vegetables, vehicles, tools, household appliances, and local landmarks. Familiarity and age of acquisition ratings for each object were also collected since these variables have been shown to influence object processing (Bates et al., 2003; Bonin et al., 2003; Cuetos & Alija, 2003; Pérez, 2007).

2.2.1 Manipulability

Presumably, a "manipulability" rating should capture some dimension of picking up and/or grasping an object. For example, Grèzes and Decety (2002) used objects they described as being "*capable of being grasped and manipulated by one hand*" (pg. 214). In Magnié et al.'s (2003) study collecting object manipulability ratings, participants were asked "*Could you easily mime the action usually associated with this object so that any*

person looking at you doing this action could decide which object goes with this action” (pg. 524). This definition has a degree of face validity, but leads to some unusual classifications of objects. For example, it is hard to pantomime the use of an apple in a way that is indistinguishable from that of a pear, a peach or many other edible objects. Thus, apples, peaches, and pears are rated as “unmanipulable” on Magnié’s et al.’s (2003) scale even though they are quite manipulable if we define manipulability as the ability to pick up and grasp an object with one or both hands (cf. Grèzes & Decety, 2002). On the other hand, it is easy to pantomime sleeping in a bed, playing a piano, or riding a bicycle. As a result, bed, piano, and bicycle were rated as “manipulable” on Magnié’s et al.’s (2003) scale even though these objects cannot be picked up. This classification of objects is counterintuitive as it is easy to pick up and grasp an apple, peach, or pear, but close to impossible to do the same for a bed, bicycle or piano. Therefore, there is a need for new manipulability ratings that capture the dimensionality of graspability as an aspect of manipulability. That is, a rating based on *grasping* instead of pantomime (Manip1). Indeed, edible objects that can be grasped are likely to be important to the cognitive system of creatures who have evolved to retrieve food with their hands (apes and humans) and do so at very early stages of development (cf. Toledo & Tudella, 2008; Witherington, 2005). Studies have indicated a unique neural pathway for grasping in the parietal (dorsal) cortex (Culham & Valyear, 2006).

There are at least two ways to motorically interact with objects: 1) grasping them and 2) using them. The new ratings in this research are based on two manipulability rating scales that distinguish between these two types of motor responses. Wolk, Coslett & Glosser (2005) came close to capturing the “using” or functional component of

manipulability when they developed their “form-manipulation ratings”. In these ratings, they had participants rate “the degree to which the shape of object implies how it should be used” (Wolk et al., 2005, p. 135). However, their ratings still confounded the concepts of grasping and using. The current research proposes a functional definition of manipulability (Manip2) that specifically incorporates the degree to which the motor scripts for using and those for picking up objects can be differentiated. In this way, the current definition describes functional motor actions in a way that is not dependent on the object’s shape.

2.2.2 Familiarity & Age of Acquisition (AoA)

Like manipulability, object familiarity and age of acquisition (AoA), or the age at which a person acquired the name for an object, are also dimensions that influence object processing. Research has shown that AoA influences object naming time such that object names learned at a younger age (low AoA) are associated with faster naming speeds than those learned later in life (e.g., Bonin, et al., 2003; Cuetos & Alija, 2003; Pérez, 2007). Object familiarity also influences object naming time, with familiar objects being named more quickly than unfamiliar ones (c.f. Bates et al., 2003). One theory, the *cumulative frequency hypothesis* suggested that AoA and object familiarity are really two labels for one effect (cf. Lewis, Gerhand, & Ellis, 2001). However, recent research has shown distinct influences of these variables (cf. Dent, Johnston, & Humphreys, 2008). This evidence suggests that object familiarity and AoA are separate constructs and should be treated as such. Given the importance of both of these dimensions in object naming, it was important for the current research to include ratings on both of these constructs for

our new object set (in order to determine effects of manipulability independently of these constructs). Ratings of these dimensions have also been provided in previous normed sets of objects (e.g. Morrison et al. 1997; Snodgrass & Vanderwart, 1980).

2.2.3 Current Study

The current study collected ratings on object Familiarity, Age of Acquisition (AoA) and Manipulability for over 320 black & white objects. Manipulability ratings were further divided into two scales for (1) grasping and (2) functional use/associations of an object. All participants rated all items on all scales, but the order of ratings was randomized such that at least 18 participants saw the items for the first time for each scale. All ratings were collected from a university-aged sample. The main goal of this research was to collect accurate, age-relevant ratings on a controlled set of objects to be used in future research. Objects were chosen *a priori* to maximize the likelihood that equal numbers would fall within each of the cells of a factorial 2x2x2 design with high and low levels for each of the variables: familiarity, AoA and manipulability.

Since Familiarity and AoA naturally correlate, it was a challenge to generate items to populate some categories. For example, to fill the category of objects with low Familiarity but acquired at a young age (low AoA), baby toys and other objects encountered in infancy were used. Also, to fill out the category of items that were high familiarity, late/high AoA and non-manipulable, local university and town landmarks were used¹. For examples of item categories and where they were expected to be rated *a priori*, see Table 2.1. On this basis, a set of 320 objects, with approximately 40 objects in each design cell were presented for rating.

Table 2.1. Examples of object categories expected to fall in each cell of the factorial design.

		Low AoA (acquired early)	High AoA (acquired late)
High Familiarity	Manipulable	fruits, vegetables	office/school supplies
	NonManipulable	furniture	local landmarks
Low Familiarity	Manipulable	baby toys	musical instruments
	NonManipulable	common animals/pets	uncommon animals

The methodology used in this study differed somewhat from that used by previous researchers. A computer program was used to present objects on a large screen to a group of participants who rated objects by using a computer mouse to assign a rating on a computerized scale (each participant had their own computer). Other researchers have used an overhead projector to present exemplars and required participants to write their ratings with pen and paper (cf. Snodgrass & Vanderwart, 1980). Also, the current study used a practice set of eight items for each scale and anchors in the form of example objects for each extreme of a scale. For example, the object “bed” was provided as an example of a high familiarity object, and “submarine” was used for low familiarity. In contrast, Snodgrass & Vanderwart (1980) used no explicit anchors, and instead, showed their participants 30 random items from their set before rating began. That is, they let the context of the first 30 items anchor the participants. In addition, in the current study each participant rated all items on all scales. Snodgrass and Vanderwart (1980), in contrast, had different groups rate each of their scales/tasks. In spite of these methodological differences, it was hypothesized that ratings collected in the current study would not differ significantly from previous ratings where identical definitions for parameters were

employed. Specifically, the current design used the same familiarity definition and 5-point scale as did Snodgrass and Vanderwart (1980), and the same AoA definition and 7-point scale as did Morrison, Chappell, & Ellis (1997). For these reasons, it was expected that our ratings on these scales would correlate significantly with those previously published for overlapping objects. Manipulability ratings, on the other hand, were compared to ratings by Magnié et al.'s (2003) and Wolk et al. (2005).

2.3 METHODS

2.3.1 Participants

Fifty-seven undergraduate students (13 males), ranging in age from 18 to 29 ($M = 19.52$, $SD = 2.30$), rated all 320 pictures on all three rating scales. Most participants were right-handed (seven left-handed and two ambidextrous). All spoke English as their first language. All had normal or corrected-to-normal vision. Participants were randomly assigned to one of three orders: 1) those who rated familiarity first ($N = 20$), 2) those who rated age of acquisition first ($N = 18$) and 3) those who rated manipulability first ($N = 19$).

2.3.2 Stimuli

A set of 320 objects was chosen such that approximately equal numbers would be assigned high and low ratings on each of the three rating scales. The object set was generated based on experimenters' predictions about classifications (e.g. baby rattle should score highly on manipulability rating) and object ratings from previous studies (such as those by Snodgrass & Vanderwart, 1980 for familiarity). Objects were also

chosen based on the ease with which unambiguous photographs could be obtained (for example a picture of the sun without the sky and clouds would look like just a circle). For example photographs see Appendix A, photographs of all the images can be found in online supplemental materials².

Each picture was cropped and shown in greyscale on a white background. The majority of the pictures were chosen from the Hemera CD photo set. However, some (particularly the Halifax, Nova Scotia, landmarks) were produced by the experimenters using a digital camera. Some were also taken from online free-use photography websites, and a few were taken from the world wide web (with permission). All images were edited in Photoshop or GIMP, a freely licensed photo editing software (<http://www.gimp.org/>). All images were saved as a .BMP and varied in size up to a maximum of 300 x 300 pixels. During rating sessions, images were viewed at an unrestrained distance ranging from 140cm to 70 cm (two rows) resulting in visual angles 6.1 to 12.2 degrees (subtended angle).

2.3.3 Rating Scales

Ratings on three dimensions were obtained: Familiarity, Age of Acquisition (AoA) and Manipulability. Manipulability was further divided into two sub-scales that were rated at the same time. Familiarity and AoA scales were rated on definitions consistent with those used in previous research (Morrison et al. 1997; Snodgrass & Vanderwart, 1980). The definitions of manipulability employed, however, were unique to the current study and less consistent with those used in previous research (e.g., Magnié et al., 2003). Each scale was assigned two anchor images that exemplified strong high and low ratings on the dimension being evaluated.

Familiarity ratings were preceded by the instructions:

“For each object you see on the screen, please give it a rating on the familiarity scale. Rate your familiarity with the object according to how usual or unusual the object is in your realm of experience. That is, please rate your **familiarity with the object or the degree to which you come into contact with or think about the concept on a day-to-day basis.**”

Familiarity was rated on a 5-point Likert scale with 5 being a high familiarity score and 1 being a low familiarity score. For anchors, a “bed” was used as an example of an item that would score high (5) on familiarity, and a “submarine” was used as an example of an item that would score low (1) on familiarity.

Age of Acquisition (AoA) ratings were preceded by the instructions:

“For each object you see on the screen, please give it a rating on the Age of Acquisition scale. That is, please rate the object according to the **age at which you think you likely learned the name for that object.** Of course it is impossible to remember EXACTLY when you acquired the vocabulary, but please take your best educated guess.”

AoA was rated on a 7-point scale and divided into ranges of 2 years. Starting with (1) 0-2 years, then (2) 3-4 years, up to (6) 11-12 years, and ending with (7) 13+ years. For anchors, “ball” was used as an example of an item that was acquired early (0-2 years old: 1 on the scale) and “iPod” was used as an example of an item acquired late (13+ years old: 7 on the scale).

Participants rated items on manipulability twice and the instructions for the first manipulability rating (Manip1) were:

“On the first scale, please **rate the manipulability of the object according to how easy it is to grasp and use the object with one hand.**”

After the examples the instructions were repeated as:

“First scale: Rate the manipulability of the object (the degree to which you can pick up and use) along a 5-point scale:”

For anchors, “rhinoceros” was as an example of item that would score low (1) on the first manipulability scale, and “spoon” was used as an example of an item that would score high (5) on the first manipulability scale⁶.

The rating on the second manipulability (Manip2) scale was contingent on the first rating and the instructions read:

“On the second scale, for the objects that you just rated 3 or higher on the first scale, we would like you to provide a second rating on a different scale. Now, please rate the **extent to which the hand-movements that you make to use the object differ from the hand-movements that you make to *pick it up***. If the two movements are very different give it a high score (5 on the second manipulability rating) if the two movements are similar or identical give it a low score (1 on the second manipulability rating).”

After the examples, the instructions were repeated as:

“Second scale: Rate the extent to which the hand-movements that you make to *use* the object differ from the hand-movements that you make to *pick it up* along a 5-point scale:”

For anchors, “apple” was used as an example of item that would score low (1) on the second manipulability scale and “calculator” was used as an example of an item that would score high (5) on the second manipulability scale.

⁶ Note, our definition explicitly made the choice to focus on movements of one and not two hands. This was done to be consistent with other literature in this area, but it did put a constraint on the size of objects that would be considered ‘manipulable’, with larger objects, and those usually used by two hands less likely to be considered manipulable. This was a limitation of the current ratings.

2.3.4 Equipment

Each participant was assigned their own Mac OSX (700 MHz PowerPC G4) computer connected to the Internet. This allowed them to connect to Opinio Survey Software™ on our local server, which was used to record their ratings for each picture. The Opinio Survey Software™ was set up so that each rating scale had its own web-address where the scale, presented with anchors for each item, could be accessed. The Opinio Survey Software™ did not show the pictures or names of the objects to be rated. Pictures were presented on a screen using a projector controlled by a laptop. A Matlab (Mathworks, Natick, MA) program on the laptop was used to control the rate of picture presentation. The laptop was a Dell PC, dual processor, Windows XP machine. All participants were angled so they would have a good view of the presentation screen from their computer station.

2.3.5 Procedure

Participants were tested in small groups of one to seven individuals (average group size = 3.24). Each group was assigned to one of three orders: FMA (Familiarity, Manipulability, then AoA), MAF, or AFM. These three orders were chosen to ensure that each scale was rated first one third of the time and each scale was rated in all positions.

After informed consent was obtained, each participant was assigned their own computer. Participants were then handed instructions (on a single page for each participant) for the first rating scale, which the experimenter read out loud to the group. Once instructions were understood and participants were given a chance to ask questions, the group began with eight practice trials for the first rating scale. All pictures were shown to all participants at the same time on a screen at the front of the room. The

picture presentation program allowed for pausing, going backwards, skipping items, slowing down and speeding up presentation rate. Thus, if any participants missed an item, they could raise their hand and the experimenter would go back to the item they missed. During presentation, each picture was paired with a number that appeared both before presentation of the object and in the lower left corner of the screen while the picture was being presented. Further, to simplify the rating process for participants, and to help keep them motivated, the experimenter read aloud the number of each object. In addition a tone was played before each item appeared to alert both the participants and the experimenter that the picture on the overhead screen had changed (Figure 2.1).

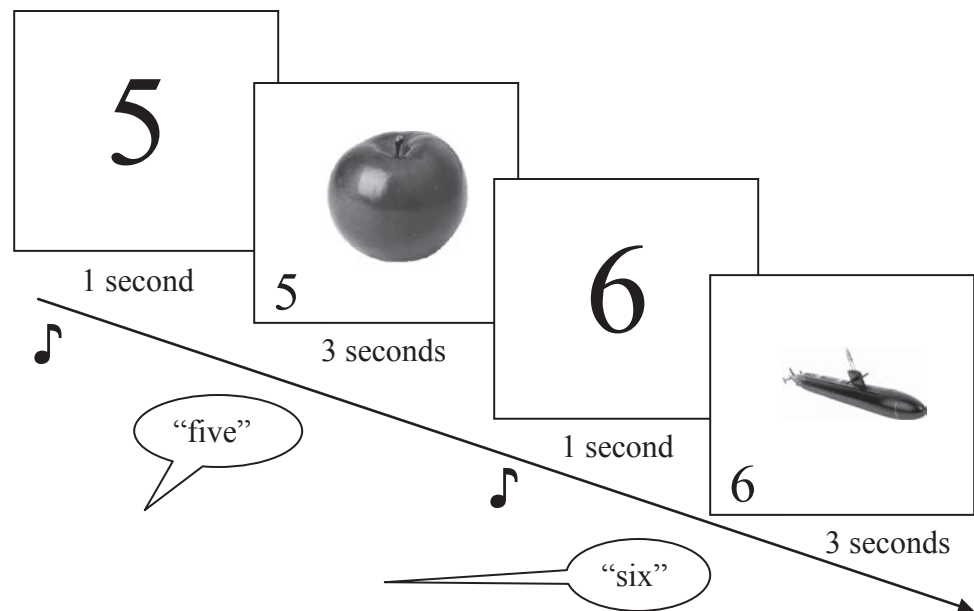


Figure 2.1 An example of two trials during the rating experiment. “♪” indicates where a warning tone was played to alert participants (and the experimenter) that a new trial was about to start. Words in the bubbles indicate numbers being said by experimenter.

After the practice items (8 photos) were rated, the experimenter reminded the group of the definition to be used to rate the items, answered any questions and then began the first block of 320 object ratings. Items were randomized by the presentation computer prior to presentation. In this way, once the experiment began, the experimenter could go back to “item 12” for example, and it would always be the same item/picture for that block. However, once the program was reloaded for a new block, the items were re-randomized. Small breaks were scheduled every 50 items. The only difference between the practice and full run was that the full run used a different set of pictures and began with a slightly faster presentation rate (objects were shown for a shorter duration).

The timing of the pictures was further modified on the basis of the scale that was currently being rated. Participants found familiarity to be the easiest scale to apply and thus the presentation rate for familiarity began at the fastest speed (three seconds per picture). The manipulability scale required two ratings, making it the most complex, so pictures remained on screen for a longer duration for this rating scale (six seconds). For AoA ratings, length of picture presentation began at four seconds. Since groups differed in the length of time they required to rate items, the option to speed up or slow down presentation time was built into the program used to project the items, and if the participants indicated that they found the presentation rate too slow or fast, the experimenter could change the speed of the program (in $\frac{1}{4}$ second increments). Speed decisions were made by the group during the brief breaks every 50 items.

Once participants had finished rating the set of 320 objects on the first scale, they were asked to provide demographic information about themselves (including their age, gender and handedness) and then submit their data. When participants hit the submit

button, the data was transferred to a central database with a timestamp that was later synchronized with the list of items presented to the participants. The experimenter then collected the instruction pages for the first scale and handed out the instruction pages for the second scale. The participants were then read the new instructions, participated in a practice block for the new scale, and then began rating the 320 objects on the new scale, as before. Finally, the third rating scale was completed following the same procedure. Between each new rating scale, longer breaks of approximately three to five minutes were allowed. Once all three rating scales were complete, participants were debriefed. The entire experiment took approximately two hours to complete. Specifically, the familiarity, AoA and manipulability blocks lasted approximately 22, 30 and 45 minutes, respectively.

2.4 RESULTS

2.4.1 Summary

The main analyses were correlations between the current ratings and ratings collected on the same items by previous researchers. These results are presented in detail below. To summarize, both Familiarity and AoA correlations between our measures and previously-published ratings were quite high ($r = .853, p < .001$; and $r = .771, p < .001$, respectively). Only for manipulability were current ratings not strongly correlated to previous ratings by Magnié et al., (2003) ($r = .507, p < .001$), and were not correlated at all to the ratings by Wolk et al. (2005) ($r = -.126, p = .419$)⁷. However, a low or absent correlation was expected for the manipulability ratings as the definition of manipulability

⁷ Note, the differences between these strong correlations for Familiarity and AoA (i.e. $r = .771$) and the moderate correlation for manipulability (i.e. $r = .507$) were found to be statistically significant using Fisher's r-to-z transformation, $z = 4.38, p < .001$.

used to obtain ratings in the current study was meant to capture a novel dimension of this construct not captured in previous research (cf. Magnié et al., 2003; and Wolk et al., 2005).

Inter-correlations between our participants' ratings for the same objects across scales were also assessed. High correlations would indicate that two rating scales were being used in a similar way by the participants. Since items/pictures were chosen to range across all categories of familiarity, AoA, and manipulability, it was predicted that correlations should be low or non-existent. For example, for objects rated as highly familiar, equal numbers of them should have been rated as being high and low on AoA. As predicted, most of our ratings scales were not correlated with each other. The largest correlation, was only a weak one ($r = .297, p < .001$) between AoA and our second manipulability scale (for the rest of these correlations see the Tables 2.2 through 2.6).

Finally, participants in the three ratings orders (FMA – Familiarity, Manipulability and AoA, AFM, & MAF) were considered separately in an exploratory time analysis. That is, familiarity ratings from participants in order FMA (familiarity first) were compared to AFM (familiarity second) and MAF (familiarity third). High correlations on all scales (range: $r = .914$ to $r = .991, p$'s $< .001$) indicated that all groups were using the scales in an equivalent way, although there was some drift in the mean for each of the scales. Since this analysis was not germane to the main objective of this paper, it is excluded from the main results section³. In addition, it was decided the main analyses should focus on ratings for items that participants rated for the first time (familiarity from group FMA, AoA from AFM, and manipulability from MAF), since these ratings were the most consistent with ratings collected in previous research.

However, for comparison, the overall ratings (collapsed across time for all participants) are also included in the summary Appendix B. For ratings at other times, as well as categories for each object, please refer to supplementary Appendix Sup-C, available online.

2.4.2 Familiarity Ratings/Norms

Two participants were eliminated from the analysis of familiarity because they arrived late for the study, and had missed the full instructions on how to properly use the familiarity rating scale. Of the remaining 55 participants, 18 rated familiarity as their first scale (Time 1), 18 as their second (Time 2) and 19 as their third scale (Time 3).

Familiarity ratings (at Time 1) were compared to those collected on the same objects in previous studies. Specifically, our ratings were further compared to familiarity ratings collected by Snodgrass and Vanderwart (1980) and Morrison et al. (1997). With 190 and 184 items being compared, respectively, our ratings correlated highly ($r = .853, p < .001$ and $r = .825, p < .001$; see Table 2.2). Therefore, despite some methodological differences, the familiarity ratings generated in the current study were similar to those obtained in previous research for the approximately 190 items in common. Additionally, the correlation for these items on familiarity between the Morrison et al. (1997) and Snodgrass and Vanderwart (1980) ratings were $r = .865, p < .001$ (not noticeably different from the current correlations).

Table 2.2. Familiarity norm correlations across studies. *** $p < .001$.

Familiarity Ratings	2. Snodgrass & Vanderwart (1980)	3. Morrison et al. (1997)
1. Current (Time 1)	.853 ***	.825 ***
2. Snodgrass & Vanderwart (1980)	----	.865 ***

2.4.3 Age of Acquisition (AoA) Ratings/Norms

Ratings based on 57 participants were used to construct norms for AoA. Eighteen (18) rated AoA as their first scale (Time 1), 19 as their second (Time 2) and 20 as their third scale (Time 3). Participants rating AoA at Time 1 were the same participants who rated Familiarity at Time 2. AoA ratings (from Time 1) were compared to those collected on the same objects in previous studies. Current ratings were compared to those of Morrison et al. (1997), who derived norms by both testing the vocabulary of (British) children (objective), and having adults retro-actively self-report AoA (subjective). Morrison et al. (1997) found objective and subjective correlations to be as high as $r = .759$, supporting the idea that subjective reports of AoA are accurate estimates of actual AoA (pg .542). The current ratings, were also highly correlated to Morrison et al.'s (1997) ratings for the $N=184$ items in common ($r = .771, p < .001$). Current ratings were also compared to Gilhooly and Logie's (1980) ratings that were collected from self-report AoA to words (not pictures). In this case, not as many items could be compared ($N=83$) but the correlation was still strong ($r = .719, p < .001$). Thus, despite minor methodological differences (e.g. using a computer to rate objects instead of pen and

paper) our ratings were highly correlated to those of previous studies thus validating the current ratings (see Table 2.3).

Table 2.3. Age of Acquisition (AoA) norm correlations across studies. *** $p < .001$.
^a based on an N = 184. ^b based on an N = 83. ^c based on an N = 61.

AoA Ratings	2. Morrison et al. (1997)	3. Gilhooly & Logie (1980)
1. Current (Time 1)	.771 *** ^a	.719 *** ^b
2. Morrison et al. (1997)	----	.748 *** ^c

2.4.4 Manipulability Ratings/Norms

While the Familiarity and AoA ratings were useful as validations of the current methodology, it was the manipulability ratings that were of most interest. Again, ratings based on 57 participants were used to construct norms for manipulability. Nineteen participants rated manipulability as their first scale (Time 1), 20 as their second (Time 2) and 18 as their third scale (Time 3). Participants rating manipulability at Time 1 were the same participants who rated Familiarity at Time 3.

All items were rated on the first manipulability scale (Manip1), but only items considered to be “manipulable” on the first scale (>3 as rated by the participants) were rated on the second (functional) manipulability scale (Manip2). As a result, some borderline manipulable items (e.g. cat, chair, frog, wheel, sewing machine) were rated on the second manipulability scale by some, but not all, participants. To adjust for this low sample (N) problem, only items that the majority (>50%) of participants labeled manipulable according to the first scale were considered to have *valid* functional

manipulability scores. The result was 178 items (out of 320) with valid functional manipulability ratings.

Our manipulability ratings (from Time 1) were correlated to Magnié's et al.'s (2003) norms. Recall Magnié et al.'s (2003) definition revolved around the extent to which an item could be pantomimed unambiguously. The current definition (for the first scale), in contrast to that of Magnié et al. (2003), related to how easy it was "to grasp and use the object with one hand". Thus, given the difference in definitions, categorical differences *were* expected between Magnié et al.'s (2003) and the current manipulability ratings. As anticipated, the current manipulability scales correlated only moderately with those of Magnié et al.'s (2003) with correlations of $r = .507$ for Manip1 and $.459$ for Manip2 (p 's $< .001$) (see Table 2.4).

Wolk et al.'s (2005) form-manipulation ratings did not correlate with either the current or Magnié et al.'s (2003) ratings (Manip1: $r = -.126$, $p = .419$ and Manip2: $r = .152$, $p = .375$, Magnié (2003): $r = .254$, $p = .109$). However, Wolk et al. (2005) only provided form-manipulation ratings for a handful of items (62 items), so power was restricted in this case. Further, the two current manipulability scales (Manip1 and Manip2) did not correlate significantly to each other ($r = -.012$, $p = .875$), indicating that they, indeed, are measuring two different dimensions of manipulability.

Table 2.4. Manipulability correlations to Magnie ratings. ***p < .001, * p < .05, ^a smallest N = 178 for these, ^b for these correlations N as low as 36 to 43 items.

Manipulability Ratings	b. Manip2 (Fxn)	c. MM Index	d. Form-Manip (Wolk) Ratings
a. Current Manip1 (Grasp)	- .012 (ns) ^a	.507 *** ^a	- .126 (ns) ^b
b. Current Manp2 (Fxn)	---	.459 *** ^a	.152 (ns) ^b
c. Magnie Manip Index		---	.254 (ns) ^b

To further illustrate the difference between the current ratings, a comparison between the way a number of items were rated on the current scale (Manip1) and Magnie et al.'s (MM Index) was done. Magnié et al.'s (2003) divided items into four categories based on ratings: (1) strongly manipulable, (2) weakly manipulable, (3) weakly unmanipulable and (4) strongly unmanipulable. Table 2.5 shows examples of items that fell into each category on their rating (MM Index) scheme (rows) and where they fit on the current (Manip1) scheme (columns). Items for which both scales agreed are depicted in blue. Items for which scales disagreed on are depicted in red and underlined. For example, both scales considered the following items to be manipulable: cigarette, hammer, boot, mitten, ruler. However, Magnié et al.'s (2003) pantomime scale also considered the following to be manipulable: bicycle, car, swing, cow, whereas these items were rated non-manipulable using the current definition. Both scales agreed that the following were unmanipulable/non-manipulable: train, cloud, chicken (live), moon, eagle, elephant. However, Magnié et al.'s (2003) pantomime scale also considered the following to be unmanipulable: pear, garbage can, celery, strawberry, and leaf. These

items were considered “manipulable” by participants using the current (Manip1) definition of manipulability.

Table 2.5. Differences between current and Magnie et al. (2003) ratings on Manipulability. Columns show current classification (as either manipulable/non-manipulable). Rows show Magnie et al. (2003) classification (MM Index). Items in **bold** indicate objects classified differently, underlined objects represent those classified similarly.

Magnie et al. (2003) Ratings	Current Ratings	
	Manipulable	Non-Manipulable
Strongly Manipulable	<u>cigarette, hammer</u>	bicycle, car
Weakly Manipulable	<u>boot, mitten, ruler</u>	swing, cow
Weakly Unmanipulable	pear, garbage can	<u>train, cloud, chicken</u>
Strongly Unmanipulable	celery, strawberry, leaf	<u>moon, eagle, elephant</u>

2.4.5 Inter-Correlations between Rating Scales

The overlap between each of the ratings given for objects in the current experiment was considered. As would be expected, Familiarity was correlated to AoA, but, importantly, this correlation was not very large ($r = -.120, p < .05$). Interestingly, the first manipulability scale was weakly correlated to familiarity ($r = .129, p < .05$) but not to AoA ($r = -0.049, p = .379$); the direction of the correlation was that familiar objects tended to be graspable. The second functional manipulability rating, on the other hand, was weakly correlated to AoA ($r = .297, p < .001$) but not to Familiarity ($r = 0.06, p = .934$), the direction of the correlation was that of objects with motor associations tended to be acquired later in life. However, these correlations were quite weak and

generalizations are likely unwarranted. As stated early, the two manipulability ratings were not significantly correlated with each other ($r = -.012, p = .875$). The low inter-correlations between all these scales were taken as a sign that each scale was indeed capturing an independent dimension of the data set. See Table 2.6 for all of these correlations.

Table 2.6. Inter-item correlations, familiarity, AoA and Manipulability. N = 320 for all items except those correlated to Manip2 (N=178 in this case).

	b. Familiarity	c. Manip1 (Grasp)	d. Manip2 (Fxn)
a. AoA	-.120 *	-.049 (ns)	.297 ***
b. Familiarity	----	.129*	.006 (ns)
c. Manip1 (Grasp)		----	-.012 (ns)

2.5 DISCUSSION

These two new ratings of manipulability reflect two recognized motor associations 1) ability to grasp (Manip1), and 2) functional usage (Manip2) that we believe are not well captured by existing ratings of Magnié et al. (2003) and Wolk et al. (2005). Magnié et al.'s (2003) ratings, based on the ability to uniquely pantomime an associated action, suffer from a lack of face validity. Their scale has meaning, in that it captures whether or not there are distinct motor associations for an object. However, it certainly does not clearly capture the grasping element of manipulability. Wolk et al.'s (2005) form-manipulation ratings, based on the extent that form predicts how an object should be used, captures both grasping and functional use in a single scale, but, it is not

clear which dimension is more strongly captured by Wolk et al.'s definition, i.e., the two are confounded. Wolk et al.'s (2005) form-manipulation ratings are also (to our knowledge) only available for a small set of items. Because of these issues with previous manipulability ratings, we feel the current ratings represent an important addition to the literature.

Specifically, we feel that the current manipulability ratings are based upon a more intuitive definition of “manipulability” than provided by the pantomime ratings of Magnié et al. (2003). For example, we believe that celery, pears and strawberries should be considered manipulable/graspable objects (as they were on the current scales), since they are regularly picked up with use; however, these items were rated as unmanipulable on Magnié et al.'s (2003) scale. We also feel that the current two ratings for manipulability were able to separate out the 1) grasping (Manip1) and 2) functional usage (Manip2) dimensions of manipulability, where these two dimensions were confounded (not separate) in Wolk et al.'s (2005) form-manipulation ratings. Obviously there were some similarities. For example, the correlation between the current manipulability scales and Magnié et al.'s was moderate ($r = .459$ or $r = .507$), suggesting that these dimensions do indeed partially overlap. For Wolk et al.'s (2005) ratings the correlations with the current ones were not significant, but this may have been constrained by the fewer ratings available (smaller N). Finally, the current manipulability ratings (Manip1 & Manip2) were found to be *not* correlated with each other ($r = -.012$, $p = .875$) which supports our assertion that these two measures represent independent dimensions of manipulability. Future research will be necessary to see which dimensions of “manipulability” are most useful in different contexts.

As for the new familiarity and AoA ratings collected, we feel these ratings are as valid as those collected by previous research. That is, despite some methodological differences in the current study, the pattern of results obtained for familiarity and AoA were highly correlated (i.e. similar) to the results obtained in previous research ($r=.719$ to $r=.853$, p 's $< .001$). These high correlations for both familiarity and AoA suggested that the methodological changes in the current study (i.e. using a computer instead of pen and paper and using explicit anchors and examples instead of anchoring through exposure) did not adversely impact the quality of the current ratings.

2.5.1 Conclusion

In conclusion, the manipulability norms collected in the current research are a valuable addition to literature. They represent a dimension distinctly different from those reported and used by others (e.g. Magnié et al., 2003; Wolk et al., 2005). In many ways, these new definitions are more intuitive (i.e. a “pear” is considered manipulable). They are also more consistent with how other researchers have used manipulability (cf. Grèzes & Decety, 2002). These ratings reported herein should have implications for future research of object recognition models that include action (cf. Yoon, Heinke, & Humphreys, 2002), as well as research into neuropsychology of agnosia and apraxia.

2.6 ENDNOTES

1. Such local landmarks, of course, would only be relevant to local research. Other researchers wanting to make full use of this database would have to replace those items with equivalent local landmarks in their own area.
2. For the complete set of pictures refer to Psychonomic Society's supplemental materials database online or author's website at: <http://myweb.dal.ca/mcmullen/>
3. For more information about these analyses please contact the authors.

2.7 REFERENCES

- Bates, E., D'Amico, S., Jacobsen, T., Székely, A., Andonova, E., Devescovi, A., Herron, D., Lu, C., Pechmann, T., Pléh, C., Wicha, N., Federmeier, K., Gerdjikova, I., Guiterrez, G., Hung, D., Hsu, J., Iyer, G., Kohnert, K., Mehotcheva, T., Orozco-Figueroa, A., Tzeng, A., & Tzeng, O. (2003). Timed picture naming in seven languages. *Psychonomic Bulletin & Review*, *10*(2), 344-380.
- Bonin, P., Peereman, R., Malardier, N., Méot, A., & Chalard, M. (2003). A new set of 299 pictures for psycholinguistic studies: French norms for name agreement, image agreement, conceptual familiarity, visual complexity, image variability, age of acquisition, and naming latencies. *Behaviour Research Methods, Instruments, & Computers*, *35* (1), 158-167.
- Borgo, F., & Shallice, T. (2003). Category specificity and feature knowledge: Evidence from new sensory-quality categories [Special issue]. *Cognitive Neuropsychology*, *20*(3-6), *The organisation of conceptual knowledge in the brain: Neuropsychological and neuroimaging perspectives*, 327-353. doi: [10.1080/02643290244000310](https://doi.org/10.1080/02643290244000310)
- Cuetos, F. & Alija, M. (2003). Normative data and naming times for action pictures. *Behaviour Research Methods, Instruments, & Computers*, *35* (1), 168-177.
- Culham, J. C., & Valyear, K. F. (2006). Human parietal cortex in action. *Current Opinion in Neurobiology*, *16*(2), 205-212. doi: [10.1016/j.conb.2006.03.005](https://doi.org/10.1016/j.conb.2006.03.005)
- Dent, K., Johnston, R. A., & Humphreys, G. W. (2008). Age of acquisition and word frequency effects in picture naming: A dual-task investigation. *Journal of*

Experimental Psychology: Learning, Memory, and Cognition, 34(2), 282-301.

doi: [10.1016/j.actpsy.2008.05.005](https://doi.org/10.1016/j.actpsy.2008.05.005)

Farah, M. J., McMullen, P. A., & Meyer, M. M. (1991). Can recognition of living things be selectively impaired? *Neuropsychologia*, 29, 185-193. doi: [10.1016/0028-3932\(91\)90020-9](https://doi.org/10.1016/0028-3932(91)90020-9)

Farah, M. J., Meyer, M. M. & McMullen, P. A. (1996). The living/nonliving dissociation is not an artifact: Giving an a priori implausible hypothesis a strong test. *Cognitive Neuropsychology*, 13 (1), 137-154. doi: [10.1080/026432996382097](https://doi.org/10.1080/026432996382097)

Filliter, J. H., McMullen, P. A., Westwood, D. (2005). Manipulability and living/non-living category effects on object recognition. *Brain and Cognition*, 57, 61-65. doi: [10.1016/j.bandc.2004.08.022](https://doi.org/10.1016/j.bandc.2004.08.022)

Gaffan, D., & Heywood, C. A. (1993). A spurious category-specific visual agnosia for living things in normal human and nonhuman primates. *Journal of Cognitive Neuroscience*, 5(1), 118-128. doi: [10.1162/jocn.1993.5.1.118](https://doi.org/10.1162/jocn.1993.5.1.118)

Gilhooly, K. J., & Logie, R. H., (1980). Age-of-acquisition, imagery, concreteness, familiarity, and ambiguity measures for 1,944 words. *Behavior Research Methods & Instrumentation*, 12(4), 395-427.


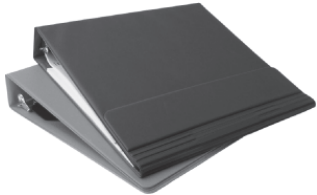






Grèzes, J., & Decety, J. (2002). Does visual perception of object afford action? Evidence from a neuroimaging study. *Neuropsychologia*, 40, 212-222.

Humphreys, G.W. (2001). Objects, affordances....action! *The Psychologist*, 14, 408-412.

- Humphreys, G.W., & Riddoch, M.J. (2001). Detection by action: neuropsychological evidence for action-defined templates in search. *Nature Neuroscience*, 4, 84-88. doi: [10.1038/82940](https://doi.org/10.1038/82940)
- Lewis, M. B., Gerhand, S., & Ellis, H. D. (2001). Reevaluating age of acquisition effects: Are they simply cumulative frequency effects? *Cognition*, 78, 189–205. doi: [10.1016/S0010-0277\(00\)00117-7](https://doi.org/10.1016/S0010-0277(00)00117-7)
- Magnié, M. N., Besson, M., Poncet, M. & Dolisi, C. (2003). The Snodgrass and Vanderwart set revisited: Norms for object manipulability and for pictorial ambiguity of objects, chimeric objects, and nonobjects. *Journal of Clinical and Experimental Neuropsychology*, 25(4), 521-560. doi: [10.1076/jcen.25.4.521.13873](https://doi.org/10.1076/jcen.25.4.521.13873)
- McMullen, P. A., Richler, J. J., Westwood, D. A., & Filliter, J. H. (in press). The time to name manipulable and non-manipulable objects. JEPHPP. *Journal of Experimental Psychology and Human Performance*.
- Morrison, C. M., Chappell, T., D., & Ellis, A. W. (1997). Age of acquisition norms for a large set of object names and their relation to adult estimates and other variables. *The Quarterly Journal of Experimental Psychology*, 50A (3), 528-559. doi: [10.1080/027249897392017](https://doi.org/10.1080/027249897392017)
- Pérez, M. A. (2007). Age of acquisition persists as the main factor in picture naming when cumulative word frequency and frequency trajectory are controlled. *The Quarterly Journal of Experimental Psychology*, 60(1), 32-42.

- Riddoch, M. J., Humphreys, G. W., & Price, C. J. (1989). Routes to action: Evidence from apraxia. *Cognitive Neuropsychology*, 6(5), 437-454. doi: [10.1080/02643298908253424](https://doi.org/10.1080/02643298908253424)
- Snodgrass, J. G., & Vanderwart, M. (1980). A standardized set of 260 pictures: Norms for name agreement, image agreement, familiarity and visual complexity. *Journal of Experimental Psychology: Human Learning and Memory*, 6(2), 174-215. doi: [10.1037/0278-7393.6.2.174](https://doi.org/10.1037/0278-7393.6.2.174)
- Toledo, A. M., & Tudella, E. (2008). The development of reaching behavior in low-risk preterm infants. *Infant Behavior & Development*, 31(3), 398-407. doi: [10.1016/j.infbeh.2007.12.006](https://doi.org/10.1016/j.infbeh.2007.12.006)
- Warrington, E. K., & Shallice, T. (1984). Category specific semantic impairments. *Brain*, 107, 829-854.
- Witherington, D. C., (2005). The development of prospective grasping control between 5 and 7 months: A longitudinal study. *Infancy*, 7(2), 143-161. doi: [10.1207/s15327078in0702_2](https://doi.org/10.1207/s15327078in0702_2)
- Wolk, D. A., Coslett, H. B., & Glosser, G. (2005). The role of sensory-motor information in object recognition: Evidence from the category-specific visual agnosia. *Brain and Language*, 94, 131-146. doi: [10.1016/j.bandl.2004.10.015](https://doi.org/10.1016/j.bandl.2004.10.015)
- Yoon, E. Y., Heinke, D., & Humphreys, G. W. (2002). Modelling direct perceptual constraints on action selection: The Naming and Action Model (NAM). *Visual Cognition*, 9 (4/5), 615-661. doi: [10.1080/13506280143000601](https://doi.org/10.1080/13506280143000601)

2.8 APPENDIX A.

	Low AoA (acquired early)	High AoA (acquired late)
High Familiarity	Manipulable 	
	NonManipulable 	
Low Familiarity	Manipulable 	
	NonManipulable 	

Examples of items / pictures used in the current design.

2.9 APPENDIX B.

	Familiarity		AoA		Manip1		Manip2	
	Time 1 N=18	All Time N=55	Time 1 N=18	All Time N=57	Time 1 N=19	All Time N=57	Time 1 N=19	All Time N=57
	Mean, SD	Mean, SD	Mean, SD	Mean, SD	Mean, SD	Mean, SD	Mean, SD	Mean, SD
accordion	1.28, 0.57	1.16, 0.46	4.06, 1.00	4.00, 1.21	3.79, 0.98	3.63, 1.13	4.35, 0.70	4.14, 0.95
Admin Building (A&A) **	4.56, 0.70	4.56, 0.71	4.56, 2.09	5.09, 2.06	1.00, 0.00	1.00, 0.00	N/A,	N/A,
airplane	2.83, 1.38	2.60, 1.13	2.28, 0.89	2.37, 0.94	1.05, 0.23	1.04, 0.19	N/A,	N/A,
anchor	1.33, 0.59	1.22, 0.46	3.67, 1.08	3.74, 1.26	2.53, 1.22	2.36, 1.26	N/A,	N/A,
animal crackers	1.89, 0.76	1.87, 0.90	2.22, 1.17	1.93, 1.02	5.00, 0.00	4.95, 0.23	1.74, 1.28	1.57, 1.11
ant	2.33, 1.14	2.04, 1.09	2.06, 0.73	2.12, 0.71	3.68, 1.49	4.07, 1.35	2.00, 1.36	2.17, 1.43
ashtray	2.56, 1.54	2.05, 1.19	3.50, 1.54	3.91, 1.37	4.53, 0.70	4.47, 0.93	2.42, 1.07	2.57, 1.22
axe	2.28, 1.32	1.56, 1.00	3.06, 1.06	3.44, 1.10	4.42, 0.61	4.32, 0.83	3.05, 1.39	2.75, 1.31
baby bib	1.39, 0.78	1.18, 0.51	2.00, 1.24	1.72, 0.98	4.63, 0.60	4.56, 0.82	2.58, 1.07	2.70, 1.16
baby bottle	1.67, 0.91	1.38, 0.76	1.33, 0.49	1.32, 0.66	4.79, 0.42	4.86, 0.35	2.11, 1.05	2.02, 1.03
baby carriage	1.83, 0.79	1.51, 0.77	2.11, 0.90	2.18, 1.02	2.21, 1.03	2.25, 1.11	N/A,	N/A,
baby cradle	1.28, 0.57	1.24, 0.51	2.17, 1.15	2.00, 0.94	1.84, 0.96	2.05, 1.03	N/A,	N/A,
baby food	2.28, 1.32	1.75, 1.09	2.59, 1.23	2.20, 1.02	4.72, 0.57	4.70, 0.63	3.26, 1.19	2.86, 1.09
baby powder	2.06, 1.39	1.85, 1.22	2.89, 1.23	2.65, 1.11	4.53, 0.84	4.72, 0.59	2.61, 1.46	2.29, 1.12
baby rattle	1.28, 0.46	1.22, 0.46	2.22, 1.00	1.65, 0.92	4.84, 0.50	4.91, 0.34	2.95, 1.31	2.16, 1.18
backpack	4.83, 0.38	4.65, 0.87	2.44, 0.70	2.54, 0.73	4.47, 0.61	4.44, 0.78	3.00, 1.00	3.04, 1.17
balloon	2.33, 0.97	2.05, 0.95	1.83, 0.86	1.72, 0.73	4.63, 0.60	4.56, 0.76	1.68, 1.11	1.76, 1.16
banana	4.28, 0.89	4.24, 0.86	1.67, 0.69	1.77, 0.78	5.00, 0.00	4.96, 0.19	2.68, 1.16	2.33, 1.21
bank	3.44, 1.20	3.53, 1.07	3.50, 1.72	3.96, 1.55	1.00, 0.00	1.00, 0.00	N/A,	N/A,
bank machine	3.69, 1.25	3.66, 1.06	4.83, 1.47	5.20, 1.37	1.47, 1.26	1.29, 0.99	N/A,	N/A,
barn	2.61, 0.92	2.05, 1.06	2.33, 0.69	2.46, 0.96	1.00, 0.00	1.05, 0.29	N/A,	N/A,
barrel	1.44, 0.70	1.38, 0.73	3.67, 1.03	3.61, 1.19	1.74, 0.87	1.93, 1.02	N/A,	N/A,
basket	2.44, 1.46	2.20, 1.21	2.44, 0.86	2.30, 0.78	4.58, 0.69	4.65, 0.58	2.11, 1.45	1.96, 1.25
bathtub	4.44, 0.98	4.09, 1.22	1.89, 1.02	1.89, 0.99	1.26, 0.73	1.27, 0.73	N/A,	N/A,
bear	1.50, 0.86	1.40, 0.71	2.00, 1.03	2.44, 1.24	1.00, 0.00	1.00, 0.00	N/A,	N/A,
bee	2.28, 1.07	1.89, 0.94	1.83, 0.62	2.04, 0.65	2.63, 1.64	3.18, 1.68	N/A,	2.15, 1.42
beetle	1.56, 0.78	1.38, 0.80	2.67, 1.28	2.84, 1.19	2.95, 1.61	3.56, 1.60	N/A,	2.19, 1.37
bell (church)	2.72, 1.45	2.07, 1.20	3.44, 1.54	3.30, 1.34	1.11, 0.32	1.12, 0.38	N/A,	N/A,
belt	4.22, 1.11	3.96, 1.25	2.83, 1.10	2.86, 0.95	4.95, 0.23	4.79, 0.53	3.53, 0.70	3.48, 1.08
bicycle	3.28, 1.13	2.98, 1.24	2.00, 0.77	2.33, 0.85	2.83, 1.20	2.71, 1.16	N/A,	N/A,
binders	4.78, 0.55	4.65, 0.67	3.50, 1.42	3.49, 1.17	4.32, 0.67	4.54, 0.63	3.21, 1.13	3.00, 1.02
blender	3.44, 1.46	2.67, 1.43	3.44, 1.25	3.67, 1.09	3.63, 1.16	3.63, 1.17	3.69, 1.25	3.66, 1.20
blocks	1.39, 0.61	1.29, 0.63	1.72, 0.67	1.49, 0.68	4.79, 0.54	4.63, 0.90	3.05, 1.43	2.56, 1.37
book	4.83, 0.51	4.80, 0.68	2.00, 1.28	1.93, 1.02	4.47, 0.61	4.63, 0.59	3.11, 1.05	2.95, 1.14
boots	3.50, 1.47	3.56, 1.32	2.35, 0.93	2.11, 0.85	4.42, 0.61	4.4, 0.75	3.11, 1.37	3.07, 1.32
bottle	3.94, 1.21	3.67, 1.35	2.78, 1.40	3.46, 1.59	4.68, 0.67	4.61, 0.75	1.95, 1.27	1.93, 1.17
bow	2.28, 1.23	2.16, 1.15	2.35, 0.86	2.41, 0.93	4.74, 0.45	4.77, 0.54	3.00, 1.49	3.14, 1.34
bowl	4.28, 1.13	4.49, 0.84	1.83, 0.79	1.84, 0.82	4.63, 0.68	4.68, 0.60	2.16, 1.01	2.19, 1.20
box	3.78, 1.26	3.33, 1.39	1.72, 0.83	1.88, 0.76	4.53, 0.61	4.58, 0.65	3.00, 0.88	3.04, 1.05
bread	4.50, 0.71	4.47, 0.90	2.35, 1.27	2.14, 0.96	4.47, 0.96	4.68, 0.69	2.72, 1.36	2.48, 1.11
bridge	3.61, 1.38	3.16, 1.33	2.56, 1.04	2.70, 1.07	1.16, 0.69	1.14, 0.67	N/A,	N/A,
broom	3.44, 1.25	3.13, 1.25	2.94, 1.55	2.77, 1.13	4.68, 0.58	4.65, 0.58	3.32, 1.16	2.82, 1.14
brush	3.89, 1.75	4.33, 1.25	2.17, 0.79	2.18, 0.73	4.95, 0.23	4.95, 0.29	3.16, 1.17	2.25, 1.21
bus	3.89, 1.32	4.27, 0.97	2.44, 1.15	2.47, 1.07	1.05, 0.23	1.09, 0.55	N/A,	N/A,
butterfly	2.50, 1.34	2.00, 1.07	2.00, 0.77	2.07, 0.82	2.74, 1.59	3.19, 1.61	N/A,	1.94, 1.17
cake	3.17, 0.86	3.04, 1.00	1.83, 0.38	1.84, 0.73	4.26, 1.05	4.30, 0.96	2.72, 1.53	2.43, 1.40
camel	1.28, 0.67	1.15, 0.45	2.89, 0.90	3.11, 1.13	1.05, 0.23	1.04, 0.19	N/A,	N/A,
camera	3.89, 1.18	3.84, 1.10	2.94, 1.00	3.04, 1.09	4.79, 0.54	4.75, 0.54	3.84, 1.17	3.77, 1.23
candle	3.17, 1.69	2.82, 1.52	3.00, 0.97	2.98, 0.94	4.58, 0.69	4.59, 0.80	2.53, 1.26	2.58, 1.26
candy canes	2.06, 1.35	1.75, 1.11	2.22, 0.88	2.33, 0.97	4.68, 0.82	4.70, 0.84	1.82, 1.13	1.57, 0.97
cannon	1.56, 0.78	1.33, 0.64	3.11, 0.90	3.79, 1.06	1.32, 0.95	1.16, 0.59	N/A,	N/A,
cap	4.17, 0.99	3.44, 1.30	2.11, 0.90	1.93, 0.78	4.63, 0.68	4.77, 0.50	2.05, 1.18	1.91, 1.03
car	4.56, 0.86	4.44, 0.96	1.83, 1.25	2.12, 1.32	1.16, 0.50	1.14, 0.61	N/A,	N/A,
carpet	3.41, 1.12	3.63, 1.28	2.50, 1.10	2.52, 0.95	2.95, 1.22	3.05, 1.23	N/A,	2.32, 1.36
carrot	3.94, 1.11	3.78, 1.20	2.28, 1.36	2.12, 1.02	4.89, 0.32	4.82, 0.54	1.83, 1.34	1.49, 0.94
car seat	1.33, 0.59	1.28, 0.53	2.17, 0.62	2.18, 1.20	3.05, 0.97	3.25, 1.09	2.60, 1.06	2.87, 1.32
cash register	3.06, 1.47	3.18, 1.23	3.33, 1.24	3.74, 1.14	2.21, 1.23	2.40, 1.27	N/A,	N/A,
cassette	1.94, 1.16	1.62, 0.95	2.94, 1.43	3.19, 1.27	4.63, 0.96	4.77, 0.78	2.89, 1.45	2.95, 1.31
castle	1.89, 1.32	1.38, 0.87	2.78, 0.88	2.82, 1.15	1.00, 0.00	1.00, 0.00	N/A,	N/A,
cat	3.61, 1.46	3.31, 1.44	2.00, 1.28	1.67, 0.89	3.16, 1.17	3.33, 1.23	2.77, 1.01	2.93, 1.26

CD rom	4.56, 0.86	4.09, 0.99	3.94, 1.26	4.51, 1.12	4.74, 0.56	4.74, 0.55	2.26, 1.33	2.42, 1.36
celery	3.61, 1.42	3.47, 1.30	2.72, 0.89	2.95, 1.08	4.58, 0.77	4.63, 0.84	2.53, 1.26	2.14, 1.09
cell phone	5.00, 0.00	4.91, 0.35	4.28, 1.53	4.81, 1.48	4.84, 0.50	4.91, 0.34	4.21, 1.36	3.86, 1.56
chain	2.17, 1.29	1.87, 1.11	2.94, 1.11	3.23, 1.07	4.47, 0.84	4.56, 0.73	2.79, 1.18	2.51, 1.07
chair	4.83, 0.38	4.87, 0.39	1.78, 0.81	1.88, 0.89	3.16, 0.96	2.96, 1.15	2.92, 0.95	N/A,
chalkboard	4.11, 1.13	3.78, 1.32	2.78, 0.73	2.84, 0.65	1.84, 0.83	1.91, 0.99	N/A,	N/A,
cherry	2.61, 1.24	2.69, 1.18	2.67, 0.97	2.33, 0.85	4.74, 0.73	4.82, 0.60	1.61, 1.29	1.39, 0.90
chest	1.78, 1.17	1.65, 0.91	2.78, 1.06	3.02, 1.08	2.58, 1.07	2.44, 1.17	N/A,	N/A,
chickadee (bird)	2.72, 1.23	2.73, 1.11	2.33, 1.14	2.44, 1.04	2.47, 1.43	3.11, 1.45	N/A,	2.36, 1.44
chicken	1.67, 0.91	1.73, 1.03	1.89, 0.96	2.21, 0.88	2.26, 1.10	2.47, 1.17	N/A,	N/A,
chisel	1.78, 0.94	1.42, 0.74	4.33, 1.64	4.67, 1.49	4.89, 0.32	4.89, 0.31	2.79, 1.23	2.58, 1.31
Christmas tree	2.44, 1.15	1.91, 1.02	2.06, 0.90	2.02, 1.02	1.37, 0.68	1.65, 0.95	N/A,	N/A,
church	2.94, 1.55	2.42, 1.37	2.39, 0.78	2.72, 1.33	1.00, 0.00	1.02, 0.13	N/A,	N/A,
cigar	2.00, 1.50	1.81, 1.17	3.83, 1.58	4.18, 1.36	4.79, 0.54	4.77, 0.54	2.21, 1.18	2.05, 1.11
cigarette	2.78, 1.66	2.46, 1.42	3.61, 1.42	3.86, 1.26	4.89, 0.32	4.91, 0.29	2.26, 1.10	2.02, 1.14
Clock (alarm)	4.72, 0.57	4.71, 0.57	2.39, 0.98	2.60, 1.08	4.53, 0.70	4.54, 0.78	2.63, 1.30	3.02, 1.25
closet	4.67, 0.59	4.70, 0.57	2.53, 1.07	2.59, 0.97	1.32, 1.00	1.25, 0.76	N/A,	N/A,
clothespin	1.89, 1.41	1.73, 1.15	3.06, 1.26	3.19, 1.22	4.95, 0.23	4.93, 0.26	2.84, 1.30	2.58, 1.19
clouds	4.94, 0.24	4.82, 0.51	2.06, 0.80	1.88, 0.73	1.00, 0.00	1.07, 0.54	N/A,	N/A,
clown	1.39, 0.70	1.25, 0.70	2.17, 0.99	2.05, 0.87	1.21, 0.42	1.42, 0.84	N/A,	N/A,
coffee pot	3.33, 1.53	3.09, 1.42	3.56, 1.10	3.68, 1.21	4.79, 0.54	4.68, 0.71	1.84, 1.01	2.09, 1.13
comb	3.44, 1.62	3.60, 1.51	2.78, 1.44	2.44, 1.13	4.95, 0.23	4.91, 0.29	2.74, 1.15	2.36, 1.14
compass	1.72, 1.07	1.56, 1.03	4.06, 1.26	4.09, 1.18	4.79, 0.42	4.86, 0.35	1.84, 1.12	2.04, 1.40
computer	4.83, 0.71	4.95, 0.40	3.28, 1.18	3.72, 1.31	2.53, 1.17	2.51, 1.27	N/A,	N/A,
couch	4.33, 0.84	4.25, 0.97	2.39, 1.04	2.25, 1.01	1.37, 0.68	1.49, 0.83	N/A,	N/A,
cow	2.22, 0.81	1.75, 0.89	1.72, 0.67	1.86, 0.74	1.00, 0.00	1.04, 0.26	N/A,	N/A,
crab	1.72, 0.75	1.45, 0.66	2.39, 0.78	2.84, 1.10	2.74, 1.48	3.02, 1.43	N/A,	2.35, 1.38
crocodile	1.33, 0.69	1.15, 0.45	2.44, 0.98	2.75, 0.98	1.21, 0.71	1.12, 0.50	N/A,	N/A,
crown	1.17, 0.38	1.31, 0.57	2.67, 1.19	2.79, 1.15	4.47, 0.84	4.35, 0.95	2.06, 1.06	2.22, 1.18
cup	4.06, 1.47	4.18, 1.14	2.56, 1.04	2.60, 1.08	4.79, 0.42	4.74, 0.52	2.05, 1.27	1.95, 1.20
deer	1.89, 1.08	1.82, 0.94	2.56, 1.04	2.84, 1.07	1.11, 0.32	1.23, 0.66	N/A,	N/A,
desk	4.44, 1.04	4.51, 0.96	2.78, 0.94	2.75, 0.95	1.63, 0.76	1.67, 0.85	N/A,	N/A,
diaper	1.44, 0.70	1.29, 0.63	1.56, 0.62	1.75, 1.07	4.32, 0.58	4.54, 0.76	3.68, 1.16	3.68, 1.16
dice	2.44, 1.15	2.25, 1.14	2.67, 0.77	2.91, 1.09	4.95, 0.23	4.93, 0.26	3.11, 1.37	2.88, 1.31
dinosaur	1.17, 0.38	1.15, 0.59	2.33, 0.84	2.32, 0.89	2.21, 1.65	2.25, 1.73	N/A,	N/A,
dish washer	3.78, 1.4	3.38, 1.43	2.89, 1.23	3.19, 1.14	1.53, 1.12	1.53, 1.05	N/A,	N/A,
dog	3.94, 1.16	3.55, 1.39	1.50, 0.71	1.52, 0.69	1.53, 0.77	1.93, 1.00	N/A,	N/A,
doll	1.56, 0.98	1.33, 0.70	1.78, 1.06	1.63, 0.88	4.42, 0.61	4.56, 0.60	2.84, 1.17	2.91, 1.14
donkey	1.33, 0.59	1.22, 0.46	2.33, 0.77	2.61, 0.96	1.16, 0.50	1.16, 0.41	N/A,	N/A,
door	4.83, 0.38	4.82, 0.55	2.06, 1.06	1.93, 0.96	1.53, 0.90	1.63, 1.10	N/A,	N/A,
dragonfly	2.11, 1.28	1.69, 0.92	3.17, 0.92	2.98, 0.86	2.89, 1.41	3.26, 1.49	N/A,	2.36, 1.53
dress	3.89, 1.53	3.71, 1.23	2.22, 1.11	2.25, 0.97	4.26, 0.65	4.56, 0.71	3.32, 1.16	3.23, 1.32
dresser	4.72, 0.75	4.31, 1.03	2.56, 0.86	2.65, 0.99	1.53, 0.77	1.56, 0.93	N/A,	N/A,
drill	2.28, 1.23	1.67, 1.00	3.72, 1.13	4.04, 1.27	4.79, 0.42	4.70, 0.53	2.95, 1.22	2.70, 1.30
drum	2.72, 1.13	2.25, 1.27	2.83, 0.92	3.19, 1.14	1.68, 1.29	1.66, 1.25	N/A,	N/A,
dryer	4.22, 1.11	3.75, 1.14	2.83, 1.15	3.16, 1.15	1.37, 0.96	1.25, 0.72	N/A,	N/A,
duck	2.39, 1.09	1.96, 0.98	2.33, 1.14	2.28, 0.86	2.42, 1.22	2.54, 1.04	N/A,	N/A,
eagle	1.67, 0.77	1.51, 0.77	2.89, 0.83	3.19, 1.19	2.00, 1.11	2.07, 1.18	N/A,	N/A,
Easter eggs	2.67, 1.28	2.44, 1.23	2.72, 0.83	2.39, 0.84	4.89, 0.32	4.91, 0.29	2.89, 1.56	2.51, 1.48
egg	4.00, 0.91	3.91, 1.06	1.83, 0.51	1.82, 0.71	4.84, 0.50	4.68, 0.96	3.11, 0.99	2.83, 1.31
elephant	1.39, 0.85	1.22, 0.57	2.17, 0.99	2.33, 0.91	1.00, 0.00	1.05, 0.40	N/A,	N/A,
envelopes	3.56, 1.54	3.20, 1.35	3.17, 1.20	3.16, 0.98	4.74, 0.65	4.82, 0.54	3.00, 1.05	3.04, 1.15
etch a sketch	1.78, 1.31	1.51, 0.92	3.17, 1.25	2.72, 1.10	4.78, 0.43	4.69, 0.54	4.33, 0.91	4.22, 1.08
fax machine	2.67, 1.33	2.47, 1.30	4.17, 1.25	4.75, 1.27	2.68, 1.29	2.96, 1.3	N/A,	N/A,
fence	3.83, 1.10	3.33, 1.20	2.56, 0.92	2.70, 0.91	1.05, 0.23	1.28, 0.67	N/A,	N/A,
filing cabinet	3.06, 1.35	2.71, 1.27	4.00, 1.33	4.09, 1.26	1.68, 1.06	2.04, 1.21	N/A,	N/A,
fire	2.56, 1.25	2.39, 1.23	2.53, 1.12	2.36, 1.02	1.26, 0.81	1.16, 0.71	N/A,	N/A,
fire hydrant	3.33, 1.33	2.95, 1.27	3.06, 0.87	3.11, 0.96	1.11, 0.32	1.26, 0.79	N/A,	N/A,
fish	2.33, 1.19	2.53, 1.14	2.11, 0.83	2.05, 0.77	3.58, 1.46	3.74, 1.26	2.20, 0.86	2.55, 1.21
floor (tiles)	3.67, 1.41	3.64, 1.53	2.78, 1.52	2.86, 1.6	1.11, 0.46	1.11, 0.49	N/A,	N/A,
flower	3.28, 1.27	3.09, 1.25	2.06, 1.06	2.00, 0.85	4.68, 0.82	4.67, 0.79	1.58, 1.07	1.82, 1.09
fly	2.72, 1.13	2.40, 1.16	1.89, 0.83	2.12, 0.85	2.79, 1.32	3.26, 1.63	N/A,	2.11, 1.30
football	2.78, 1.44	2.18, 1.22	2.78, 1.40	2.89, 1.23	4.74, 0.56	4.75, 0.54	2.95, 1.35	2.53, 1.18
forest	4.06, 1.16	3.38, 1.38	2.72, 1.32	2.53, 1.00	1.00, 0.00	1.00, 0.00	N/A,	N/A,
fork	4.83, 0.71	4.89, 0.50	1.94, 0.64	1.77, 0.66	4.89, 0.46	4.96, 0.26	2.11, 1.37	1.75, 1.21
fox	1.56, 0.86	1.35, 0.67	2.50, 0.99	2.58, 0.91	1.47, 0.84	1.67, 0.95	N/A,	N/A,
frog	1.72, 0.67	1.58, 0.83	2.17, 0.86	2.26, 0.77	3.11, 1.45	3.54, 1.34	1.69, 0.95	2.23, 1.26
frying pan	4.28, 0.89	3.76, 1.30	2.33, 1.03	2.88, 1.17	4.79, 0.42	4.71, 0.62	2.74, 1.33	2.23, 1.21
garbage can	4.06, 1.11	3.73, 1.35	2.44, 1.10	2.51, 0.98	3.58, 1.12	3.60, 1.15	2.25, 0.93	2.50, 1.05
gas station	2.94, 1.55	3.09, 1.29	3.28, 1.36	3.49, 1.38	1.00, 0.00	1.05, 0.40	N/A,	N/A,

gazebo	2.56, 1.04	1.87, 1.00	4.50, 1.50	4.65, 1.30	1.11, 0.46	1.05, 0.29	N/A,	N/A,
giraffe	1.44, 0.78	1.24, 0.58	2.72, 1.23	2.58, 1.05	1.05, 0.23	1.11, 0.56	N/A,	N/A,
glasses	4.11, 1.45	3.89, 1.56	2.11, 0.76	2.33, 0.89	4.89, 0.32	4.89, 0.36	2.53, 1.17	2.54, 1.30
glove	3.39, 1.38	3.33, 1.36	2.22, 0.81	2.40, 0.96	4.79, 0.42	4.70, 0.73	2.79, 1.44	2.76, 1.26
goat	1.39, 0.85	1.24, 0.61	2.39, 1.09	2.82, 1.17	1.21, 0.42	1.33, 0.72	N/A,	N/A,
gorilla	1.39, 0.85	1.33, 0.79	3.00, 0.94	2.80, 1.00	1.11, 0.32	1.07, 0.26	N/A,	N/A,
grapes	3.67, 1.14	3.58, 1.10	2.00, 0.59	2.00, 0.60	4.89, 0.32	4.93, 0.26	1.63, 1.26	1.60, 1.13
grass	4.00, 0.91	4.09, 1.02	1.89, 0.83	1.82, 0.85	2.56, 1.69	2.80, 1.53	N/A,	N/A,
guitar	3.56, 1.50	3.06, 1.46	2.89, 0.90	3.07, 1.00	4.00, 0.94	3.98, 1.09	4.41, 0.87	4.27, 1.13
gun	1.67, 0.97	1.62, 1.06	3.22, 1.26	3.56, 1.20	4.95, 0.23	4.82, 0.58	2.58, 1.35	2.60, 1.30
hair dryer	3.61, 1.61	3.74, 1.51	3.17, 1.10	3.46, 1.25	4.79, 0.42	4.79, 0.45	2.84, 1.21	2.44, 1.18
Halifax Citadel**	2.72, 1.71	2.40, 1.38	4.82, 1.74	4.93, 1.63	1.00, 0.00	1.16, 0.75	N/A,	N/A,
hammer	2.67, 1.14	2.11, 1.10	2.94, 1.06	2.95, 1.00	4.89, 0.32	4.84, 0.37	3.26, 1.33	2.63, 1.33
harmonica	1.89, 1.18	1.53, 0.88	3.56, 1.25	3.56, 1.28	4.95, 0.23	4.77, 0.73	3.47, 1.26	3.44, 1.33
harp	1.56, 0.98	1.24, 0.67	3.67, 1.50	4.21, 1.28	2.74, 1.41	2.67, 1.35	N/A,	N/A,
hat	3.61, 1.33	3.09, 1.51	2.28, 1.27	1.95, 1.01	4.53, 1.07	4.79, 0.67	1.78, 1.06	2.02, 1.20
helicopter	1.89, 0.83	1.73, 0.89	3.11, 1.02	3.21, 1.11	1.32, 1.00	1.19, 0.72	N/A,	N/A,
high chair	1.83, 1.15	1.40, 0.81	1.78, 0.73	1.91, 1.14	2.00, 1.00	2.23, 1.08	N/A,	N/A,
hole punch	3.33, 1.46	3.38, 1.34	4.33, 0.91	4.14, 1.01	4.79, 0.42	4.70, 0.53	3.22, 1.22	3.21, 1.16
horse	1.83, 0.71	1.62, 0.83	2.44, 1.62	2.12, 1.12	1.11, 0.32	1.09, 0.34	N/A,	N/A,
house	4.56, 1.04	4.58, 0.85	2.00, 0.87	1.86, 0.86	1.00, 0.00	1.19, 0.83	N/A,	N/A,
ice scraper	3.28, 1.74	3.13, 1.55	3.28, 1.45	3.74, 1.55	4.74, 0.45	4.82, 0.38	3.37, 1.12	2.86, 1.22
iron	3.00, 1.24	2.71, 1.23	3.39, 1.42	3.61, 1.31	4.89, 0.32	4.60, 0.76	2.74, 1.37	2.35, 1.28
ironing board	2.83, 1.42	2.55, 1.26	3.17, 1.25	3.51, 1.18	3.47, 0.96	3.23, 1.09	3.40, 1.24	3.21, 1.28
jacket	4.56, 0.86	4.67, 0.61	2.44, 0.78	2.07, 0.84	4.37, 0.68	4.39, 0.87	3.16, 1.26	3.31, 1.22
jack-o-lantern	2.28, 1.32	1.71, 1.01	2.61, 0.70	2.39, 0.73	3.74, 0.99	3.84, 1.05	3.13, 1.46	2.88, 1.39
jelly beans	2.78, 1.35	2.62, 1.25	2.39, 0.85	2.32, 0.83	4.84, 0.50	4.82, 0.63	1.32, 0.95	1.31, 0.94
kangaroo	1.44, 0.92	1.22, 0.60	2.78, 1.00	2.95, 1.09	1.16, 0.37	1.14, 0.35	N/A,	N/A,
kettle	4.33, 1.03	3.76, 1.35	2.89, 1.28	3.18, 1.09	4.53, 0.51	4.53, 0.63	2.42, 1.17	2.46, 1.31
key	4.67, 0.97	4.67, 0.94	2.78, 1.22	2.70, 1.00	4.95, 0.23	4.91, 0.54	3.47, 1.50	3.09, 1.37
kite	1.67, 0.69	1.45, 0.63	2.17, 0.79	2.21, 0.77	3.89, 1.10	4.18, 1.01	3.63, 1.41	3.51, 1.24
knife	4.44, 1.04	4.05, 1.27	2.56, 0.62	2.47, 0.91	5.00, 0.00	4.86, 0.52	2.95, 1.03	2.57, 1.08
ladder	2.22, 0.94	1.76, 0.86	2.67, 0.77	2.81, 0.93	2.63, 1.30	2.63, 1.20	N/A,	N/A,
lamp	4.56, 0.98	4.38, 1.10	2.22, 0.81	2.23, 0.85	3.74, 1.10	3.63, 1.15	3.19, 1.22	2.93, 1.25
lawn mower	2.11, 1.18	1.73, 0.91	3.00, 0.91	3.12, 1.13	2.26, 1.33	2.23, 1.18	N/A,	N/A,
leaf	3.78, 1.26	3.64, 1.16	2.44, 0.98	2.26, 0.95	4.53, 1.07	4.72, 0.80	2.11, 1.18	1.89, 1.13
lego	1.61, 0.85	1.51, 0.82	2.00, 0.79	1.82, 0.83	4.79, 0.42	4.84, 0.41	3.74, 1.19	3.12, 1.32
lemon	3.61, 1.04	3.15, 1.15	2.76, 1.03	2.66, 0.86	4.89, 0.32	4.84, 0.42	2.37, 1.26	2.14, 1.17
leopard	1.44, 0.78	1.25, 0.62	2.94, 1.35	3.11, 1.22	1.05, 0.23	1.21, 0.65	N/A,	N/A,
lettuce	4.28, 0.96	4.04, 1.05	2.78, 0.88	2.75, 0.97	4.68, 0.58	4.70, 0.57	3.16, 1.21	2.74, 1.14
light bulb	4.44, 0.98	4.29, 1.01	2.72, 0.96	2.84, 1.00	4.68, 0.67	4.72, 0.56	3.37, 1.12	3.11, 1.29
lion	1.56, 1.04	1.29, 0.74	1.89, 0.76	2.21, 0.90	1.11, 0.46	1.05, 0.29	N/A,	N/A,
lobster	2.61, 1.20	1.93, 1.03	2.89, 1.41	3.21, 1.40	3.56, 1.15	3.55, 1.19	2.47, 1.37	2.96, 1.35
lock	2.67, 1.37	2.65, 1.28	3.67, 1.24	3.93, 1.32	4.84, 0.37	4.86, 0.35	3.89, 1.33	3.89, 1.11
LSC	4.67, 0.69	4.44, 0.90	3.82, 1.88	4.66, 2.13	1.00, 0.00	1.07, 0.53	N/A,	N/A,
manhole cover	3.50, 1.34	3.13, 1.40	4.06, 1.39	4.00, 1.20	1.26, 0.45	1.30, 0.53	N/A,	N/A,
maracas	1.50, 0.86	1.22, 0.57	3.67, 0.97	3.75, 1.19	4.68, 0.48	4.77, 0.50	2.89, 1.29	2.42, 1.24
marker	3.78, 0.94	3.96, 1.04	2.94, 1.16	2.33, 1.02	4.95, 0.23	4.91, 0.34	3.58, 1.17	3.04, 1.31
milk	4.78, 0.65	4.55, 0.81	2.17, 1.04	1.79, 0.90	4.67, 0.59	4.61, 0.76	2.39, 1.33	2.00, 1.22
mitten	3.72, 0.96	3.64, 1.18	1.89, 0.83	2.04, 1.00	4.95, 0.23	4.88, 0.47	2.84, 1.26	2.52, 1.19
mixer	2.83, 1.25	2.20, 1.19	3.39, 0.70	3.68, 1.17	3.11, 1.10	3.16, 1.11	3.31, 1.18	3.38, 1.19
monkey	1.50, 0.71	1.42, 0.76	2.17, 1.10	2.35, 0.99	1.84, 1.07	2.00, 1.21	N/A,	N/A,
monument	2.72, 1.23	2.33, 1.36	4.39, 1.61	4.86, 1.52	1.00, 0.00	1.02, 0.13	N/A,	N/A,
moon	4.56, 0.86	4.49, 0.74	1.89, 1.13	2.11, 0.99	1.00, 0.00	1.00, 0.00	N/A,	N/A,
motorcycle	2.50, 0.99	2.25, 1.09	2.67, 0.91	3.35, 1.25	1.37, 0.96	1.26, 0.74	N/A,	N/A,
mountain	2.44, 1.34	2.09, 1.19	2.94, 1.06	3.19, 1.20	1.00, 0.00	1.11, 0.59	N/A,	N/A,
mouse	1.72, 0.89	1.69, 0.84	2.22, 0.73	2.19, 0.81	3.42, 1.26	3.70, 1.27	1.71, 0.99	2.18, 1.32
movie theatre	4.22, 1.31	4.05, 1.37	4.24, 1.68	4.64, 1.59	1.00, 0.00	1.02, 0.13	N/A,	N/A,
Mr potato head	1.78, 1.26	1.35, 0.91	2.61, 0.85	2.18, 1.00	4.68, 0.48	4.72, 0.53	4.53, 0.61	3.93, 1.15
mushroom	3.56, 1.54	3.22, 1.30	2.72, 1.02	2.74, 1.06	4.84, 0.50	4.75, 0.71	1.89, 1.13	1.75, 0.97
nails	2.78, 1.31	2.07, 1.15	2.94, 1.11	3.07, 1.04	4.89, 0.32	4.88, 0.38	3.53, 1.07	3.37, 1.20
necklace	3.22, 1.52	3.82, 1.33	2.44, 1.10	2.53, 0.98	4.79, 0.54	4.68, 0.76	2.74, 1.19	2.78, 1.23
onion	4.28, 0.96	3.67, 1.02	2.11, 0.68	2.65, 0.86	4.89, 0.32	4.88, 0.38	2.68, 1.16	2.32, 1.17
orange	4.39, 0.78	4.18, 1.04	1.78, 0.73	1.86, 0.74	4.88, 0.49	4.95, 0.30	3.00, 1.33	2.30, 1.36
ornament	1.94, 1.11	1.71, 1.10	2.78, 1.26	2.77, 1.23	4.74, 0.45	4.74, 0.55	2.21, 1.18	2.21, 1.18
ostrich	1.28, 0.57	1.13, 0.39	3.39, 1.38	3.51, 1.15	1.26, 0.45	1.12, 0.33	N/A,	N/A,
owl	1.50, 0.62	1.49, 0.69	2.53, 0.87	2.55, 0.87	2.11, 1.10	2.28, 1.21	N/A,	N/A,
pacifier	1.39, 0.85	1.15, 0.52	2.11, 1.45	1.82, 1.31	4.95, 0.23	4.88, 0.47	2.95, 1.65	2.46, 1.40
paintbrush	2.17, 1.25	2.00, 1.15	2.50, 0.99	2.70, 1.03	4.89, 0.46	4.84, 0.45	2.79, 1.36	2.53, 1.28
pants	4.89, 0.47	4.89, 0.37	2.39, 0.98	2.26, 0.94	4.53, 0.84	4.54, 0.68	2.84, 1.30	3.02, 1.27

parking meter	3.67, 1.46	2.95, 1.39	4.33, 1.28	4.43, 1.28	1.47, 1.17	1.37, 0.82	N/A,	N/A,
parrot	1.50, 1.04	1.29, 0.69	2.72, 1.23	2.75, 1.01	2.53, 1.17	2.65, 1.16	N/A,	N/A,
peach	4.00, 1.08	3.45, 1.26	2.24, 0.83	2.20, 0.84	5.00, 0.00	4.93, 0.26	1.21, 0.92	1.21, 0.73
peacock	1.61, 0.92	1.38, 0.73	3.61, 1.65	3.44, 1.32	1.89, 0.74	1.95, 1.00	N/A,	N/A,
pear	2.94, 1.39	3.15, 1.30	2.39, 0.98	2.21, 0.82	4.89, 0.46	4.91, 0.34	1.21, 0.92	1.19, 0.67
pen	4.89, 0.47	4.96, 0.27	2.56, 0.62	2.56, 0.91	5.00, 0.00	4.96, 0.19	3.21, 1.40	3.21, 1.39
penguin	1.39, 0.85	1.27, 0.62	2.56, 0.78	2.81, 1.16	1.42, 0.61	1.54, 0.80	N/A,	N/A,
pepper (bell)	3.94, 1.35	3.62, 1.35	2.89, 0.76	3.00, 1.09	5.00, 0.00	4.86, 0.58	2.21, 1.27	2.12, 1.05
photocopier	2.94, 1.21	2.93, 1.07	4.83, 1.29	4.70, 1.21	1.47, 1.26	1.44, 1.07	N/A,	N/A,
piano	3.17, 1.25	2.65, 1.29	2.67, 1.03	2.60, 1.03	1.32, 1.00	1.44, 1.13	N/A,	N/A,
pigeon	3.83, 1.34	3.35, 1.42	2.39, 1.04	2.70, 1.05	2.37, 1.16	2.70, 1.28	N/A,	N/A,
pineapple	3.00, 1.28	2.80, 1.23	2.61, 1.14	2.88, 1.12	4.42, 0.61	4.53, 0.57	2.89, 1.33	2.95, 1.34
pipe	1.78, 1.31	1.62, 1.11	3.44, 1.20	4.16, 1.33	4.95, 0.23	4.82, 0.60	2.37, 1.12	2.36, 1.26
pitcher	2.44, 1.38	1.93, 1.16	3.44, 1.29	3.39, 1.18	4.37, 0.83	4.35, 0.92	1.94, 1.06	1.96, 0.96
plate	4.67, 1.03	4.82, 0.72	1.67, 0.49	1.79, 0.70	4.79, 0.42	4.82, 0.38	1.95, 1.13	2.07, 1.22
pliers	2.17, 1.10	1.73, 0.95	3.78, 1.31	4.07, 1.22	4.89, 0.32	4.91, 0.29	2.94, 1.26	2.89, 1.21
plug	4.72, 0.83	4.64, 0.73	3.00, 1.14	2.89, 1.18	4.63, 0.60	4.72, 0.65	2.05, 1.27	1.95, 1.21
police car	3.28, 1.41	3.04, 1.19	2.89, 1.32	3.07, 1.10	1.21, 0.71	1.12, 0.57	N/A,	N/A,
pool table	3.33, 1.28	2.51, 1.39	3.50, 1.15	4.21, 1.37	1.47, 0.90	1.37, 0.88	N/A,	N/A,
popsicle / lollipop	2.78, 1.06	2.36, 1.08	2.17, 0.51	2.11, 0.79	4.63, 0.83	4.84, 0.53	1.83, 1.25	1.63, 1.05
pot	4.11, 1.32	3.65, 1.35	2.78, 1.26	2.84, 1.08	4.58, 0.61	4.49, 0.68	2.32, 1.16	2.11, 1.17
potato	3.94, 1.30	3.78, 1.13	2.56, 0.86	2.53, 0.87	4.89, 0.32	4.89, 0.31	2.47, 1.17	2.40, 1.28
present	2.39, 1.24	2.36, 1.09	2.33, 0.77	1.89, 0.77	4.21, 1.08	4.32, 0.91	4.00, 1.22	3.48, 1.31
prison	1.11, 0.32	1.27, 0.73	3.56, 1.04	3.88, 1.30	1.05, 0.23	1.02, 0.13	N/A,	N/A,
protractor	2.50, 1.34	2.24, 1.20	4.56, 1.34	4.86, 1.27	4.89, 0.32	4.86, 0.40	3.58, 0.96	3.32, 1.07
purse	3.89, 1.53	3.98, 1.39	2.89, 1.02	2.72, 0.86	4.42, 1.02	4.49, 0.87	2.72, 1.07	2.73, 1.29
rabbit	2.22, 1.11	1.87, 1.07	1.78, 0.65	2.00, 0.76	3.11, 1.20	3.30, 1.27	2.23, 1.09	2.49, 1.25
raccoon	1.72, 1.07	1.51, 0.81	3.11, 1.32	3.00, 1.02	2.05, 0.97	2.00, 0.96	N/A,	N/A,
raspberry	2.50, 1.29	2.67, 1.17	2.83, 1.10	2.67, 1.04	4.84, 0.50	4.86, 0.52	1.21, 0.92	1.23, 0.71
refrigerator	4.72, 0.46	4.69, 0.64	2.28, 0.96	2.39, 1.05	1.32, 0.82	1.35, 0.88	N/A,	N/A,
remote control	4.28, 1.32	4.20, 1.18	2.72, 0.83	2.95, 1.03	4.95, 0.23	4.93, 0.26	3.79, 1.62	3.65, 1.66
ring	3.22, 1.59	3.38, 1.48	2.71, 1.21	2.71, 1.09	4.89, 0.46	4.88, 0.50	2.53, 1.12	2.45, 1.25
road	4.56, 0.98	4.71, 0.69	2.28, 0.96	2.23, 0.95	1.11, 0.46	1.14, 0.64	N/A,	N/A,
rocking horse	1.72, 1.27	1.35, 0.82	2.50, 1.38	2.12, 1.23	2.63, 0.83	2.61, 0.98	N/A,	N/A,
rolodex	2.94, 1.39	2.35, 1.33	4.39, 1.54	4.63, 1.38	4.26, 0.87	4.23, 0.93	3.39, 1.20	3.56, 1.22
roof	4.39, 0.92	4.04, 1.15	2.33, 0.84	2.70, 0.91	1.11, 0.46	1.07, 0.32	N/A,	N/A,
rooster	1.56, 0.78	1.53, 0.84	2.39, 0.78	2.40, 0.86	2.47, 1.31	2.42, 1.25	N/A,	N/A,
roulette wheel	1.44, 1.04	1.36, 0.82	5.17, 1.69	5.53, 1.39	1.68, 1.00	1.77, 1.13	N/A,	N/A,
Rowe Building**	3.78, 1.52	3.71, 1.31	4.17, 1.98	4.72, 2.10	1.00, 0.00	1.00, 0.00	N/A,	N/A,
ruler	3.61, 1.20	3.31, 1.18	3.00, 0.84	3.09, 0.85	4.84, 0.37	4.89, 0.31	2.84, 1.12	2.79, 1.11
sailboat	2.28, 1.13	2.11, 1.17	2.39, 0.70	2.53, 0.95	1.26, 0.81	1.21, 0.75	N/A,	N/A,
salt shaker	4.11, 1.28	4.11, 1.15	2.33, 0.59	2.60, 0.96	4.89, 0.32	4.91, 0.29	2.63, 1.26	2.37, 1.14
sandbox	1.39, 0.50	1.40, 0.66	2.33, 1.19	1.95, 0.95	1.53, 0.90	1.41, 0.83	N/A,	N/A,
sandwich	4.11, 0.96	4.31, 0.84	2.22, 0.73	2.30, 0.91	4.79, 0.42	4.70, 0.53	2.11, 1.33	1.74, 1.06
Santa Claus	2.28, 1.32	1.82, 1.12	2.00, 0.97	1.61, 0.82	1.21, 0.42	1.37, 0.88	N/A,	N/A,
saw	2.44, 0.98	1.76, 0.88	3.33, 1.08	3.47, 1.02	4.42, 0.96	4.33, 1.07	3.78, 1.17	2.98, 1.35
scarf	4.11, 0.90	4.04, 1.13	2.78, 1.11	2.86, 1.03	4.89, 0.32	4.81, 0.48	2.79, 1.03	2.67, 1.19
scissors	3.56, 1.15	3.64, 1.22	2.28, 0.67	2.33, 0.72	5.00, 0.00	4.96, 0.19	3.47, 1.26	3.19, 1.17
screw	2.56, 1.29	2.04, 1.12	3.33, 0.84	3.21, 1.06	4.89, 0.32	4.86, 0.44	2.89, 1.24	3.13, 1.29
screwdriver	2.56, 1.29	2.07, 1.14	3.61, 1.09	3.65, 1.23	5.00, 0.00	4.96, 0.19	3.63, 1.12	3.25, 1.20
seagull	3.11, 1.32	2.71, 1.24	2.78, 0.94	2.65, 0.97	2.16, 1.12	2.32, 1.20	N/A,	N/A,
seahorse	1.50, 1.15	1.24, 0.79	3.61, 1.20	3.49, 1.24	2.58, 1.39	2.93, 1.51	N/A,	N/A,
seal	1.56, 0.98	1.31, 0.72	2.94, 1.26	3.04, 1.12	1.37, 0.50	1.35, 0.64	N/A,	N/A,
sewing machine	1.82, 1.13	1.74, 0.96	3.72, 1.23	3.74, 1.17	3.05, 1.08	3.12, 1.02	4.00, 1.11	3.96, 1.28
sheep	1.56, 1.04	1.36, 0.85	2.22, 1.06	2.35, 0.95	1.21, 0.42	1.39, 0.75	N/A,	N/A,
shell	2.22, 1.22	1.75, 1.11	2.61, 1.09	2.60, 1.15	4.42, 1.07	4.61, 0.92	2.00, 1.46	2.02, 1.28
shovel	2.44, 1.25	2.00, 1.02	2.50, 0.62	2.88, 1.01	4.32, 0.89	4.29, 0.99	3.56, 0.98	3.15, 1.13
shower	4.94, 0.24	4.80, 0.73	3.00, 1.24	2.75, 1.31	1.50, 1.04	1.25, 0.74	N/A,	N/A,
sink	4.89, 0.32	4.95, 0.23	2.11, 1.02	2.18, 0.85	1.32, 0.82	1.44, 1.02	N/A,	N/A,
sippy cup	1.39, 0.78	1.22, 0.57	1.44, 0.51	1.47, 0.78	4.89, 0.32	4.88, 0.33	1.68, 1.00	1.63, 0.96
skirt	3.89, 1.23	3.53, 1.30	2.39, 1.14	2.49, 1.09	4.42, 0.84	4.46, 0.95	3.17, 1.20	2.91, 1.15
sled	1.78, 1.17	1.58, 0.90	2.39, 0.92	2.35, 1.08	3.26, 1.15	3.25, 1.18	3.08, 1.32	3.05, 1.34
slide	1.94, 1.00	1.73, 0.89	1.88, 0.72	1.91, 0.93	1.26, 0.73	1.21, 0.53	N/A,	N/A,
slot machine	1.61, 1.04	1.45, 0.92	5.22, 1.48	5.28, 1.45	1.50, 1.10	1.61, 1.19	N/A,	N/A,
snail	1.67, 0.84	1.42, 0.69	2.56, 1.15	2.67, 0.91	3.63, 1.34	3.93, 1.43	1.80, 0.94	2.00, 1.26
snake	1.72, 1.02	1.45, 0.88	2.28, 0.83	2.44, 0.98	2.42, 1.35	2.53, 1.45	N/A,	N/A,
snowflake	2.94, 1.39	3.29, 1.29	2.61, 0.85	2.47, 1.10	3.53, 1.58	3.51, 1.62	1.94, 1.29	2.07, 1.40
sock	4.67, 0.84	4.78, 0.66	2.00, 1.08	1.77, 0.91	4.79, 0.54	4.84, 0.45	3.00, 1.37	3.02, 1.29
spider	1.56, 0.70	1.44, 0.71	3.00, 1.14	2.93, 1.10	3.26, 1.28	3.56, 1.46	1.93, 0.88	2.39, 1.42
spider web	2.65, 1.11	2.04, 1.03	2.61, 0.78	2.61, 0.88	1.68, 1.11	2.58, 1.64	N/A,	N/A,

stairs	4.44, 1.20	4.76, 0.74	1.78, 0.65	1.84, 0.84	1.16, 0.69	1.07, 0.42	N/A,	N/A,
staple gun	2.17, 1.29	2.07, 1.25	3.94, 1.16	4.12, 1.21	4.68, 0.48	4.67, 0.72	3.05, 1.08	2.75, 1.21
staple remover	4.00, 0.97	3.91, 0.93	3.44, 0.98	3.47, 1.00	4.74, 0.56	4.81, 0.44	3.58, 1.17	3.14, 1.25
stapler	2.22, 1.17	2.38, 1.16	4.39, 1.65	4.61, 1.39	4.95, 0.23	4.82, 0.61	3.16, 1.38	2.84, 1.30
statue	1.61, 0.92	1.50, 0.88	4.24, 1.56	4.55, 1.54	1.21, 0.71	1.18, 0.68	N/A,	N/A,
stocking	2.06, 1.00	1.73, 0.97	2.39, 1.04	2.09, 0.85	4.53, 0.77	4.49, 0.83	2.63, 1.54	2.68, 1.38
stool	3.72, 1.32	3.37, 1.20	2.72, 1.07	2.53, 1.02	3.39, 1.09	3.46, 1.01	3.13, 1.36	2.75, 1.31
stove	4.44, 1.10	4.04, 1.33	2.00, 0.84	2.26, 0.88	1.42, 0.90	1.30, 0.80	N/A,	N/A,
strawberry	3.56, 1.50	3.45, 1.32	2.00, 0.69	2.02, 0.67	5.00, 0.00	4.91, 0.54	1.58, 1.26	1.39, 0.89
stroller	1.72, 0.96	1.56, 0.90	2.50, 1.20	2.26, 1.22	2.47, 1.07	2.42, 1.10	N/A,	N/A,
SUB **	4.33, 1.19	4.36, 1.02	4.00, 1.88	4.77, 2.12	1.00, 0.00	1.00, 0.00	N/A,	N/A,
suitcase	2.78, 1.31	2.65, 1.25	3.11, 0.90	3.30, 1.02	4.21, 0.79	4.30, 0.82	1.94, 1.11	2.29, 1.23
sweatshirt	4.50, 1.15	4.71, 0.79	2.28, 1.18	2.19, 0.90	4.47, 0.70	4.56, 0.73	2.84, 1.26	3.00, 1.13
swing set	1.89, 0.96	1.87, 0.79	2.00, 0.59	1.93, 0.59	1.47, 1.02	1.37, 0.77	N/A,	N/A,
table	4.67, 0.59	4.64, 0.70	2.00, 0.97	2.12, 0.96	2.21, 0.98	2.18, 0.98	N/A,	N/A,
tambourine	2.00, 1.24	1.55, 0.92	3.22, 1.22	3.32, 1.15	4.79, 0.42	4.82, 0.43	2.95, 1.39	2.60, 1.28
tape measure	2.50, 1.25	2.07, 1.03	3.39, 1.04	3.60, 1.07	4.89, 0.32	4.79, 0.62	3.61, 1.04	3.56, 1.25
telephone	4.83, 0.38	4.87, 0.34	2.11, 1.18	2.16, 1.10	4.42, 0.61	4.61, 0.56	3.26, 1.41	3.48, 1.45
television	4.06, 1.55	4.45, 1.15	2.22, 1.06	2.19, 1.09	1.89, 0.94	2.02, 1.09	N/A,	N/A,
thread	2.28, 1.36	1.91, 1.13	3.06, 0.94	3.21, 1.01	4.95, 0.23	4.88, 0.33	3.84, 1.07	3.68, 1.19
tie	2.72, 1.41	2.15, 1.19	3.06, 0.94	3.00, 1.02	4.53, 0.70	4.70, 0.53	3.72, 1.18	3.79, 1.16
tiger	1.28, 0.67	1.22, 0.5	2.06, 0.8	2.28, 0.82	1.11, 0.32	1.16, 0.59	N/A,	N/A,
toaster	4.39, 1.04	4.18, 1.14	2.83, 0.86	2.81, 0.88	3.79, 0.92	3.79, 0.94	3.50, 1.10	3.51, 1.08
toilet	5.00, 0.00	4.91, 0.55	1.61, 0.92	1.63, 0.70	1.32, 0.95	1.34, 0.88	N/A,	N/A,
toilet paper	4.56, 1.15	4.84, 0.69	2.17, 1.29	2.04, 0.93	4.79, 0.42	4.86, 0.40	3.42, 1.22	3.23, 1.23
tomato	4.17, 0.92	3.71, 1.30	2.44, 1.04	2.37, 0.84	4.89, 0.46	4.81, 0.58	1.84, 1.12	1.80, 1.03
toothbrush	4.94, 0.24	4.98, 0.13	2.00, 1.08	1.86, 1.09	5.00, 0.00	4.98, 0.13	2.89, 1.56	2.53, 1.49
tractor	1.67, 0.91	1.44, 0.74	2.50, 1.10	2.82, 1.20	1.21, 0.54	1.18, 0.57	N/A,	N/A,
train	2.11, 1.18	1.71, 0.98	2.94, 1.98	2.52, 1.39	1.00, 0.00	1.09, 0.54	N/A,	N/A,
tree	4.67, 0.84	4.58, 0.79	1.89, 1.13	1.77, 0.87	1.00, 0.00	1.05, 0.23	N/A,	N/A,
truck	3.72, 1.36	3.58, 1.34	1.94, 0.87	2.14, 0.95	1.00, 0.00	1.07, 0.53	N/A,	N/A,
turtle	1.50, 0.92	1.39, 0.71	2.22, 0.73	2.32, 0.89	2.63, 1.26	2.82, 1.26	N/A,	N/A,
umbrella	2.83, 1.04	2.84, 1.05	2.72, 1.02	2.68, 0.93	4.63, 0.60	4.63, 0.62	2.58, 1.22	2.52, 1.29
vase	2.50, 1.38	2.13, 1.09	3.39, 0.85	3.44, 1.00	3.79, 0.79	3.84, 1.05	2.00, 0.91	2.24, 1.26
vest	2.59, 1.23	2.37, 1.15	3.00, 1.03	2.96, 0.96	4.44, 0.86	4.55, 0.74	3.22, 1.17	3.19, 1.17
violin	2.50, 1.65	1.89, 1.31	3.22, 1.06	3.56, 1.31	4.47, 0.61	4.51, 0.78	4.47, 0.90	4.27, 1.02
wagon	1.61, 0.78	1.41, 0.63	2.11, 0.83	2.21, 1.01	2.74, 0.73	2.67, 1.01	N/A,	N/A,
wall (brick)	4.00, 1.22	4.00, 1.15	3.33, 1.94	2.95, 1.52	1.00, 0.00	1.04, 0.19	N/A,	N/A,
washing machine	3.83, 1.10	3.62, 1.08	3.22, 1.11	3.30, 0.94	1.37, 1.01	1.35, 0.86	N/A,	N/A,
watch	4.33, 1.24	4.24, 1.22	3.06, 1.00	2.82, 0.97	4.74, 0.56	4.81, 0.48	3.00, 1.33	3.13, 1.31
water fountain	4.06, 1.30	3.72, 1.28	2.89, 0.68	2.93, 0.68	1.32, 0.95	1.42, 1.10	N/A,	N/A,
well	1.39, 0.85	1.13, 0.51	2.78, 0.88	3.23, 1.20	1.32, 0.82	1.49, 1.14	N/A,	N/A,
wheel	2.44, 1.58	2.44, 1.52	2.72, 1.07	2.72, 1.06	3.32, 1.11	3.37, 1.22	2.53, 1.19	2.82, 1.30
whistle	2.28, 1.27	2.07, 1.30	2.94, 1.16	2.81, 0.93	4.95, 0.23	4.95, 0.23	2.47, 1.26	2.44, 1.34
Wickwire Field **	4.78, 0.43	4.33, 1.11	3.22, 1.40	3.91, 1.88	1.00, 0.00	1.14, 0.74	N/A,	N/A,
windmill	1.67, 1.08	1.36, 0.78	4.00, 1.33	4.12, 1.30	1.16, 0.50	1.14, 0.61	N/A,	N/A,
wreath	2.17, 1.15	1.85, 0.99	3.11, 1.13	3.27, 1.21	4.11, 0.66	3.98, 1.06	2.26, 1.15	2.45, 1.24
wrench	2.61, 1.38	1.85, 1.10	3.78, 0.94	3.84, 1.18	4.95, 0.23	4.89, 0.36	3.42, 1.26	3.00, 1.25
yarn	1.78, 0.94	1.76, 0.96	2.83, 1.04	3.05, 1.11	4.79, 0.42	4.84, 0.37	3.84, 1.12	3.74, 1.32
zebra	1.44, 0.98	1.22, 0.63	2.39, 0.61	2.58, 0.84	1.26, 0.93	1.09, 0.54	N/A,	N/A,

Appendix B. Average (Mean) and standard deviation (SD) of Ratings on Each Scale for Each Object. (Note: Only time 1 (T1) and overall ratings are provided, for T2 and T3 please refer to online supplementary Appendix Sup-C). ** denotes Halifax specific locations.

**CHAPTER 3 THE INFLUENCE OF OBJECT MANIPULABILITY
ON CATEGORIZATION AND NAMING OF BACKWARD-MASKED
PHOTOGRAPHS SHOWN FOR BRIEF DURATIONS: A
REVERSAL EFFECT FOR OBJECT MANIPULABILITY**

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3.1 ABSTRACT

Previous research investigating the influence of object manipulability (the properties of objects that make them appropriate for manual action) has not tightly controlled for effects of both object familiarity and age of acquisition of objects. The current research carefully controlled these two variables on a balanced set of 120 photographs and showed significant effects of object manipulability during object categorization (Experiment 1) and object naming (Experiment 2). Critically, the data showed a manipulability-effect reversal, with faster categorization of non-manipulable objects, but faster naming of manipulable objects, suggesting that task moderates the direction of the manipulability effect. Exposure duration (the amount of time the object was visible to participants) was also investigated, but no interactions between exposure duration and manipulability were found. These results indicate that not only can manipulability influence object identification, but the way in which it does depends on the task.

3.2 INTRODUCTION

3.2.1 Object Representations

Recent ‘embodied’ theories of cognition have challenged traditional symbolic theories, proposing instead that the way in which an organism interacts with the environment is critical in understanding the cognitive processes that underlie cognitive tasks, including action and object identification (cf. Allport, 1985; Lakoff & Johnson, 1999; Wilson, 2002). These theories reject the notion that amodal symbols underlie cognitive processes, proposing instead that simulations of sensory-motor activity (e.g. visual, auditory, and sensory-motor imagery), situated action (e.g. experiences of performing motor acts under different conditions), or bodily states (e.g. experiences of arousal and other effects of emotional experience), implemented in their respective modal brain systems, underlie complex cognitive process (see Barsalou, 2008, for a review of evidence in favour of embodied theories in perception, action, memory, language, social cognition, problem solving and reasoning, and development). Further, these theories suggest that the representation of the external world is built primarily from the properties that afford action (i.e. object affordances, Gibson, 1979).

These theories draw upon an important neuropsychological model of vision that proposes that visual information is parsed into ventral and dorsal visual streams (see, for example, Goodale, 2008; Goodale & Ganel, 2009; Goodale & Milner, 1992, 1994; Goodale, Milner, Jakobson, & Carey, 1991, for extensive evidence). Within each stream, early visual information is separated based on the types of information that is processed, resulting in distributed neural representations of objects. First, the ‘ventral visual stream’ processes invariant perceptual information about objects (e.g. information about color,

texture, shape) that allows us to identify objects and form long-term representations of them. Second, the ‘dorsal visual stream’, processes the variant aspects of objects (e.g. location, distance, depth, movement) that allow us to coordinate actions including reaching and grasping, localize objects in the environment, and allocate attention. Importantly, the ventral and dorsal streams interact efficiently both with each other and with regions of the frontal lobe, to ensure organisms successfully interact with their environments (see Matheson & McMullen, 2010, for a neuropsychological review of interactions between the two streams).

Importantly, embodied theories make specific predictions about how the ventral and dorsal streams contribute to the representation of different types of objects. For instance, in response to the visual presentation of a manipulable object (an object with properties affording a manual grasp), embodied theories posit activity in the dorsal action system even in the absence of explicit movement or action. Using fMRI, Chao and Martin (2000) have provided evidence for this, showing BOLD activation in dorsal stream areas (fronto-parietal areas) while participants passively viewed manipulable but not non-manipulable objects (cf. Boronat, et al., 2005; Chao, Haxby, et al., 1999; Fang & He, 2005). These findings suggest that viewing manipulable objects activate brain areas along the dorsal visual pathways in addition to areas in the ventral pathway. Additionally, a recent meta-analysis on object naming (Chouinard & Goodale, 2010) concluded that non-manipulable objects (i.e. animals) primarily activated ventral and frontal regions of cortex, but manipulable objects (i.e. tools) invoked a greater responses in motor areas of the frontal lobe as well as in sensory-motor areas of the parietal lobe. As the authors note, “naming tools not only engages visual areas in the ventral stream but also a fronto-

parietal network associated with tool use” (Chouinard & Goodale, 2010, p. 409). This fronto-parietal network associated with tool use has also been identified in other reviews (cf. Johnson-Frey, 2004; Lewis, 2006). These neurophysiological data support the notion that both ventral and dorsal representations contribute to the overall representation of objects.

3.2.2 Behavioural evidence for distributed representations

Though there is a host of neurophysiological evidence that the ventral and dorsal streams differentially represent manipulable and non-manipulable objects, the behavioral consequences of these differences remain unclear. A recent model by Yoon, Heinke, and Humphreys (2002) posits that the relationship between object identification and action systems is bidirectional. This implies that action information can influence identification, and vice-versa. Evidence that action information can aid object identification has come from Humphreys and Riddoch's (2001) research on a patient with unilateral neglect. This patient, MP, was impaired at finding targets defined by perceptual features, but reported he had an easier time finding objects when “he thought of what to do with them” (p. 84). Results during a visual search task indicated he was, indeed, better able to find objects when cued with an action (“find the object to drink from”) than when cued with the object’s name (“find the cup”), or cued with the object’s color (“find the red object”). Wolk et al. (2005) also showed that objects with high manipulability ratings (based on ratings by Magnié, et al., 2003) were more likely to be recognized by a patient with mild visual agnosia. These results suggest that action information aids patients during identification.

Interactions between action and object identification have been revealed further by studies that investigate the role of object identity on the production of action. For instance, a study by Tucker and Ellis (1998) showed that the presentation of a manipulable object can potentiate (i.e. speed-up) manual button-press responses when the handle of the object points toward the response hand. Similarly, Tucker and Ellis (2004) showed that the presentation of an object affording a precision grasp will potentiate precision movements (i.e. making a pincer grasp in response to a clothes pin) and the presentation of an object affording a power grip will potentiate power movements (e.g. making a power grasp in response to a bottle). These results suggest that the presentation of manipulable objects automatically activate sensory-motor representations in neurologically typical individuals. However, the way in which afforded actions influence object identification in normal subject remains unclear, perhaps because object identification is so fast in healthy individuals under normal viewing circumstances.

Only a small number of studies have addressed this issue explicitly and the results have been inconsistent. For instance, Filliter, McMullen & Westwood (2005) had participants perform a picture-word matching task with manipulable and non-manipulable objects and showed faster picture-word matching of manipulable objects when object familiarity of objects was not controlled, but faster matching of non-manipulable objects when object familiarity was controlled. This suggests that, beyond confounds such as object familiarity, sensory-motor associations do affect object identification and are activated automatically. However, Kalénine and Bonthoux (2008) found participants were faster to match manipulable objects when judging their thematic relationships (i.e whether a coat hanger is paired with a coat) but faster to match non-

manipulable objects during basic-level taxonomic judgments (i.e. jacket matched with a coat). This result shows that the effects of object manipulability depend on the task. This suggestion is further supported by a study by Bub, Masson, and Bukach (2003). These authors trained participants to associate colour cues with different gestures. In a test phase, participants were presented with object-colour pairs and either had to make a gesture in response to the colour cue, or name the object. Importantly, the colour-cued gesture could be either congruent with the normal functional use of an object (e.g. a pinch gesture to a match or a needle) or incongruent with the object (e.g. a pinch gesture to a calculator). The results showed an effect of congruency when making learned gestures in response to colour cues, suggesting that representations of functional use were activated in response to the presentation of the object. Despite the effects of object manipulability on learned gestures, there were no effects of congruency on object naming, suggesting that object manipulability does not affect naming. Importantly, these results are inconsistent with the results of Filliter et al. (2005) and Kalénine and Bonthoux (2008), and suggest that sensory-motor associations do not affect object identification. Overall then, that the ways in which object manipulability affect object identification remain unclear.

3.2.3 Confounds and operational-definitions

Behaviourally, it has been difficult to delineate the effects of object manipulability on the identification of objects. This is likely the consequence of a number of things. First, mounting evidence suggests that action influences on object representations may depend on whether participants are identifying the objects for the purpose of naming versus categorization. For instance, Chao and Martin's (2000) fMRI

finding that passively viewing and silently naming tools activated pre-motor regions of cortex, suggests that viewing manipulable objects always activates dorsal pathways. However, PET research by Gerlach, Law, Gade, and Paulson (1999, 2002) challenges this assumption. These studies found no association between manipulable-objects and pre-motor activation on an object decision task in which objects had to be matched in visual memory (Gerlach, et al., 1999); further, they presented evidence that the pre-motor cortex is not activated more during the naming of manipulable objects than during the naming of non-manipulable, (i.e. natural) objects. This suggests that this area is not involved in the processing of manipulable objects, in general. Gerlach, et al. (2002) did, however, find evidence that the pre-motor cortex is more activated during categorization of manipulable objects than during the categorization of natural objects. Thus, there is considerable evidence that task-goal modulates the activation of sensory-motor related representations.

Second, previous research has often investigated object representations using ‘natural objects’ and ‘man-made objects’ (e.g. Warrington & McCarthy, 1983, 1987; Warrington & Shallice, 1984), ignoring the fact that not all natural objects are non-manipulable (as we can grasp fruit) and not all man-made objects are manipulable (as we cannot manipulate an airplane by grasp alone). Importantly, manipulability affects neural processing within these categories. For instance, different brain regions respond to tools and furniture (Spitzer, Kwong, Kennedy, & Rosen, 1995). Additionally, Kraut, Moo, Segal, and Hart (2002) compared fMRI frontal regions active during a category-comparison task that involved tools, animals, fruits, and vegetables. Fruits and vegetables activated the same frontal areas as tools, but to a lesser extent than tools. In contrast,

animals activated only a subset of these regions, suggesting that activation for fruits or vegetables is more similar to tools than animals (Kraut, et al., 2002). This suggests that manipulability can be a more important predictor than the ‘naturalness’ of an object.

Third, there has been some criticism that previous studies have not sufficiently controlled for the effects of confounding variables. For example, Filliter et al. (2005) controlled for object familiarity but not for age of acquisition (AoA, i.e. the age at which one first acquired the vocabulary). Kalénine and Bonthoux (2008) did not control for either familiarity or AoA. AoA, in particular is an important variable to control because it has been shown to account for a high degree of the variance in identification times in a number of studies (cf. Bonin, Peereman, Malardier, Méot, & Chalard, 2003; Catling, Dent, & Williamson, 2008; Cuetos & Alija, 2003; Dent, Catling, & Johnston, 2007; Dent, Johnston, & Humphreys, 2008; Pérez, 2007). Thus, there remains a need to show significant effects of manipulability on identification in healthy participants with the effects of these important confounds sufficiently controlled for.

3.2.4 Level of Identification

Categorization and naming both require some form of object recognition, and one might reasonably expect similar object-type effects for both tasks. However, as observed by Price and Humphreys (1989), this is not always the case. Specifically, Price and Humphreys (1989) measured effects of surface detail, and found larger effects for tasks that required finer discrimination (e.g. naming instead of categorization). Thus, with objects from categories with structurally similar exemplars effects are stronger on naming since naming requires finer within-category differentiation. That is, the effects of naming and categorization are influenced by within-category structural similarity of objects.

Arguments based on structural similarity have been articulated more recently in the pre-semantic account of category effects or PACE model (Gerlach, 2009; Gerlach, Law, & Paulson, 2004, 2006) which explains that structurally similar objects can be categorized more quickly since they share more common features, but this shared commonality can slow them down when naming (see also Gale, Laws, & Foley, 2006, for counter-findings). Thus, natural objects which are typically considered to exhibit high within-category visual similarity (cf. Gaffan & Heywood, 1993; Laws & Neve, 1999; Turnbull & Laws, 2000) can be categorized more quickly than man-made objects (Gerlach, 2001; Kirchner & Thorpe, 2006; Riddoch & Humphreys, 2004) but then named more slowly (Coppens & Frisinger, 2005; Gaffan & Heywood, 1993).

When manipulable objects are compared to non-manipulable objects, the confound of “visual similarity” is usually present. That is, manipulable objects are usually represented as tools (i.e. manmade) and non-manipulable objects by animals (i.e. natural). Reversals *have* been observed across the line of manipulability. For example, as cited earlier, Kalénine and Bonthoux (2008) found faster basic-level taxonomic judgments (e.g. “jacket-coat”) for non-manipulable objects, but faster thematic judgments (e.g. “jacket-hanger”) for manipulable objects. However, Kalénine and Bonthoux (2008), did not carefully balance their object sets, or measure them according to visual similarity. So, it is impossible to say to whether their observed reversal was based on object manipulability and action associations with objects, or simply based on the presence of visual similarity confounds within their chosen object-set.

In addition, visual similarity may not be the only important type of similarity. “Action similarity” may also affect object identification. Action similarity would be

defined as the extent to which two objects afford similar actions, for example “pear”-“apple” or “cell phone”-“calculator” are pairs of objects with similar actions, but “calculator”-“apple” have very different actions. Desmarais, Dixon, and Roy (2007) were able to show that “action similarity” for newly learned objects can influence object identification. Specifically, they began with a set of novel objects with known levels of visual similarity based on Desmarais and Dixon (2005). They were then able to show that the same objects were confused less often (during naming) if assigned dissimilar actions than when assigned similar actions (Desmarais, Dixon, et al., 2007). Thus, these results suggest that when identifying objects action dissimilarity can lead to less confusion. In particular, one could imagine a continuum of action similarity with non-manipulable objects having high action similarity (all objects have no or few actions associated with them), fruits and vegetables having a medium level of action similarity (most fruits & vegetables are grasped and eaten in a similar way) and tools/artefacts having a low level of action similarity (there’s a wide variety of ways in which tools are grasped and used)⁸. Thus, part of the dissimilarity perceived within manipulable objects may be based on the wide variety of action representations within these types of objects. Regardless of where similarity comes from, both visual similarity and action similarity suggest that non-manipulable objects generally come from a more similar set than manipulable objects.

⁸ This argument may seem a little odd, because it’s suggesting that non-manipulable objects are ‘similar’ in that they lack associated action, and usually similarity is measured in terms shared features (and not shared lack of features). However, the proposition might be clarified by thinking in terms of semantic space and semantic distance. Similar objects tend to be represented in close proximity in semantic space, and are therefore more likely to get confused. Desmarais, Dixon, et al. (2007) demonstrated that when two objects are arbitrarily assigned very different actions they are confused less often than when the same objects are assigned similar actions. Thus, suggesting that objects that get assigned different actions get pushed away from each other or develop more semantic distance from each other than they would have if they had no action associations. Thus, we would expect no increase to semantic distance between non-manipulable objects based on action, but we would expect those increases for manipulable objects, and more so for certain kinds of manipulable objects (e.g. tools, and objects with very specific and specialized actions).

Thus, applying arguments of similarity, one could predict faster categorization of non-manipulable objects but slower naming. This hypothesis was tested in the current research.

A second prediction based on PACE model arguments of *visual* similarity, but perhaps equally applicable to arguments of action similarity, is that categorization of similar objects is less impaired by visual degradation. In numerous studies, Thorpe and colleagues have demonstrated that natural scenes and animals are categorized very quickly compared to man-made objects even when scenes are backward masked and shown for very brief durations (e.g. Bacon-Macé, Kirchner, Fabre-Thorpe, & Thorpe, 2007; Bacon-Macé, Macé, Fabre-Thorpe, & Thorpe, 2005; Fabre-Thorpe, Delorme, Marlot, & Thorpe, 2001; Kirchner, Barbeau, Thorpe, Régis, & Liegeois-Chauvel, 2009; Kirchner & Thorpe, 2006; Thorpe, 2009; VanRullen & Thorpe, 2001). The PACE model, as articulated by Gerlach (2009), would explain this advantage for natural things as related to the structural similarity within natural objects. That is, the co-occurrence of all natural features makes them more easy to detect or “the shapes of natural objects are more easily configured than the shapes of artefacts” therefore degradation should have more devastating effects on processing artefacts (Gerlach, 2009, p. 285). Could the same similarity arguments be applied to manipulability? If so, non-manipulable objects (if they represented a set of more visually similar objects) would be less affected by stimulus degradation as compared to manipulable objects. Or, to state it another way, the presence of an exposure duration by manipulability interaction (with larger exposure duration effects for manipulable objects) would suggest a visual similarity confound.

3.3 THE CURRENT STUDY: EARLY VISUAL PROCESSING, BRIEF EXPOSURE AND MASKING

The present study sought to clarify these issues, and addresses three main questions. First, we sought to replicate the effect of manipulability on object naming while controlling for the effects of Familiarity and Age of Acquisition. Additionally, we wished to use a stimulus set that was balanced on both the number of natural and manmade objects, as well as the number of manipulable and non-manipulable objects. This balancing, we felt, would act as a partial control for confounds of visual similarity. Second, we investigated similarity predictions relating to manipulability effects, including (1) that object manipulability would interact with exposure duration, and (2) that effects of manipulability depend on task. This was done by examining that same set of carefully balanced objects across two experiments: categorizing (Experiment 1) and naming (Experiment 2).

3.4 EXPERIMENT 1 – CATEGORIZATION

Experiment 1 attempted to replicate previously observed manipulability effects with a set of 120 objects balanced on object Familiarity and Age of Acquisition during object categorization. A number of outcomes were possible given the current design. First, according to Filliter et al. (2005) and arguments based on object similarity, we should observe faster reaction times (RTs) and/or fewer errors for non-manipulable objects. In contrast, faster RTs and/or fewer errors could be predicted for manipulable objects; this would be consistent with the advantage observed by Wolk, et al. (2005) and other neuropsychological research (e.g. Humphreys & Riddoch, 2001). Finally, it was

possible that with such a carefully balanced set of objects no significant manipulability effects would be observed, which would support the assertion that manipulability effects observed previously were due to a lack of experimental control, and the effects of other confounding variables (such as AoA or Familiarity).

In addition to manipulability, we manipulated exposure duration (ED). Two exposure durations were used, and it was hypothesized that there would be a significant interaction between exposure duration and manipulability. Based on similarity arguments (i.e. Gerlach, 2009) and observations that non-manipulable objects may be more visually similar (*cf.* Kalénine & Bonthoux, 2008) and action similar (*cf.* Desmarais & Dixon, 2005), it was predicted that non-manipulable objects would be less affected by a brief exposure duration than manipulable objects.

3.5 METHODS

3.5.1 Participants

Forty undergraduate students (8 males; age range: 17 to 36; $M = 19.9$, $SD = 3.6$) were recruited from the Psychology Department at Dalhousie University and the surrounding community. All participants had normal or corrected-to-normal vision and English as a first language. One participant identified themselves as ambidextrous, and one as left-handed. The rest were right-handed.

3.5.2 Materials

Black and white photographs of common objects from the set developed by Salmon, McMullen and Filliter (2010) were used for this experiment. Thirty (30) objects

were chosen equally from each of four categories: natural manipulable, natural non-manipulable, manmade manipulable, and manmade non-manipulable. Objects were considered “manipulable” if they had a manipulability-score of 3.0 or higher, based on average ratings collected by Salmon et al. (2010), and considered “non-manipulable” otherwise. These scores were based on average ratings from participants who were asked to “rate the manipulability of the object according to how easy it is to grasp and use the object with one hand,” along a 5-point scale. Participants were given as anchors (i.e. examples): “rhinoceros” as an example of an item that would score low (1), and “spoon” as an example of an item that would score high (Salmon, et al., 2010, p. 85). For examples of objects in each category, see Figure 3.1.

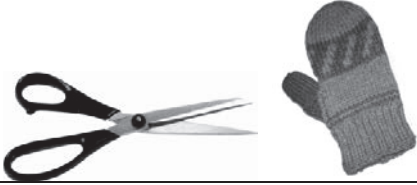



	Manmade	Natural
Manipulable	<p>tools, clothing</p> 	<p>fruits, vegetables</p> 
Non-Manipulable	<p>vehicles, furniture</p> 	<p>animals, landscapes</p> 

Figure 3.1. Example objects in each category. Each of the four cells was comprised of 30 objects, for a total object set of 120 objects. See Supplementary Appendix A1 for a complete list of the 120 objects.

Objects were chosen to be closely matched on object familiarity and age of acquisition (based on ratings gathered by Salmon et al., 2010). It was not possible to balance the manmade versus natural set perfectly (manmade objects such as vehicles and tools were more familiar than natural objects such as animals and plants). There was also a small bias for natural objects to be rated as more manipulable than manmade objects (see bottom right scores of Table 3.1). However, the manmade versus natural distinction was not the focus of this research, and importantly, the manipulable objects were balanced on both AoA and Familiarity (see Table 3.1). Manipulable objects, by definition, had significantly higher manipulability scores than non-manipulable objects ($M = 4.38$ for manipulable; $M = 1.65$ for non-manipulable, on a 5-point scale).

Table 3.1. Average ratings for objects in each group. Each group consisted of 60 objects (that is 60 manipulable and 60 non-manipulable objects). Note, Age of Acquisition (AoA) was on a 7-point Likert scale (1=young AoA, 7=old AoA), Familiarity (Fam) on a 5-point scale (1=low Fam, 5=high Fam), and Manipulability (Manip) on 5-point scale (1=low Manip, 5=high Manip).

	AoA	Fam	Manip
Manipulable	2.36	3.17	4.38
non-manipulable	2.38	3.21	1.65 ***
Manmade	2.40	3.56	2.90
Natural	2.34	2.82 ***	3.13 *

Each group of objects was further split into balanced (on AoA and Familiarity) groups of 15. Each of these groups was randomly assigned an exposure duration (short or long) such that the means for each feature (AoA, Fam or Manip) were as close as possible between the groups. In addition, a stimulus mask was used for these experiments. The mask was made by parsing out sections of representative images (equal numbers of objects from each category, see Figure 3.2).

All stimuli were presented on a Windows (XP) machine using Direct RT software (Jarvis, 2008) on a NEC AccuSync 120 CRT monitor (21” inches) running at 85 Hz. Participants sat at an unrestrained distance of approximately 55 cm from the display. All stimuli subtended a visual angle between 9.5 to 12 visual degrees.

3.5.3 Procedure

Each participant completed 2 blocks of trials. During each block the participant was presented all 120 objects in the object set with half presented at a shorter exposure duration (approximately 35 ms, range = 22 to 48 ms) and half presented at a longer exposure duration (approximately 105 ms, range = 93 to 129 ms)⁹. In the second block the exposure duration for each object was switched. That is, in block 1 participants’ would see List A items presented for 35 ms and List B for 105 ms, but in block 2 list A items would be shown for 105 ms and B for 35 ms. The order of presentation was counterbalanced across participants.

Each trial began with a fixation shown for 1000ms followed by the picture (shown at one of two exposure durations) and then a visual mask for 100ms (see Figure 3.2). Afterward the screen would remain blank (i.e. white) until the participant made a response. Participants were asked to respond on a keyboard by pressing the left or right arrow key to categorize the object as either “manmade” or “natural”. Key correspondence was counter-balanced across participants. The middle key (or “down” arrow) was to be pressed when participants experienced a high degree of uncertainty. However, guessing

⁹ During testing the requested presentation times were 20ms and 100ms, and during pilot research, DirectRT appeared to be displaying the stimuli, reliably, at these durations. However, after data were collected it became evident that for certain participants DirectRT failed achieve the requested time and showed, for example, all stimuli at 35 ms or longer. Thus, exposure durations reported in this research are consistent with the median exposure duration witnessed across all participants.

was encouraged. In addition, each participant was asked to make their responses as quickly and as accurately as possible. Trial presentation order was randomized (that is short exposure duration objects were mixed in with long exposure duration objects).

Prior to the experiment, each participant was allowed two practice blocks on a different set of objects shown at the same presentation rate. Again, each object was shown once at the fast exposure duration (35 ms) and once at the long exposure duration (105 ms), with equal numbers of objects shown at each duration. The entire experiment was completed in approximately 60 minutes.

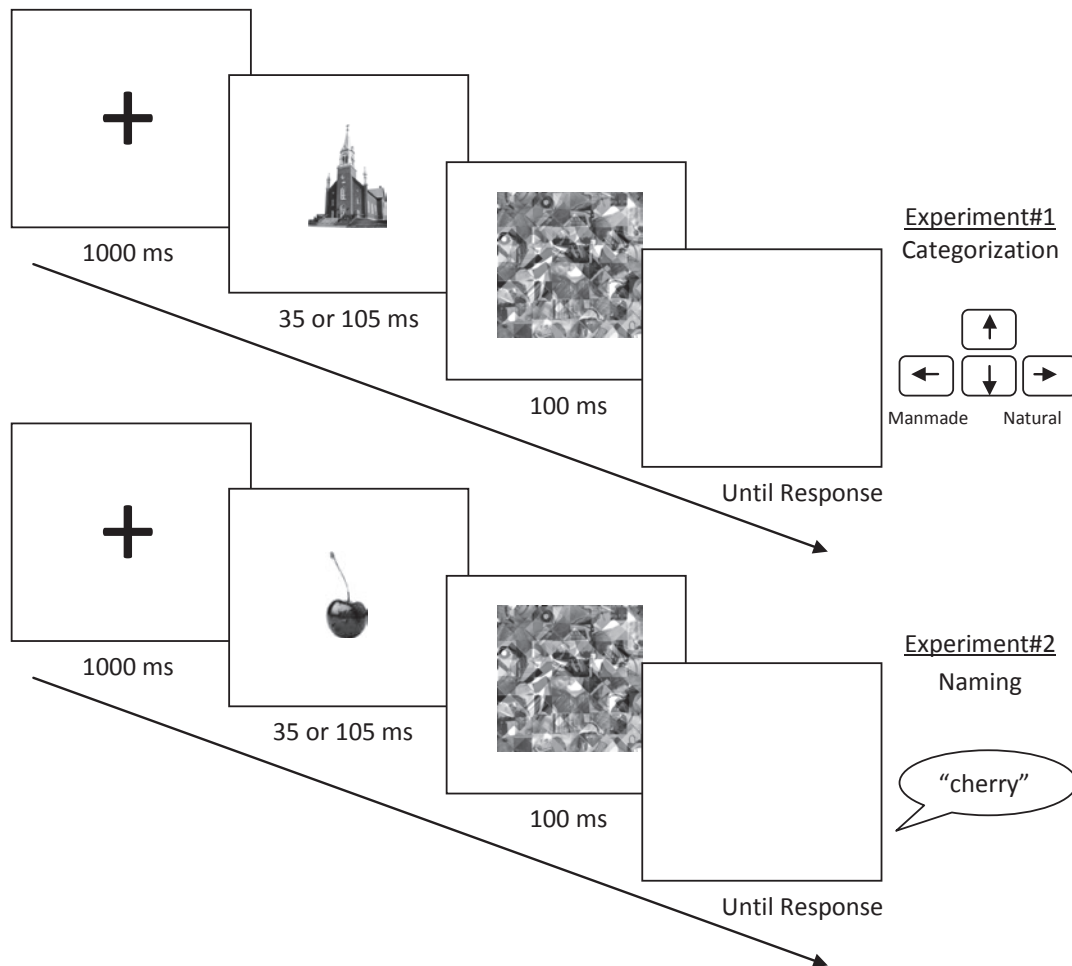


Figure 3.2 General method employed. (Show Experiment #1 Categorization & Experiment #2 Naming).

3.5.4 Data Analysis

The primary variables of interest were manipulability (manipulable versus non-manipulable and exposure duration (ED, or short versus long). Of particular interest was the presence or lack of presence of an interaction. Block (first or second) was also considered as a variable to explore any mitigating effect of practice or exposure to the items. Although sets were divided equally between manmade versus natural, it was not possible to balance these sets fully on Familiarity and AoA, and therefore this variable was not analyzed in the main analysis. This led to a 2 (manipulability) x 2 (ED) x 2 (block) within-subjects factorial design. The main analysis was a repeated measures ANOVA on the mean of subjects' median reaction times (RTs) for objects (on correct responses only) in each cell of the design¹⁰. The secondary analysis was a repeated measures ANOVA on subjects' errors (accuracy) on the same objects. Follow-up item-analyses were used to confirm that the pattern of results did not differ when averaged over items. Analyses considering block 1 (only) were also conducted, but the results of these analyses were either (a) identical to the full analysis, or (b) had fewer significant effects, indicating that block 1-only analyses in these cases were less powerful and yielded no new information of merit (see supplementary Appendix A2 for these analyses).

¹⁰ Group analyses reaction times (RTs) are based on the mean of the median RTs. For simplicity, instead of stating "the mean of the median RTs" each time RT results are reported, terminology will be shortened to "average RT", as both means and medians are after all, measures of central tendencies.

3.6 RESULTS

3.6.1 Reaction Time (Subject Analysis)

A 2 (manipulability) x 2 (ED) x 2 (block) repeated measures ANOVA on subjects' average reaction time (for accurate trials only) revealed a main effect of manipulability, $F(1, 39) = 12.45, p < .01$, with faster reaction time to non-manipulable objects ($M = 608$ ms) than manipulable objects ($M = 622$ ms). There was a main effect of ED, $F(1, 39) = 25.79, p < .001$, with faster categorization for the longer ED ($M = 599$ ms) than the short ED ($M = 631$ ms). Additionally, there was a main effect of block, $F(1, 39) = 44.28, p < .001$, due to faster categorization in block 2 ($M = 587$ ms) than block 1 ($M = 643$ ms). There was a significant 2-way interaction between block and ED, $F(1, 39) = 5.00, p < .05$, indicating bigger ED effects in block 1 (mean difference of 43 ms in block 1 compared to a 20 ms difference in block 2). Critically, the manipulability x ED interaction was not significant, $F(1, 39) = 5.00, p = .582$. No other interaction reached significance, p 's $> .362$.

3.6.2 Error (Subjects Analysis)

A 2 (manipulability) x 2 (ED) x 2 (block) repeated measures ANOVA on subjects' average error revealed a main effect of block, $F(1, 39) = 23.33, p < .001$, with fewer errors in block 2 ($M = 9\%$ error) than block 1 ($M = 13\%$ error). There was a main effect ED, $F(1, 39) = 54.99, p < .001$, with fewer errors in the long exposure duration condition ($M = 4\%$ error) than the short ($M = 18\%$ error). Again, the block by ED interaction was significant, $F(1, 39) = 21.54, p < .001$, with a larger ED error effect in the first block (mean difference of 17% error in block 1 compared to 10% error in block 2).

Critically, the main effect of manipulability was not significant, $F(1, 39) = 1.45, p = .235$, with no obvious error advantage for non-manipulable ($M=11\%$ error) over manipulable objects ($M=12\%$ error). Additionally, the interaction between manipulability and ED, was not significant, $F(1, 39) = 3.95, p = .054$, although there was a trend towards bigger exposure duration effects for non-manipulable objects, which would be in the opposite direction of predicted effects based on object similarity. That is, for non-manipulable objects participants had 14.8% more errors in the short exposure duration condition ($M = 18.3\%$ error-rate for short durations, and $M = 3.5\%$ for long durations), but for manipulable objects, participants had 12.8% more errors for short exposure durations ($M = 18.0\%$ error-rate for short durations, and $M = 5.2\%$ for long durations).

Importantly, there was no evidence of a speed-accuracy trade-off for any of the main effects or interactions. For a list of all the significant main effects and interaction(s) refer to Table 3.2. (See Figure 3.3 for a depiction of the non-significant manipulability by ED interaction for RT and error/accuracy.)

Table 3.2. List of significant main effects and interactions (underlined) and key effects that were not significant (grey). Partial Eta-Squared (η^2).

Reaction Time (RT)		Error / Accuracy (%)	
Effect Type	Significance Values	Effect Type	Significance Values
<u>(ME) block</u>	$F(1,39) = 44.3, p < .001, \eta^2 = .53$	<u>(ME) block</u>	$F(1,39) = 23.3, p < .001, \eta^2 = .37$
<u>(ME) ED</u>	$F(1,39) = 25.8, p < .001, \eta^2 = .40$	<u>(ME) ED</u>	$F(1,39) = 55.0, p < .001, \eta^2 = .59$
<u>(ME) Manip</u>	$F(1,39) = 12.5, p = .001, \eta^2 = .24$	(ME) Manip	$F(1,39) = 1.5, p = .235, \eta^2 = .04$
<u>(2-way) block x ED</u>	$F(1,39) = 5.0, p = .031, \eta^2 = .11$	<u>(2-way) block x ED</u>	$F(1,39) = 21.5, p < .001, \eta^2 = .36$
(2-way) Manip x ED	$F(1,39) = 0.3, p = .582, \eta^2 = .01$	(2-way) Manip x ED	$F(1,39) = 3.9, p = .054, \eta^2 = .09$

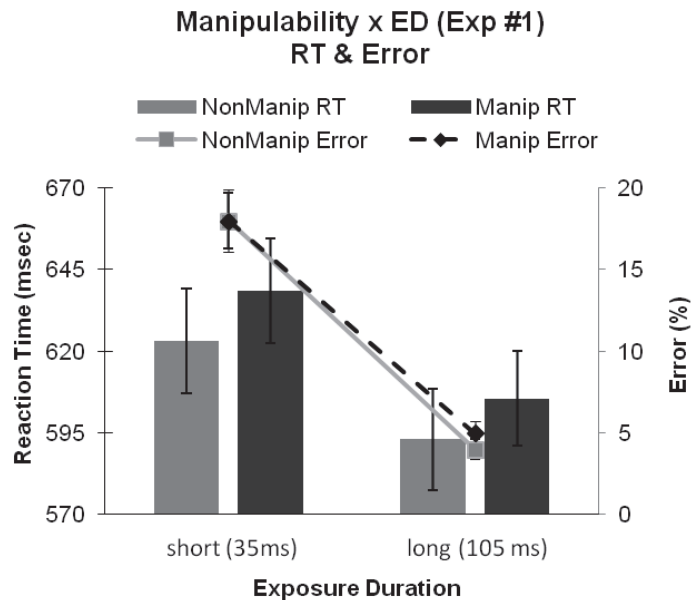


Figure 3.3 Bars show average reaction times (RT) in milliseconds for Categorization of Manipulable (black) versus Non-Manipulable (grey) objects. Percent error is shown with the solid and dashed line. X-axis indicates exposure duration or ED (short-35ms, or long-105ms). Note, smaller bars indicate faster RTs, and lower lines indicate fewer errors. Error bars indicate the standard error.

3.6.3 Item Analysis

A follow-up 2 (manipulability) x 2 (ED) x 2 (block) mixed ANOVA was used in an item analysis. ED and block were treated as repeated measures and manipulability was treated as between-groups (items) factor. The same effects from the Subjects analysis were supported, with an effect of manipulability, $F(1,110) = 9.12, p < .01$, with faster RTs to non-manipulable objects ($M = 594$ ms) than manipulable objects ($M = 615$ ms)¹¹, and no significant interaction between manipulability and ED, $F(1,110) = 0.25, p = .621$. Interestingly, there was a significant interaction between manipulability and block,

¹¹ Note, the size of the manipulability effect was unchanged when familiarity and AoA were entered as covariates to the same analysis. This lack of change was likely due to the fact that the effects of these variables were already neutralized from the balancing procedure outlined in the methods.

$F(1,110) = 6.11, p < .05$, with a larger manipulability effect in block 1. Specifically, the manipulability effect in block 1 was 28 ms, but it was only 13 ms in block 2 (faster categorization of non-manipulable objects in both cases). In all other ways, the pattern of significant effects for the Item Analysis was identical to obtained from the Subjects analysis.

The same follow-up Item Analysis was done with error. The results confirmed the results of the Subjects analysis, with no significant effect of manipulability, $F(1,118) = 0.11, p = .744$, and no significant interaction between ED and manipulability for error, $F(1,118) = 0.68, p = .410$. As in the Subjects analysis, there was a main effect of block, $F(1,118) = 41.80, p < .001$, with fewer errors in block 2 ($M = 9\%$ error) compared to block 1 ($M = 13\%$ error). There was a main effect of ED, $F(1,118) = 98.56, p < .001$, with fewer errors for long EDs ($M = 6\%$ error) compared to short EDs ($M = 17\%$). In addition, the same block by ED interaction from before was still significant, $F(1,118) = 46.11, p < .001$.

3.7 DISCUSSION

This experiment provided strong evidence of manipulability effects during an object categorization task in normal participants when the effects of familiarity and age of acquisition (AoA) were controlled for, and the set was balanced on the number of natural and manmade objects. This manipulability effect was significant for RT (but not for errors), with faster RTs to categorize non-manipulable objects. However, the current results did not support an interaction between exposure duration (ED) and manipulability. That is, the impact of manipulability on reaction time and accuracy was not modulated by exposure duration.

3.7.1 The Manipulability Effect

The main effect of manipulability replicated the manipulability effect (faster RTs for non-manipulable objects) reported by Filliter, et al. (2005) on a picture-word matching task with a familiarity-controlled set of objects. It was also consistent with similarity predictions of the PACE model, if non-manipulable objects are assumed to represent a set of more visually similar objects. Further, this effect was shown despite the tight experimental control of familiarity, AoA, and origin of the objects (natural or manmade). The current findings, however, are inconsistent with the advantage that Wolk et al. (2005) and other neuropsychological research (e.g. Humphreys & Riddoch, 2001) has found for identification of manipulable objects. However, there are some critical differences in the current design, and that of Wolk et al. (2005). Specifically, Wolk et al. (2005) studied patients (not healthy individuals), investigated object naming (not categorization), and did not control for object familiarity and AoA.

Additionally, the current manipulability effect appeared in reaction times but not in errors/accuracy, although there was no evidence of a speed-accuracy trade-off with few errors for categorizing both manipulable and non-manipulable objects. We also revealed main effects of block and ED. This is consistent with previous research that has shown faster naming or categorization of repeated stimuli (i.e. research on “repetition priming”) and that longer exposure durations accumulate in more thorough and efficient processing (e.g. Bacon-Macé, et al., 2007). Finally, it is worth noting that average accuracies in the current research were similar to those reported previously by Bacon-Macé, et al. (2007) with 96 % for exposure durations (EDs) of 105 ms and 82 % accuracy for EDs of 35 ms, suggesting that the exposure durations, and accompanying mask, used

here were of equal difficulty. That is, these results suggest equivalent degradation of stimuli.

3.7.2 Timing of Manipulability effects

Importantly, this research found no interaction between manipulability and ED in either RTs or errors. This lack of interaction was rather surprising considering manipulability effects are expected to occur early in visual processing, and thus degrading the stimulus input was predicted to disrupt manipulability effects. This lack of interaction was also inconsistent with similarity arguments that assume higher similarity within non-manipulable objects. For comparison, an exploratory analysis between nature (natural versus manmade) and ED was conducted with the current data. Importantly, the PACE model (Gerlach, (2009; see also Gerlach, et al., 2004; 2006) predicts that objects with many attributes and high similarity, such as natural objects, are more robust to visual degradation during categorization tasks; thus, this model would predict an interaction between object-origin and ED with a larger advantage for natural objects at brief exposure durations. An exploratory analysis supported this interaction, $F(1,39)= 5.72, p < .05$, with bigger effects of object-origin at brief EDs and a significant main effect of object-origin (faster RTs for natural objects)¹². That is, a post-hoc analysis of the current data was able to support PACE model predictions that natural objects are more robust to stimulus degradation (based partly on their high degree of visual similarity). Note, however, this was in stark contrast to object manipulability which failed to show this interaction. Therefore, the EDs used in the current design appeared to be sufficient to

¹² Specifically, the mean (subjects) there was a 26.7 ms advantage for natural objects over manmade objects at short exposure durations, but only a 12.3 ms advantage for natural objects over manmade objects at the longer exposure duration.

interact with the nature effect despite not appearing for manipulability, weakening the argument that visual similarity can explain away manipulability effects.

Importantly, the lack of an interaction between ED and object-manipulability might be the consequence of a number of things. First, it could suggest that there is no difference between manipulable and non-manipulable objects in terms of visual similarity (i.e. non-manipulable objects do not represent a more visually similar group). Second, it may suggest that action similarity is a more important dimension for manipulable and non-manipulable objects (Desmarais & Dixon, 2005; Desmarais, Dixon, et al., 2007; Desmarais, Pensa, Dixon, & Roy, 2007). Recall, in their study, Desmarais, Dixon, et al. (2007) assigned similar or dissimilar actions to novel objects with known levels of similarity and found that same novel objects were confused less if they were assigned dissimilar actions compared to similar actions. That is, assigning dissimilar actions to objects resulted in less confusion, suggesting that action similarity can increase semantic confusion and action dissimilarity can help alleviate it. Thus, with respect to manipulability effects, action similarity may be a more important mediator of effects than visual similarity of the objects. Specifically, non-manipulable objects, by definition, have few or no actions associated them while manipulable objects have at least the property of being graspable. Tools and artefacts, further, tend to have unique and specific actions associated with them, more-so than fruits and vegetables. In fact, in the current set of items, manmade manipulable objects were rated higher as having functional use than the natural manipulable objects (Salmon et al., 2010). However, it was not possible to fully balance object familiarity and AoA across the 2x2 cells of manmade/natural and manipulability. Thus, a full investigation of the effects of functional-use manipulability

will have to be pursued in future research. However, within manipulable objects, there was a trend in the data set for faster categorization of natural manipulable objects (low functional-use ratings) versus manmade manipulable objects (high functional-use ratings). Thus, we suggest that action similarity (as measured by low functional use ratings) may lead to faster categorization.

3.7.3 Experiment 1 – Summary

In summary, the major finding from the current experiment was a significant main effect of manipulability during object categorization in healthy normal participants. Specifically, participants were faster to categorize non-manipulable objects, a finding consistent with the results of Filliter, et al. (2005) with a familiarity-controlled set. The second key finding from this research was a lack of significant interaction between exposure duration (ED) and manipulability. This lack of interaction was inconsistent with visual similarity based predictions as a mediator of manipulability effects. Specifically, it suggested that assumptions about manipulability based on visual similarity may be inappropriate. Theories based around action similarity may have more relevance to this dimension in future research. To further explore ED and manipulability effects, the same stimuli and design was tested in a naming task.

3.8 EXPERIMENT 2 - NAMING

In a second experiment, we tested the same set of objects used in experiment 1 in a naming paradigm. There is evidence that object-categorization and categorization-like tasks require different processes than tasks requiring basic-level identification (e.g.

Kalénine & Bonthoux, 2008). Thus, one of the main goals of experiment 2 was to see if manipulability effects during naming would be consistent or reversed compared to categorization. We made the same predictions here as in experiment 1. First, we predicted a significant main effect of object manipulability. Second, an interaction between exposure duration and manipulability was expected. This interaction was not significant during categorization, and thus experiment 2 allowed the opportunity to test whether task was important for this interaction.

It is worth noting that the PACE model would predict that brief exposure durations and categorization would both provide a benefit for similar objects. On the other hand, naming provides a benefit for dissimilar objects. Thus, in the current design, Naming and ED effects might cause a cancelling of benefits based on similarity – leading to non-significant main effects of manipulability, if manipulability effects were based purely on visual similarity (Gerlach, 2009).

3.9 METHODS

3.9.1 Participants

Forty-eight new participants participated in this study. Five were excluded from analysis because they had participated in another experiment using the same stimuli. Two were excluded because they did not have English as a first-language, and one was excluded because they were exhausted at the time of testing and admitting to having a neurological disorder that might affect their results. The remaining forty participants (7 males; age range 18 to 35, $M = 20.1$, $SD = 2.9$), all had normal or corrected to normal vision, and English as a first language. All were right-handed.

3.9.2 Materials

The same set of 120 objects from experiment 1 was used in experiment 2. Pictures were shown at the same visual angles and at the same exposure durations (35 or 105ms). Again, the software DirectRT was used to present stimuli. A Logitech microphone was used to capture vocal response times from the participants. For each trial the experimenter would code (on the keyboard) whether or not vocal responses were correct or not. To decrease visual load for the experimenter, the experimenter wore Nexxtech headphones which would quietly tell them the current answer. The volume was adjusted so that the participant could not hear these correct answers.

3.9.3 Procedure

As in experiment 1, participants viewed each object at two exposure durations. Procedural details of experiment 2 were identical to experiment 1, with the exception of the participant's response. Participants were instructed to vocally name the object. Participants were told they could also respond with "didn't see" or "don't know" (these were marked as errors), but were encouraged to guess at the name of objects even when uncertain. The experimenter was present during the course of the experiment and coded errors by button press on keyboard. Three types of errors were recorded (1) "didn't see" or "don't know", (2) wrong word supplied, or (3) voice key error (microphone did not hear response, or triggered to a non-vocal event). Again, participants were given two practice sessions on a different set of objects. Vocal feedback/encouragement was given during the practice session but not during the regular blocks. Each participant completed two blocks, one in which List A items were presented at 35 ms (List B at 105 ms) and one in which List A items were presented at 105 ms (List B at 35 ms). Order of

presentation was counterbalanced across participants. The entire experiment was completed in approximately 60 minutes.

3.9.4 Data Analysis

As in experiment 1, the primary variables of interest were manipulability (manipulable versus non-manipulable) and exposure duration (ED or short versus long). Of particular interest was the interaction. Block (first or second) was also considered as a variable to explore any mitigating effect of practice or exposure to the items. As before, this led to a 2 (manipulability) x 2 (ED) x 2 (block) within-subjects factorial design. The main analysis was a repeated measures ANOVA on subjects' median reaction time (RT) for objects in each category. One participant was excluded from this analysis due to high error-rate in one condition, they were the only participant to fail to identify all the objects in one cell of the design (specifically they had 100% error in block 1, short exposure condition for natural-manmade objects, this resulted in an average error of 97% for all manipulable objects in block 1 shown for short exposure durations, i.e. they only got one manipulable object correct at a short ED in block 1¹³). The secondary analysis was a repeated measures ANOVA on subjects' errors on the same objects. Follow-up item-analyses were used to confirm that the pattern of results did not differ when averaged over items. Analyses considering block 1 (only) were also conducted, but the results of these analyses were either (a) identical to the full analysis, or (b) had fewer significant effects, indicating that block 1 only analyses in these cases were less powerful and yielded no new information of merit (see supplementary Appendix A2 for these analyses).

¹³ By comparison, all other participants had an error rate of 90% or less in all conditions.

3.10 RESULTS

3.10.1 Reaction Time (Subjects' Analysis)

A 2 (manipulability) x 2 (ED) x 2 (block) repeated measures ANOVA on subjects' average naming reaction time (for accurate trials only) again revealed significant main effects for all variables and the same block by ED interaction. Specifically, the main effect of block was significant, $F(1,38) = 38.17, p < .001$, with faster RTs in block 2 ($M = 790$ ms) compared to block 1 ($M = 861$). The main effect of ED was significant, $F(1,38) = 33.64, p < .001$, with faster RTs to name objects at long EDs ($M = 794$ ms) compared to short EDs ($M = 857$ ms). Critically, the main effect of manipulability was significant, $F(1, 38) = 10.22, p < .01$, with longer RTs to name non-manipulable objects, ($M = 842$ ms) compared to manipulable objects ($M = 809$). Notably, this was a reversal in the direction of the manipulability effect as compared to experiment #1.

However, the interaction between manipulability and ED was still not significant, $F(1, 38) = 1.08, p = .305$. The only significant interaction for RT was the block by ED interaction, $F(1, 38) = 24.03, p < .001$. This interaction, as in experiment 1, indicated a bigger ED effect in block 1 (mean difference of 112 ms in block 1 compared to a 12 ms difference in block 2). None of the other interactions were significant, p 's $> .246$. Thus, the pattern of effects in this experiment replicated those found in experiment 1 (categorization) in every way except that the *direction* of the significant effect of manipulability effect reversed with faster naming of manipulable objects (experiment 2) and faster categorization of non-manipulable objects (experiment 1).

3.10.2 Errors / Accuracy (Subjects' Analysis)

A 2 (manipulability) x 2 (ED) x 2 (block) repeated measures ANOVA on subjects' average error revealed significant main effects for all variables, and significant interactions, including a significant 3-way interaction between all three variables. Because this was a naming task, only the correct specific name for each object was considered correct, making baseline or 'chance' error-rate close to 100 % (versus 50% during categorization). The main effects in error were all in the same direction as the RT effects, with fewer errors and faster RTs in the same conditions. Specifically, the main effect of block was significant, $F(1, 38) = 105.50, p < .001$, with fewer errors in block 2 ($M = 29\%$ error) compared to block 1 ($M = 42\%$ error). The main effect of ED was significant, $F(1, 38) = 804.37, p < .001$, with fewer errors for longer EDs ($M = 14\%$ error) as compared to shorter EDs ($M = 56\%$ error). Importantly, the main effect of manipulability was significant, in the direction consistent with the RT effect for naming, $F(1, 38) = 182.10, p < .001$. That is, there were fewer errors for manipulable objects ($M = 31\%$ error) compared to for non-manipulable objects ($M = 40\%$ error). Thus, there was no evidence of any speed-accuracy trade-offs, as participants were more accurate for conditions in which they had faster RTs.

Interestingly, the 3-way interaction between manipulability, ED & block for error was significant, $F(1, 38) = 9.24, p < .01$. In looking at this pattern, the effects indicated a manipulability by ED interaction in block 2, but not in block 1. Specifically, the error difference between manipulable and non-manipulable objects was consistent across ED in block 1 (about a 7% advantage for manipulable objects, specifically for short durations $M = 72\%$ and $M = 65\%$, and for long durations $M = 18\%$ and $M = 11\%$ for non-

manipulable and non-manipulable objects, respectively) but in block 2, at short EDs this error difference for manipulable objects increased faster than errors for non-manipulable objects leading to 15% fewer errors for manipulable objects shown at brief EDs as compared to non-manipulable objects (specifically, for short durations $M = 51\%$ and $M = 37\%$, and for long duration $M = 17\%$ and $M = 11\%$ for non-manipulable and manipulable objects, respectively). This pattern resulted in an overall significant interaction between manipulability and ED, $F(1, 38) = 9.70, p < .01$ (with a bigger manipulability effect at long durations, specifically a 11% error difference at long exposure durations, and a 7% error difference at long exposure durations), and, a significant manipulability by block interaction, $F(1, 38) = 6.68, p < .05$, with bigger error differences in block 2 (with a bigger manipulability in block 2 than block 1, specifically a 10% error difference in block 2, compared to a 7% error difference in block 1). Please refer to Table 3.3 and Figure 3.4 for a summary and depiction of the effects of RT and errors.

Table 3.3. Subject Analysis repeated measures ANOVAs effects and interactions. Partial Eta-Squared (η^2). One participant was excluded from the RT analysis because of very high error rates at short EDs compared to other participants (less than 10% of objects in category correct, i.e. over 90% error in one of the cells of the design).

Reaction Time (RT)		Error / Accuracy (%)	
Effect Type	Significance Values	Effect Type	Significance Values
<u>(ME) block</u>	$F(1,38) = 38.2, p < .001, \eta^2 = .50$	<u>(ME) block</u>	$F(1,38) = 105.5, p < .001, \eta^2 = .74$
<u>(ME) ED</u>	$F(1,38) = 33.6, p < .001, \eta^2 = .47$	<u>(ME) ED</u>	$F(1,38) = 804.4, p < .001, \eta^2 = .96$
<u>(ME) Manip</u>	$F(1,38) = 10.2, p = .003, \eta^2 = .21$	<u>(ME) Manip</u>	$F(1,38) = 182.1, p < .001, \eta^2 = .83$
<u>(2-way) block x ED</u>	$F(1,38) = 24.0, p < .001, \eta^2 = .39$	<u>(2-way) block x ED</u>	$F(1,38) = 176.1, p < .001, \eta^2 = .82$
(2-way) Manip x ED	$F(1,38) = 1.1, p = .305, \eta^2 = .03$	<u>(2-way) Manip x ED</u>	$F(1,38) = 9.7, p = .003, \eta^2 = .20$
(2-way) block x Manip	$F(1,38) = 0.5, p = .479, \eta^2 = .01$	<u>(2-way) block x Manip</u>	$F(1,38) = 6.7, p = .014, \eta^2 = .15$
(3-way) block x Manip x ED	$F(1,38) = 1.4, p = .246, \eta^2 = .04$	<u>(3-way) block x Manip x ED</u>	$F(1,38) = 9.2, p = .004, \eta^2 = .20$

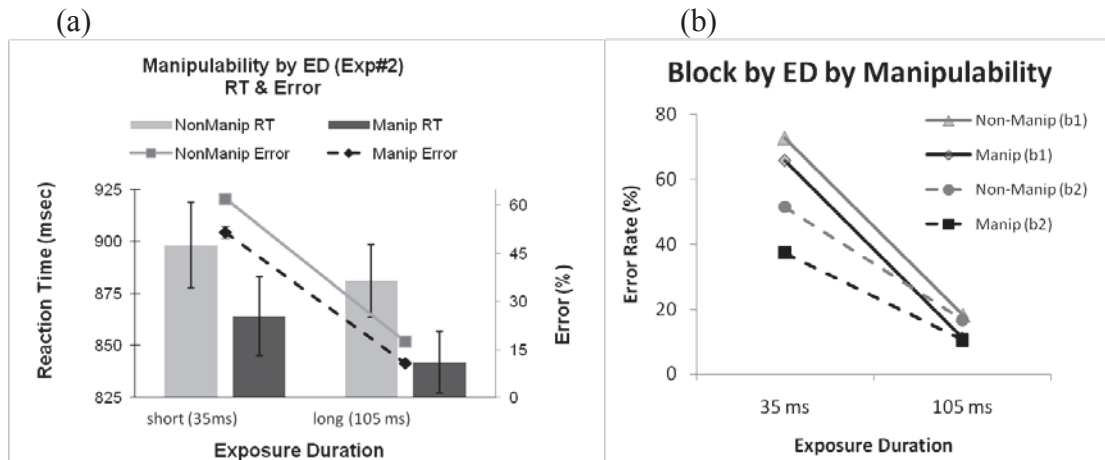


Figure 3.4 (A) Reaction time (RT) and error rates for Manipulability by Exposure Duration (ED). Bars show average reaction times (RT) in milliseconds for Naming of Manipulable (black) versus Non-Manipulable (grey) objects. Percent error is shown with the solid and dashed line. Error bars indicate the standard error. (B) Error rates (% error) for the Manipulability by ED by block 3-way interaction. Block 1 represented by solid lines, and block 2 represented by dashed lines. Note: Task was naming, so there was no “chance” level – the only correct reply was the correct name of the object, meaning chance guessing accuracy would be close to 0%. X-axis indicates exposure duration or ED (short-35ms, or long-105ms). Note, smaller bars indicate faster RTs, and lower lines indicate fewer errors.

3.10.3 Item Analyses

A follow-up 2 (manipulability) x 2 (ED) x 2 (block) mixed ANOVA was used in an item analysis. ED and block were treated as repeated measures and manipulability was treated as between-groups (items) factor. Unlike the subjects’ analysis, there was no significant main effect, in RTs, for manipulability, $F(1, 86) = 0.62, p = .432$, although the means were going in the same direction of faster for manipulable objects ($M = 862$ ms) compared to non-manipulable objects ($M = 896$ ms). Part of the problem was reduced power since 30 of the 120 objects (25%) were not identified correctly by any of the participants in the first block when shown at the brief exposure duration and had to be excluded from the Item analysis (even though they were identified correctly in

subsequent blocks). Of these items not correctly identified in the first block, 11 were manipulable (e.g. candle, celery, lettuce, pacifier) and the other 19 were non-manipulable (e.g. bee, closet, clouds, road, sheep).¹⁴ As in the subjects' analysis, there was a main effect of block, $F(1, 86) = 11.86, p < .01$, with faster RTs in block 2 ($M = 837$ ms) as compared to block 1 ($M = 920$ ms). There was a main effect of exposure duration, $F(1, 86) = 47.29, p < .001$, with faster RTs for long EDs ($M = 812$ ms) as compared to short EDs ($M = 946$ ms). In addition, the block by ED interaction was significant, $F(1, 86) = 9.24, p < .01$ (with bigger exposure duration effects in block 1, specifically a 202 ms exposure duration difference compared to 66 ms difference in block 2), but none of the other interactions were significant, with p 's $< .119$.

The same follow-up Item Analysis was done with errors. All the main effects were significant, but not all the interactions were. Importantly, the main effect of manipulability was, as before, significant, $F(1, 118) = 4.92, p < .05$, with fewer errors for manipulable objects ($M = 31\%$ error) compared to non-manipulable objects ($M = 39\%$ error). The main effect of ED was significant, $F(1, 118) = 278.83, p < .001$, with fewer errors for long EDs ($M = 14\%$ error) compared to short EDs ($M = 56\%$ error). The main effect of block was significant, $F(1, 118) = 193.39, p < .001$, with fewer errors in block 2 ($M = 28\%$ error) as compared to block 1 ($M = 42\%$ error). The block by ED interaction was still significant, $F(1, 118) = 157.14, p < .001$ (as always, with bigger exposure duration effects in block 1, a difference of 55 % errors compared to 30% error difference in block 2), and the 3-way interaction between manipulability, ED & block was trending towards significance, $F(1, 118) = 3.62, p < .060$, with the same pattern as before. Thus,

¹⁴ Of note, some items, like the moon and cake, were identified by 100% of participants when shown at the longer duration (105 ms) despite being not identified by any participants when shown at a shorter duration (35 ms).

the Item Analyses, overall, had reduced power to detect significance but the directions of the effects agreed with the Subjects' analyses.

3.11 DISCUSSION

In experiment 2 we investigated the effects of object manipulability on object naming. During naming, we found a significant advantage for manipulable objects with both RT and error measures (although RT only reached significance in the Subjects, and not the Item Analysis). This finding is consistent with the naming advantage observed by Wolk et al. (2005) and other patients with visual agnosia. However, the direction of this result was the opposite of that obtained during categorization in experiment 1, supporting the hypothesis that the effects of object manipulability on object processing depend on the task. That is, across experiments, manipulable objects were named more quickly but categorized more slowly than non-manipulable objects.

The reversal in the direction of the manipulability effect was consistent with predictions based on action and visual similarity, with faster categorization of similar/non-manipulable objects (experiment 1) and faster naming of dissimilar/manipulable objects (experiment 2) (Gerlach, 2009; Gerlach, et al., 2004, 2006; Kalénine & Bonthoux, 2008). This reversal supports the notion that the role of motor associations in object representation depends on task. This reversal occurred despite the fact that both experiments used the same stimulus set that carefully controlled for object familiarity and age of acquisition.

In experiment 2, the effects of ED on naming were less clear, as the interaction between manipulability and ED did not reach significance in RTs, but did in errors

(significant for the Subjects' analysis, but not for the Item analysis). In addition, a new 3-way interaction between ED, manipulability and block was observed that was not present during Categorization (experiment 1). The 3-way interaction between all the variables shed a little light on this with what appeared to be a significant 2-way interaction between these variables in block 2, but not in block 1 (see right panel of Figure 3.4). Again, the interaction indicated larger ED effects on non-manipulable objects, which was inconsistent with the notion that non-manipulable objects represented a set of objects with more within-category visually similarity. That is, if non-manipulable objects were more visually similar, they should have been more robust to degradation of the stimuli (had smaller not larger ED effects).

For categorization (Experiment 1), the biggest effects were in RTs, but for naming (Experiment 2) the biggest effects were in errors measures. Larger effects in errors during naming may have something to do with the fact that error levels were much higher in this experiment. Higher errors were likely caused by the increase in task difficulty; after all, the naming task took longer than the categorization task, a result consistent with previous research (e.g. Gerlach et al., 2002). Another reason why RTs effects were likely smaller for categorization were that response times were generally faster for all objects – narrowing the range of possible RTs.

In conclusion, results across the two experiments showed a reversal effect: faster naming for manipulable objects (Experiment 2) but slower categorization of the same objects (Experiment 1). Even though (1) the current research attempted to balance objects visual similarity across manipulability (by putting equal numbers of natural and manmade objects in each group), and (2) the current research showed no exposure

duration by manipulability interactions that would suggest high visual similarity for non-manipulable objects, there was still the concern that the confound of visual similarity was not completely ruled out. Specifically, it could be said, in regards to visual similarity, that the current results were conflicting. On one hand, the main effects in the two experiments (faster categorization of non-manipulable objects but slower naming) would suggest higher similarity for non-manipulable objects. On the other hand, the direction of the exposure duration by manipulability interaction in errors (which was significant for naming, and had a trend towards being significant for categorization) would suggest higher similarity for manipulable objects, since they had smaller exposure duration effects indicating they were more robust to visual degradation - a property usually attributed to items with high within category similarity. Thus, from our pattern of results it was not clear as to the extent to which these manipulability effects could be explained away by an underlying confound of visual similarity. Therefore, a follow-up analysis was conducted to see if there was evidence of increased visual similarity within our set of non-manipulable objects (that could be explaining this categorization by naming reversal). See below.

3.11.1 Ruling out the confound of Visual Similarity

In order to rule out the potential confound of visual similarity, a visual similarity analysis was done with *all* objects that had been used in the experiments. The method we chose to use was calculating the average pixel intensity difference (aPID) of each photograph compared to every other photograph. This method was mathematically equivalent to the Euclidean Overlap measure reported by Laws, Gale and colleagues (Laws & Gale, 2002a, 2002b; Laws, Gale, Frank, & Davey, 2002). Alternatively, we

could have used a more global measure of visual similarity such as the contour overlap method advocated by Humphreys and colleagues, which ignores overall details and textures of the stimuli, and just compares overall outline/contour of objects (Humphreys & Forde, 2001; Humphreys & Riddoch, 2002; Humphreys, Riddoch, & Quinlan, 1988). However, our object set used real photographs with more complex textures and surface detail than would be found in a set of line drawings, such as those by Snodgrass and Vanderwart (1980). Thus, we felt justified using a measure of visual similarity that including pixel-level comparisons, and had been shown in previous research to correlate with participant error rates (cf. Laws & Gale, 2002a). For more on the debate between contour versus pixel-based measures of similarity see, in particular, Humphreys and Riddoch (2002) and the response from Laws and Gale (2002b). Also, see Appendix 3.15 for an exploratory analysis into whether or not any measures of similarity could predict any of the variation in the reaction times observed in the current research at an item-by-item level.

If visual similarity was a confound that could explain the manipulability reversal effect we observed, then our analysis would indicate that non-manipulable objects would have higher within-group visual similarity than manipulable objects. However, across multiple visual similarity analyses our results did not show this effect. In fact, our analyses, if anything, showed the reverse: higher visual similarity for manipulable objects as compared to non-manipulable objects.

For example, when aPID for every object compared to every other object was calculated (with a low score indicating low average difference and therefore increased visual similarity), the average aPID value for within category comparisons of

manipulable objects was 12.28 as compared to 15.25 (std. error = 0.118) for non-manipulable objects, $F(1,3538) = 315.421, p < .001$. To control for white-space contamination, a second measure of visual similarity was conducted for which only non-white pixel intensity differences were calculated. We called this method relative average pixel intensity difference (raPID). Importantly, the results from the raPID analysis were consistent with the previous aPID result, $F(1,3538) = 42.010, p < .001$ (lower values for manipulable objects, indicating greater visual similarity of manipulable objects).

For comparison, the same analysis was done comparing “manmade” objects to “natural” objects. The results showed no difference in average pixel intensity difference between the set manmade and natural objects, $F(1,3538) = 2.747, p = .098$. Finally, a further restricted “tools”-only and “animals”-only analysis was calculated on a subset of the objects. Note: insects, fish and birds were considered “animals” for this analysis. This sub-analysis seemed relevant since much previous research has analyzed visual similarity on the basis of more semantically homogeneous sets of objects than the set used in the current research, (e.g. “tools” versus “animals”, in particular). Results from this sub-analysis indicated no significant difference between the within-category visual similarity of “animals” and “tools”, $F(1,484) = .010, p = .919$. This result was consistent with Laws, et al. (2002), who failed to find evidence that living things were more visually similar to each other than objects from the category of non-living things.

In summary, not only did our visual similarity analyses fail to provide support that our set of non-manipulable objects were more visually similar to each other, if anything, our results tended to suggest the opposite. Thus, these analyses indicate that our behavioural results, and in particular, the manipulability reversal effect was not driven by

differences in visual similarity. A final omnibus ANOVA was conducted across the two experiments to confirm that this task by manipulability reversal was significant (see below).

3.11.2 Comparing across the Two Experiments: A Task by Manipulability Interaction

One of the most interesting results across these two experiments was that with the same stimuli, and virtually identical tasks, participants were identifying one set of objects quickly during one task, but slowly during the other. The two tasks: categorization and naming were completed in different experiments, with different participants, but all other properties (i.e. stimuli, timing, and even lab-space and computer) were identical. Thus, a follow-up omnibus ANOVA across both experiments was done (with *task* as a between subjects variable) to determine if this was indeed a significant reversal.

Specifically, the analysis was a 2 (task) by 2 (block) by 2 (ED) by 2 (manipulability) analysis of variance on Subjects' mean RT. The critical two-way *task* by *manipulability* interaction was significant, $F(1,77) = 18.52, p < .001$, indicating a significant manipulability reversal effect according to task (see Figure 3.5). The other results echoed those observed in the experiments, with a main effect of block, $F(1,77) = 80.10, p < .001$, a main effect of exposure duration, $F(1,77) = 57.96, p < .001$, and a main effect of task, $F(1,77) = 98.87, p < .001$, with faster identification times for the categorization task (experiment #1). The main effect of manipulability was not significant, $F(1,77) = 2.91, p = .092$, but this made sense since the means from the two experiments were going in different directions, as explained by the task by manipulability interaction.

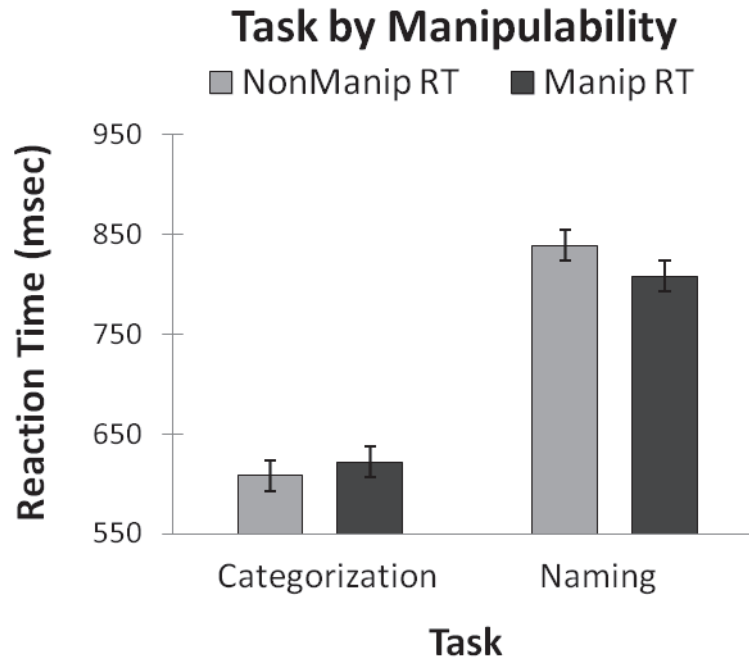


Figure 3.5. Reaction time (RT) for the Task (across experiments) by Manipulability interaction. Note that the same manipulable objects (dark grey) are named more quickly despite being categorized more slowly compared to non-manipulable objects (light grey). Error bars indicate the standard error.

The only other significant interactions from the omnibus ANOVA was a block by ED interaction, $F(1,77) = 2.91, p=.092$, with larger exposure duration effects in the first block, and one 3-way task by block by ED interaction, $F(1,77) = 2.91, p=.092$, which was related to a larger block by ED interaction for the naming task, by the pattern of results between naming and categorization was otherwise the same.

In summary, the most significant contribution from this analysis was verifying that the manipulability reaction time reversal based on task was significant. That is, this analysis demonstrated a significant task (naming or categorization) by manipulability (manipulable or non-manipulable) cross-over interaction, with faster *naming* of manipulable objects and faster *categorization* of non-manipulable objects. This cross-

over interaction or manipulability effect “reversal” is what *visual similarity* arguments would predict IF non-manipulable objects were more visually-similar than manipulable objects. However, as explained in our visual similarity analysis, there was no support for the hypothesis that our non-manipulable objects represented a more visually similar set, and thus something other than visual similarity must have been causing this reversal.

3.12 GENERAL DISCUSSION

This research sought to investigate the role of object manipulability in object categorization and identification. Across two different experiments we show that effects of object-manipulability depend on task. Specifically, manipulable objects were named more quickly than non-manipulable objects but categorized more slowly. Importantly, these effects were found even after carefully controlling the object sets on object familiarity, age-of-acquisition, and the numbers of manmade and natural objects in each set. Effects were bigger for reaction time during object categorization, and bigger for errors with naming. The effects of exposure duration (ED) were also explored in an attempt to investigate the timing of manipulability effects. The only exposure duration (ED) and manipulability interaction that was significant was in the naming task for errors / accuracy in the analysis across subjects (although, there was a trend, $p = 0.54$, that was almost significant, for the same analysis in the categorization experiment). Analysis of the means, however, suggested larger exposure duration effects for non-manipulable objects compared to manipulable ones. Standard argument based on *visual* similarity would predict that sets of similar objects would be more robust to visual degradation. Therefore, the direction of this interaction would suggest that manipulable objects were

drawn from a more visually similar set than non-manipulable objects. On the other hand, the task by manipulability interaction suggested the opposite – higher similarity for non-manipulable objects. Thus, from these results, it was unclear that visual similarity was saying anything meaningful about these findings. Ergo, if visual similarity cannot convincingly explain these effects, then other explanations must be considered. The next logical thing to consider is the action system itself. Something about our sensory-motor experiences with objects appears to organize the brain such that objects with associated actions (i.e. manipulable objects) can be identified more quickly when done so at a specific level (i.e. naming) but do not receive the same benefit for more abstract identification tasks (i.e. categorization). This difference is consistent with recent ‘embodied’ theories of object representation that posit different distributed representations for manipulable and non-manipulable objects.

3.12.1 Significant Effects of Manipulability

One criticism of previous research reporting manipulability effects has been that objects were not carefully controlled on a number of important confounding variables including object familiarity, the age of acquisition of the object concept, and whether the objects are living or non-living. In the present study, two major predictor variables were controlled using recently collected ratings on each object (Salmon et al., 2010). In addition, we used a stimulus set that contained equal numbers of natural and manmade objects across manipulable and non-manipulable objects. While controlling for these potential confounds, we found significant effects of manipulability in two experiments using two different tasks (naming and categorization). Thus, these results replicate findings of manipulability effects in previous research, including those of Filliter et al.

(2005), Kalénine and Bonthoux (2008) and Wolk et al. (2005). Importantly, it is known that for real-world objects there are many other variables that can influence object processing such as color (Ostergaard & Davidoff, 1985; Wurm, Legge, Isenberg, & Luebker, 1993), image quality (Sanocki, Bowyer, Heath, & Sarkar, 1998), size (Uttl, Graf, & Siegenthaler, 2007), and orientation of the object (Hamm & McMullen, 1998). It is difficult to control for all of these potential confounds in a single study.

Furthermore, the current study took a very simplistic view of action by lumping all ‘graspable’ objects into a single category, implying a singular role of “action” during identification. However, there has been a fair amount of recent research suggesting that there are at least two, and probably more neuro-anatomically distinct areas for processing different types of actions (e.g. Boronat, et al., 2005; Buxbaum & Kalenine, 2010; Buxbaum, et al., 2006; Buxbaum & Saffran, 2002; Buxbaum, et al., 2000; McNair & Harris, 2012; Spunt, et al., 2010). For example, one such distinction is the difference between volumetric versus functional use gestures (cf. Bub, et al., 2008; Lee, Middleton, Mirman, Kalénine, & Buxbaum, 2013). The ratings collected in our lab (Salmon et al., 2010) do allow the opportunity to differentiate on these two dimensions, because they contain ratings both on the extent to which an object can be “grasp[ed] and use[d]” “with one hand” (a volumetric measure) as well as the extent to which hand movements made when using the objects “differ from hand movements” made “to pick it up” (a functional use measure, p.85). However, the current research was designed with only the focus on one dimension of manipulability, and how they differ from non-manipulable objects¹⁵.

¹⁵ In fact, it could be said that the effects of two types of manipulability collected by Salmon et al. (2010) were confounded in the current research since only “manipulable” objects had valid functional use measures. That is, the observed reversal pattern in the current research could have been driven by either

Furthermore, the stimuli were chosen carefully to suit the planned ANOVA analyses, with balanced set of objects, and it was outside the scope to explore the nuances of effects within the manipulability dimension. However, detailed exploration of these differences is planned in future research, now that we have shown that basic manipulability effects can be found in healthy subjects with a balanced stimulus set.

Importantly, our finding of significant manipulability effects supports the notion that experience manipulating objects results in behaviorally distinguishable representations of manipulable versus non-manipulable objects. In this research, although we did not directly test the role of motor-representations in response to the presentation of our objects, we argue that our naming and categorization differences suggest that we have more extensive sensory-motor associations with our manipulable objects, and that these associations play a role in the visual processing of manipulable and non-manipulable objects. However, our results do not allow us to address the relative contributions of the ventral and dorsal visual streams to this effect. Thus, future research should consider employing the use of computational models as a method of validating these theoretical effects. Computational models have the advantage of overcoming real-life confounds by using abstract representations that the modeler maintains control over. Further, the modeler maintains the ability to impose limitations on the amount of variability within the model.

dimensions of manipulability, since they varied together (i.e. only functional use ratings for objects with high graspability / manipulability ratings).

3.12.2 Reversing Effect of Manipulability based on Task

The reversal observed in the current research (faster naming of manipulable objects, but slower categorization) is consistent with the reversal shown by Kaléine and Bonthoux (2008). Kaléine and Bonthoux (2008) found faster thematic matching of manipulable objects but slower functional matching of the same objects relative to non-manipulable objects. One could draw a parallel between Kaléine and Bonthoux's (2008) and our findings suggesting that their basic-level taxonomic task was similar to our categorization task in that it only relied more on the shared or diagnostic aspects of the object. Similarly, their thematic task could be argued to be similar to our naming task since it relied heavily on object-specific information about the function of the object. These findings taken together suggest that we are faster to process manipulable objects during tasks that require specific information about the objects but slower during tasks that require broader more category-based decisions.

The findings of a naming-categorization reversal would be consistent with theories comparing categories with high inter-item visual similarity compared to low visual similarity, *if* non-manipulable objects were more visually similar (see, for example, the pre-semantic account of category effects or PACE model, Gerlach, 2009; Gerlach, et al., 2004, 2006). However, we have multiple reasons to rule out this possible role of *visual* similarity. First, our direct measurement of visual similarity did not support the notion the non-manipulable objects were more visually similar. Second, object manipulability did not interact with exposure duration in a way that would suggest a higher visual similarity for non-manipulable objects. Finally, our sets of manipulable and non-manipulable objects contained equal numbers of natural and manmade objects, a

conscious choice in our design that we hoped would minimize any visual similarity differences between these two categories of objects.

However, if visual similarity differences could not explain this reversal, then what other factors could lead to manipulable objects being named more quickly, but categorized more slowly? One possibility is that these effects were driven by other types of similarity – such as action or even semantic similarity. As theories about similarity expound, objects with a high degree of similarity (whether visual or otherwise), crowd together in representational space. On the other hand, sets of objects that contain less inter-item overlap would have a more sparse (i.e. less crowded) representation. These same lines of arguments would suggest that crowded domains are categorized more quickly (because all items share common features) but named more slowly because all the items are so similar it takes long to pull out the correct specific identity. Along the same lines, objects occupying sparse domains can be specifically identified (named) faster due to less competition, but are categorized more slowly since they share fewer features.

Typically, arguments about ‘sparse versus crowded’ domains are used to explain how living things (crowded domain) are categorized more quickly than manmade things, despite being named more slowly. However, in the current research the number of living versus non-living things was controlled in each set. Thus, extending the reasoning of the similarity accounts, the current results indicate that manipulable objects may be represented more sparsely than non-manipulable objects. This makes sense in light of the research supporting activation of pre-motor areas in the dorsal pathway for manipulable objects but not for non-manipulable objects (e.g. Chao & Martin, 2000; Grèzes, et al.,

2003). Specifically, if manipulable objects are represented in both visual and action-specific areas of the brain, but non-manipulable objects only in visual areas, then, by definition, manipulable objects have a more sparse representation compared to non-manipulable objects.

In addition, there may also be something special about action-activation of manipulable objects that helps them during specific identification of an item (naming), but fails to help during a task like categorization (see Yoon, et al., 2002 for an example of computational support of a dedicated action processor for manipulable objects).

However, our results do not allow us to address this specifically. Therefore, whether these reversals effects are driven by specific action-related activity in dorsal stream for manipulable objects, or the representation of these objects (crowded versus sparse representation), will need to be explored in future research.

3.12.3 In Summary

The current research answered a number of existing questions about the effects of object manipulability during identification. First, do manipulability effects still appear when object familiarity and age of acquisition are controlled for? Yes, they do. Second, does high manipulability speed up object identification? Yes, but it depends on the task: in the case of naming it does, but in the cases of categorization it slows down identification. Third, do manipulability effects interact with exposure duration? It appears that they do not, at least not with reaction times, and the exposure durations used in the current research. Finally, are “manipulability effects” in research completely confounded by effects of visual similarity? Our results would certainly suggest not. Thus, the results

in the current research must have been driven by something related to the action system – such as action similarity or manipulability, generally.

3.13 REFERENCES

- Allport, D. A. (1985). Distributed memory, modular subsystems and dysphasia. In S. K. Newman & R. Epstein (Eds.), *Current Perspectives in Dysphasia* (pp. 32-60). Edinburgh: Churchill Livingstone.
- Bacon-Macé, N., Kirchner, H., Fabre-Thorpe, M., & Thorpe, S. J. (2007). Effects of task requirements on rapid natural scene processing: From common sensory encoding to distinct decisional mechanisms. *Journal of Experimental Psychology: Human Perception and Performance*, 33(5), 1013-1026.
- Bacon-Macé, N., Macé, M. J. M., Fabre-Thorpe, M., & Thorpe, S. J. (2005). The time course of visual processing: Backward masking and natural scene categorisation. *Vision Research*, 45(11), 1459-1469.
- Barsalou, L. W. (2008). Grounded cognition. *Annual Review of Psychology*, 59, 617-645.
- Bonin, P., Peereman, R., Malardier, N., Méot, A., & Chalard, M. (2003). A new set of 299 pictures for psycholinguistic studies: French norms for name agreement, image agreement, conceptual familiarity, visual complexity, image variability, age of acquisition, and naming latencies. *Behavior Research Methods, Instruments & Computers*, 35(1), 158-167.
- Boronat, C. B., Buxbaum, L. J., Coslett, H. B., Tang, K., Saffran, E. M., Kimberg, D. Y., et al. (2005). Distinctions between manipulation and function knowledge of objects: Evidence from functional magnetic resonance imaging. *Cognitive Brain Research*, 23(2-3), 361-373.

- Bub, D. N., Masson, M. E. J., & Bukach, C. M. (2003). Gesturing and naming: The use of functional knowledge in object identification. *Psychological Science, 14*(5), 467-472.
- Bub, D. N., Masson, M. E. J., & Cree, G. S. (2008). Evocation of functional and volumetric gestural knowledge by objects and words. *Cognition, 106*(1), 27-58.
- Buxbaum, L. J., & Kalenine, S. (2010). Action knowledge, visuomotor activation, and embodiment, in the two action systems. *Annals of the New York Academy of Sciences, 1191*, 201-218.
- Buxbaum, L. J., Kyle, K. M., Tang, K., & Detre, J. A. (2006). Neural substrates of knowledge of hand postures for object grasping and functional object use: Evidence from fMRI. *Brain Research, 1117*, 175-185.
- Buxbaum, L. J., & Saffran, E. M. (2002). Knowledge of object manipulation and object function: Dissociations in apraxic and nonapraxic subjects. *Brain and Language, 82*(2), 179-199.
- Buxbaum, L. J., Veramonti, T., & Schwartz, M. F. (2000). Function and manipulation tool knowledge in apraxia: Knowing 'what for' but not 'how.'. *Neurocase, 6*(2), 83-97.
- Catling, J. C., Dent, K., & Williamson, S. (2008). Age of acquisition, not word frequency affects object recognition: Evidence from the effects of visual degradation. *Acta Psychologica, 129*(1), 130-137.
- Chao, L. L., Haxby, J. V., & Martin, A. (1999). Attribute-based neural substrates in temporal cortex for perceiving and knowing about objects. *Nature Neuroscience, 2*(10), 913-919.

- Chao, L. L., & Martin, A. (2000). Representation of manipulable manmade objects in the dorsal stream. *NeuroImage*, *12*, 478-484.
- Chouinard, P. A., & Goodale, M. A. (2010). Category-specific neural processing for naming pictures of animals and naming pictures of tools: An ALE meta-analysis. *Neuropsychologia*, *48*(2), 409-418.
- Coppens, P., & Frisinger, D. (2005). Category-specific naming effect in non-brain-damaged individuals. *Brain and Language*, *94*(1), 61-71.
- Cuetos, F., & Alija, M. (2003). Normative data and naming times for action pictures. *Behavior Research Methods, Instruments & Computers*, *35*(1), 168-177.
- Dent, K., Catling, J. C., & Johnston, R. A. (2007). Age of acquisition affects object recognition: Evidence from visual duration thresholds. *Acta Psychologica*, *125*(3), 301-318.
- Dent, K., Johnston, R. A., & Humphreys, G. W. (2008). Age of acquisition and word frequency effects in picture naming: A dual-task investigation. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *34*(2), 282-301.
- Desmarais, G., & Dixon, M. J. (2005). Understanding the structural determinants of object confusion in memory: An assessment of psychophysical approaches to estimating visual similarity. *Perception & Psychophysics*, *67*(6), 980-996.
- Desmarais, G., Dixon, M. J., & Roy, E. A. (2007). A role for action knowledge in visual object identification. *Memory & Cognition*, *35*(7), 1712-1723.
- Desmarais, G., Pensa, M. C., Dixon, M. J., & Roy, E. A. (2007). The importance of object similarity in the production and identification of actions associated with

- objects. *Journal of the International Neuropsychological Society*, 13(6), 1021-1034.
- Fabre-Thorpe, M., Delorme, A., Marlot, C., & Thorpe, S. (2001). A limit to the speed of processing in ultra-rapid visual categorization of novel natural scenes. *Journal of Cognitive Neuroscience*, 13(2), 171-180.
- Fang, F., & He, S. (2005). Cortical responses to invisible objects in the human dorsal and ventral pathways. *Nature Neuroscience*, 8(10), 1380-1385.
- Filliter, J. H., McMullen, P. A., & Westwood, D. (2005). Manipulability and living/non-living category effects on object recognition. *Brain and Cognition*, 57, 61-65.
- Gaffan, D., & Heywood, C. A. (1993). A spurious category-specific visual agnosia for living things in normal human and nonhuman primates. *Journal of Cognitive Neuroscience*, 5(1), 118-128.
- Gale, T. M., Laws, K. R., & Foley, K. (2006). Crowded and sparse domains in object recognition: Consequences for categorization and naming. *Brain and Cognition*, 60(2), 139-145.
- Gerlach, C. (2001). Structural similarity causes different category-effects depending on task characteristics. *Neuropsychologia*, 39(9), 895-900.
- Gerlach, C. (2009). Category-specificity in visual object recognition. *Cognition*, 111(3), 281-301.
- Gerlach, C., Law, I., Gade, A., & Paulson, O. B. (1999). Perceptual differentiation and category effects in normal object recognition: A PET study. *Brain: A Journal of Neurology*, 122(11), 2159-2170.

- Gerlach, C., Law, I., Gade, A., & Paulson, O. B. (2002). The role of action knowledge in the comprehension of artefacts - A PET study. *NeuroImage*, *15*, 143-152.
- Gerlach, C., Law, I., & Paulson, O. B. (2004). Structural similarity and category-specificity: A refined account. *Neuropsychologia*, *42*(11), 1543-1553.
- Gerlach, C., Law, I., & Paulson, O. B. (2006). Shape configuration and category-specificity. *Neuropsychologia*, *44*(7), 1247-1260.
- Gibson, J. J. (1979). *The ecological approach to visual perception*. Boston: Houghton-Mifflin.
- Goodale, M. A. (2008). Action without perception in human vision. *Brain and Cognition*, *60*(2), 139-145.
- Goodale, M. A., & Ganel, T. (2009). Two visual systems: Separate pathways for perception and action in the human cerebral cortex. In M. R. M. Jenkin & L. R. Harris (Eds.), *Cortical mechanisms of vision*. (pp. 375-397). New York, NY US: Cambridge University Press.
- Goodale, M. A., & Milner, A. D. (1992). Separate visual pathways for perception and action. *Trends in Neurosciences*, *15*(1), 20-25.
- Goodale, M. A., & Milner, A. D. (1994). Separate visual pathways for perception and action. In H. Gutfreund & G. Toulouse (Eds.), *Biology and computation: A physicist's choice*. (pp. 606-611). River Edge, NJ US: World Scientific Publishing Co.
- Goodale, M. A., Milner, A. D., Jakobson, L. S., & Carey, D. P. (1991). A neurological dissociation between perceiving objects and grasping them. *Nature*, *349*(6305), 154-156.

- Grèzes, J., Tucker, M., Armony, J., Ellis, R., & Passingham, R. E. (2003). Objects automatically potentiate action: An fMRI study of implicit processing. *European Journal of Neuroscience*, *17*(12), 2735-2740.
- Hamm, J. P., & McMullen, P. A. (1998). Effects of orientation on the identification of rotated objects depend on the level of identity. *Journal of Experimental Psychology: Human Perception and Performance*, *24*(2), 413-426.
- Humphreys, G. W., & Forde, E. M. E. (2001). Hierarchies, similarity, and interactivity in object recognition: 'Category-specific' neuropsychological deficits. *Behavioral and Brain Sciences*, *24*(3), 453-509.
- Humphreys, G. W., & Riddoch, M. J. (2001). Detection by action: neuropsychological evidence for action-defined templates in search. *Nature Neuroscience*, *4*, 84-88.
- Humphreys, G. W., & Riddoch, M. J. (2002). Do pixel-level analyses describe psychological perceptual similarity? A comment on 'Category-specific naming and the 'visual' characteristics of line drawn stimuli' by Laws and Gale. *Cortex: A Journal Devoted to the Study of the Nervous System and Behavior*, *38*(1), 1-3.
- Humphreys, G. W., Riddoch, M. J., & Quinlan, P. T. (1988). Cascade processes in picture identification. *Cognitive Neuropsychology*, *5*(1), 67-104.
- Jarvis, B. G. (2008). DirectRT (Version 2008.1.0.11) [Computer Software]. New York, NY: Empirisoft Corporation.
- Johnson-Frey, S. H. (2004). The neural bases of complex tool use in humans. *Trends in Cognitive Sciences*, *8*(2), 71-78.
- Kalénine, S., & Bonthoux, F. (2008). Object manipulability affects children's and adult's conceptual processing. *Psychonomic Bulletin & Review*, *15*(3), 667-672.

- Kirchner, H., Barbeau, E. J., Thorpe, S. J., Régis, J., & Liegeois-Chauvel, C. (2009). Ultra-rapid sensory responses in the human frontal eye field region. *The Journal of Neuroscience*, 29(23), 7599-7606.
- Kirchner, H., & Thorpe, S. J. (2006). Ultra-rapid object detection with saccadic eye movements: Visual processing speed revisited. *Vision Research*, 46(11), 1762-1776.
- Kraut, M. A., Moo, L. R., Segal, J. B., & Hart, J., Jr. (2002). Neural activation during an explicit categorization task: Category- or feature-specific effects? *Cognitive Brain Research*, 13(2), 213-220.
- Lakoff, G., & Johnson, M. (1999). *Philosophy in the flesh: The embodied mind and its challenge to Western philosophy*. New York: Basic Books.
- Laws, K. R., & Gale, T. M. (2002a). Category-specific naming and the 'visual' characteristics of line drawn stimuli. *Cortex: A Journal Devoted to the Study of the Nervous System and Behavior*, 38(1), 7-21.
- Laws, K. R., & Gale, T. M. (2002b). Why are our similarities so different? A reply to Humphreys and Riddoch. *Cortex: A Journal Devoted to the Study of the Nervous System and Behavior*, 38(4), 643-650.
- Laws, K. R., Gale, T. M., Frank, R., & Davey, N. (2002). Visual similarity is greater for line drawings of nonliving than living things: The importance of musical instruments and body parts. *Brain and Cognition*, 48(2-3), 421-424.
- Laws, K. R., & Neve, C. (1999). A 'normal' category-specific advantage for naming living things. *Neuropsychologia*, 37(11), 1263-1269.

- Lee, C.-I., Middleton, E., Mirman, D., Kalénine, S., & Buxbaum, L. J. (2013). Incidental and context-responsive activation of structure- and function-based action features during object identification. *Journal of Experimental Psychology: Human Perception and Performance*, *39*(1), 257-270.
- Lewis, J. W. (2006). Cortical networks related to human use of tools. *Neuroscientist*, *12*(3), 211-231.
- Magnié, M. N., Besson, M., Poncet, M., & Dolisi, C. (2003). The Snodgrass and Vanderwart set revisited: Norms for object manipulability and for pictorial ambiguity of objects, chimeric objects, and nonobjects. *Journal of Clinical and Experimental Neuropsychology*, *25*(4), 521-560.
- Matheson, H. E., & McMullen, P. A. (2010). Neuropsychological dissociations between motion and form perception suggest functional organization in extrastriate cortical regions in the human brain. *Brain and Cognition*, *74*(2), 160-168.
- McNair, N. A., & Harris, I. M. (2012). Disentangling the contributions of grasp and action representations in the recognition of manipulable objects. *Experimental Brain Research*, *220*(1), 71-77.
- Ostergaard, A. L., & Davidoff, J. B. (1985). Some effects of color on naming and recognition of objects. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *11*(3), 579-587.
- Pérez, M. A. (2007). Age of acquisition persists as the main factor in picture naming when cumulative word frequency and frequency trajectory are controlled. *The Quarterly Journal of Experimental Psychology*, *60*(1), 32-42.

- Price, C. J., & Humphreys, G. W. (1989). The effects of surface detail on object categorization and naming. *The Quarterly Journal of Experimental Psychology A: Human Experimental Psychology*, *41*(4), 797-827.
- Riddoch, M. J., & Humphreys, G. W. (2004). Object identification in simultanagnosia: When wholes are not the sum of their parts. *Cognitive Neuropsychology*, *21*(2-4), 423-441.
- Salmon, J. P., McMullen, P. A., & Filliter, J. H. (2010). Norms for two types of manipulability (graspability and functional usage), familiarity, and age of acquisition for 320 photographs of objects. *Behavior Research Methods*, *42*(1), 82-95.
- Sanocki, T., Bowyer, K. W., Heath, M. D., & Sarkar, S. (1998). Are edges sufficient for object recognition? *Journal of Experimental Psychology: Human Perception and Performance*, *24*(1), 340-349.
- Snodgrass, J. G., & Vanderwart, M. (1980). A standardized set of 260 pictures: Norms for name agreement, image agreement, familiarity, and visual complexity. *Journal of Experimental Psychology: Human Learning and Memory*, *6*(2), 174-215.
- Spitzer, M., Kwong, K. K., Kennedy, W., & Rosen, B. R. (1995). Category-specific brain activation in fMRI during picture naming. *Neuroreport: An International Journal for the Rapid Communication of Research in Neuroscience*, *6*(16), 2109-2112.
- Spunt, R. P., Falk, E. B., & Lieberman, M. D. (2010). Dissociable neural systems support retrieval of how and why action knowledge. *Psychological Science*, *21*(11), 1593-1598.

- Thorpe, S. J. (2009). The speed of categorization in the human visual system. *Neuron (Previews)*, 62, 168-170.
- Tucker, M., & Ellis, R. (2004). Action priming by briefly presented objects. *Acta Psychologica*, 116(2), 185-203.
- Turnbull, O. H., & Laws, K. R. (2000). Loss of stored knowledge of object structure: Implications for 'category-specific' deficits. *Cognitive Neuropsychology*, 17(4), 365-389.
- Uttl, B., Graf, P., & Siegenthaler, A. L. (2007). Influence of object size on baseline identification, priming, and explicit memory. *Scandinavian Journal of Psychology*, 48, 281-288.
- VanRullen, R., & Thorpe, S. J. (2001). Is it a bird? Is it a plane? Ultra-rapid visual categorisation of natural and artifactual objects. *Perception*, 30(6), 655-668.
- Warrington, E. K., & McCarthy, R. (1983). Category specific access dysphasia. *Brain*, 106(4), 859-878.
- Warrington, E. K., & McCarthy, R. (1987). Categories of knowledge: Further fractionations and an attempted integration. *Brain*, 110(5), 1273-1296.
- Warrington, E. K., & Shallice, T. (1984). Category specific semantic impairments. *Brain*, 107, 829-854.
- Wilson, M. (2002). Six views of embodied cognition. *Psychonomic Bulletin & Review*, 9(4), 625-636.
- Wolk, D. A., Coslett, H. B., & Glosser, G. (2005). The role of sensory-motor information in object recognition: Evidence from the category-specific visual agnosia. *Brain and Language*, 94, 131-146.

- Wurm, L. H., Legge, G. E., Isenberg, L. M., & Luebker, A. (1993). Color improves object recognition in normal and low vision. *Journal of Experimental Psychology: Human Perception and Performance*, 19(4), 899-911.
- Yoon, E. Y., Heinke, D., & Humphreys, G. W. (2002). Modelling direct perceptual constraints on action selection: The Naming and Action Model (NAM). *Visual Cognition*, 9(4-5), 615-661.

**3.14 SUPPLEMENTARY APPENDIX A1. LIST OF OBJECTS USED
(AND CORRESPONDING RATINGS)**

	Manipulable (Manmade)	AoA	Fam	Manip
1	baby bib	2.00	1.39	4.63
2	baby bottle	1.33	1.67	4.79
3	balloon	1.83	2.33	4.63
4	bow	2.35	2.28	4.74
5	brush	2.17	3.89	4.95
6	cake*	1.83	3.17	4.26
7	candle	3.00	3.17	4.58
8	candy canes*	2.22	2.06	4.68
9	chair	1.78	4.83	3.16
10	fork*	1.94	4.83	4.89
11	garbage can*	2.44	4.06	3.58
12	glasses	2.11	4.11	4.89
13	ironing board*	3.17	2.83	3.47
14	knife	2.56	4.44	5.00
15	lamp*	2.22	4.56	3.74
16	lock*	3.67	2.67	4.84
17	mitten*	1.89	3.72	4.95
18	mixer	3.39	2.83	3.11
19	pacifier*	2.11	1.39	4.95
20	paintbrush*	2.50	2.17	4.89
21	pen*	2.56	4.89	5.00
22	present	2.33	2.39	4.21
23	ruler	3.00	3.61	4.84
24	salt shaker*	2.33	4.11	4.89
25	scissors*	2.28	3.56	5.00
26	sippy cup*	1.44	1.39	4.89
27	sled	2.39	1.78	3.26
28	stool*	2.72	3.72	3.39
29	toaster	2.83	4.39	3.79
30	wheels	2.72	2.44	3.32

* Part of list A.

	Manipulable (Natural)	AoA	Fam	Manip
1	ant*	2.06	2.33	3.68
2	banana	1.67	4.28	5.00
3	carrot	2.28	3.94	4.89
4	cat*	2.00	3.61	3.16
5	celery	2.72	3.61	4.58
6	cherry	2.67	2.61	4.74
7	egg*	1.83	4.00	4.84
8	fish*	2.11	2.33	3.58
9	flower	2.06	3.28	4.68
10	frog*	2.17	1.72	3.11
11	grapes	2.00	3.67	4.89
12	leaf	2.44	3.78	4.53
13	lemon*	2.76	3.61	4.89
14	lettuce	2.78	4.28	4.68
15	lobster	2.89	2.61	3.56
16	mouse	2.22	1.72	3.42
17	mushroom*	2.72	3.56	4.84
18	onion	2.11	4.28	4.89
19	orange	1.78	4.39	4.88
20	peach*	2.24	4.00	5.00
21	pear	2.39	2.94	4.89
22	pineapple*	2.61	3.00	4.42
23	potato*	2.56	3.94	4.89
24	rabbit*	1.78	2.22	3.11
25	raspberry*	2.83	2.50	4.84
26	shell	2.61	2.22	4.42
27	snail	2.56	1.67	3.63
28	spider*	3.00	1.56	3.26
29	strawberry*	2.00	3.56	5.00
30	tomato*	2.44	4.17	4.89

* Part of list A.

	Non-Manipulable (Manmade)	AoA	Fam	Manip
1	airplane	2.28	2.83	1.05
2	barn	2.33	2.61	1.00
3	bathtub	1.89	4.44	1.26
4	bell*	3.44	2.72	1.11
5	bicycle	2.00	3.28	2.83
6	car*	1.83	4.56	1.16
7	chalkboard	2.78	4.11	1.84
8	church	2.39	2.94	1.00
9	closet*	2.53	4.67	1.32
10	computer*	3.28	4.83	2.53
11	couch*	2.39	4.33	1.37
12	desk*	2.78	4.44	1.63
13	dresser	2.56	4.72	1.53
14	dryer*	2.83	4.22	1.37
15	fire hydrant	3.06	3.33	1.11
16	helicopter*	3.11	1.89	1.32
17	house	2.00	4.56	1.00
18	pool table*	3.50	3.33	1.47
19	refrigerator	2.28	4.72	1.32
20	road	2.28	4.56	1.11
21	roof*	2.33	4.39	1.11
22	sailboat*	2.39	2.28	1.26
23	sink	2.11	4.89	1.32
24	stairs	1.78	4.44	1.16
25	stove	2.00	4.44	1.42
26	table*	2.00	4.67	2.21
27	television*	2.22	4.06	1.89
28	toilet*	1.61	5.00	1.32
29	truck*	1.94	3.72	1.00
30	washing machine	3.22	3.83	1.37

* Part of list A.

	Non-Manipulable (Natural)	AoA	Fam	Manip
1	bear*	2.00	1.50	1.00
2	bee	1.83	2.28	2.63
3	beetle*	2.67	1.56	2.95
4	butterfly	2.00	2.50	2.74
5	chickadee*	2.33	2.72	2.47
6	chicken	1.89	1.67	2.26
7	clouds*	2.06	4.94	1.00
8	cow*	1.72	2.22	1.00
9	crab*	2.39	1.72	2.74
10	deer*	2.56	1.89	1.11
11	dog*	1.50	3.94	1.53
12	dragonfly	3.17	2.11	2.89
13	duck*	2.33	2.39	2.42
14	eagle	2.89	1.67	2.00
15	fly	1.89	2.72	2.79
16	forest	2.72	4.06	1.00
17	giraffe	2.72	1.44	1.05
18	grass	1.89	4.00	2.56
19	lion*	1.89	1.56	1.11
20	monkey	2.17	1.50	1.84
21	moon*	1.89	4.56	1.00
22	mountain	2.94	2.44	1.00
23	owl*	2.53	1.50	2.11
24	peacock	3.61	1.61	1.89
25	pigeon*	2.39	3.83	2.37
26	raccoon	3.11	1.72	2.05
27	rooster*	2.39	1.56	2.47
28	sheep	2.22	1.56	1.21
29	snake*	2.28	1.72	2.42
30	tree	1.89	4.67	1.00

* Part of list A.

3.15 SUPPLEMENTARY APPENDIX A2. BLOCK 1 (ONLY)

ANALYSIS

Experiment #1 - Categorization

RT (Block 1 only)

A separate analysis of block 1 only (manipulability x ED) was conducted to test for fleeting effects of manipulability (based on previous research that suggested manipulability effects were largest on the first block). However, the results on block 1 did not show a significant interaction, $F(1,39) = 0.69, p = .410$. Although the two main effects were still significant for manipulability and ED, with $F(1,39) = 10.58, p < .01$ and $F(1,39) = 17.91, p < .001$, respectively. These effects were consistent with the overall (2 blocks) analysis.

Error / Accuracy (Block 1 only)

A separate block 1 error analysis (manipulability x ED) revealed only a significant ED effect, $F(1, 39) = 53.83, p < .001$, with fewer errors for long exposure durations. The main effect of manipulability was not significant, $F(1,39) = 2.77, p = .104$, nor was the interaction $F(1,39) = 0.40, p = .842$. Thus, these results were consistent with the analysis including both blocks.

Item Analysis (Block 1 only - RT)

The block 1 item analysis (manipulability x ED) replicated the block 1 subjects-RT analysis, with two significant main effects, but an interaction that did not reach significance, $F(1,110) = 3.22, p = .076$. The statistics for the main effect of manipulability and ED were $F(1,110) = 10.90, p < .01$, and $F(1,110) = 59.82, p < .001$, respectively. Thus, again, this analysis was consistent with the overall (2 blocks) analysis.

Experiment #2 - Naming

RT (Block 1 only)

As before, a separate block 1 only analysis (manipulability x ED) was conducted to test for fleeting effects of manipulability. Again, the results on block 1 did not show a significant interaction, $F(1,39) = 2.20, p = .146$. Also, the effect of manipulability was not significant in block 1, $F(1,39) = 1.67, p = .204$, although the main effect of ED was, $F(1,39) = 32.94, p < .001$. This suggested that, in contrast to previous research, the manipulability effect was actually larger in block 2 for naming. That is, the manipulable object advantage was larger for objects shown for a longer time.

Error / Accuracy (Block 1 only)

A separate block 1 analysis for errors (manipulability x ED), revealed a main effect both manipulability and ED, $F(1,39) = 70.86, p < .001$ and $F(1,39) = 931.86, p < .001$, respectively. However, unlike the full (2 block) analysis, the interaction between the two variables was no longer significant, $F(1, 39) = 0.16, p = .899$. This, therefore, indicated that the presence of the interaction was stronger in the second block.

Item Analysis (Block 1 only - RT)

For the item analysis with block 1 only (manipulability x ED), only the ED effect was found to be significant, $F(1, 88) = 55.56, p < .001$. Neither the main effect of manipulability nor the interaction was significant, $F(1,88) = .12, p = .730$ and $F(1,88) = 2.73, p = .102$, respectively. Again, these results demonstrated weaker effects of block 1 only analysis, suggesting manipulability effects were either (a) larger in the second block, or (b) required the data from two blocks to have enough power to reveal the effects.

3.16 SUPPLEMENTARY APPENDIX A3. SIMILARITY AND RT?

Laws and Gale (2002b) said that their pixel-level measures of similarity did a better job of predicting the variance than did a measure of contour overlap (as per Humphreys et al., 1988 and 2000). In order to compare to these previous analyses and to explore the possibility that our results were mediated by visual similarity we did a further analysis to see if measures of visual similarity derived from our stimulus set could predict the variance in reaction times for the various conditions in our data.

First, in order to ensure maximum comparability, we rotated our objects so that they had a common orientation (as per comparisons done Laws & Gale, 2002b versus Humphreys et al., 1988 and 2000). Note, this rotation had not been done in previous comparisons, since the goal in previous comparisons was to compare objects exactly as they were shown (i.e. exactly as they would hit the retina). For example, tools were rotated to the vertical with their handles down, and animals were flipped so their head was on the left side, likewise for insects. See figure 3.6 for examples of before and after.

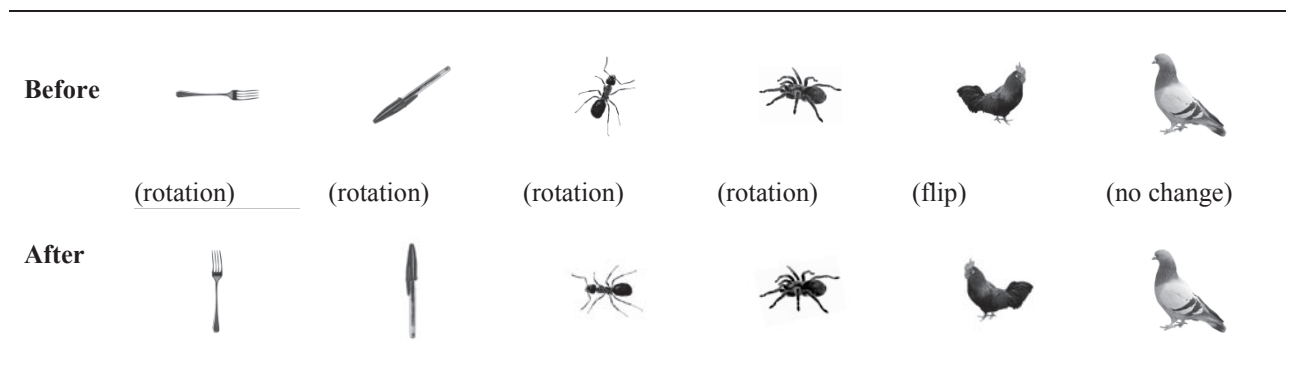


Figure 3.6. Examples of flips and rotations that were done to the stimulus set to align features of the objects for subsequent similarity analyses.

Second, for each of the 120 items, an average RT (across all participants) was calculated for each of the experiments (2) for each block (2) for each exposure duration. In this way, eight (2x2x2) reaction times were calculated for each of the 120 items (see table 3.4 for the list). Furthermore, new similarity measures based on the rotated objects were derived for each of the 120 objects. These measures were derived by comparing every object to every other object (pairwise comparisons) to derive a value of difference. These difference values were then averaged together for each object with the category that it belonged. For example, similarity values for the ‘fork’ (manipulable) were derived from the average value of its difference as compared to every OTHER manipulable object. Where, similarity values for the ‘sailboat’ (non-manipulable) were derived from the average value of its difference as compared to every OTHER non-manipulable object. Since these measures were derived on a rotated set of objects “-R” was appended to abbreviation for each measure of similarity. Thus, for these analyses we had (1) our measure of average pixel intensity difference (aPID-R) as described before, (2) Laws, Gale and colleagues’ Euclidean Overlap (EO-R) measure, and an addition “relative” aPID measure which was designed to account for the relative amount of empty / white pixels in the image (RaPID-R). These were compared to two measures of contour overlap, one that set a grayscale threshold to turn pixels black in an image and then counted the number of overlapping pixels in two images (CO-R), and a second that did the same thing but controlled for white-space by divided the number of overlapping pixels by total number of filled in pixels of the larger object (rCO-R).

Abbreviation	Explanation / Definition
cat_b1s_RT	Mean Categorization RT for objects in block 1 shown at a short duration
cat_b1l_RT	Mean Categorization RT for objects in block 1 shown at a long duration
cat_b2s_RT	Mean Categorization RT for objects in block 2 shown at a short duration
cat_b2l_RT	Mean Categorization RT for objects in block 2 shown at a long duration
name_b1s_RT	Mean Categorization RT for objects in block 1 shown at a short duration
name_b1l_RT	Mean Categorization RT for objects in block 1 shown at a long duration
name_b2s_RT	Mean Categorization RT for objects in block 2 shown at a short duration
name_b2l_RT	Mean Categorization RT for objects in block 2 shown at a long duration

Table 3.4. Abbreviations for the eight reaction times (left), and the five measures of visual similarity explored.

3.16.1 Does visual similarity predict variance in reaction times?

Data analysis involved using these derived measures when then used to determine the extent to which these measures of similarity could explain the variance in reaction times (RTs). This was done by conducting eight multiple regressions (one which of RT variables as a DV), with the five similarity measures as possible predictors in each analysis. In order to control for type I error, significance was evaluated at an $\alpha = .05$ divided by the number of comparisons = $\alpha_{\text{CRIT}} = .05 / 8 = .006$.

Of these eight multiple regressions, only one was significant at $\alpha_{\text{CRIT}} = .006$ (see table 3.5). The only significant regression was during categorization at short exposure durations, but only during the second time seeing the objects (i.e. block 2 but not block 1), $F(5,110) = 3.69, p = .004$. Furthermore, the significance of this regression was being driven by pixel-derived measures of similarity (aPID-R and EO-R) and not contour-derived measures. In this case, aPID-R and EO-R were measuring equal amounts of variance in reaction times. The direction of this effect was that high measures of aPID-R and EO-R were related to slower reaction times during object categorization. That is, objects that were more visually different / distinct (e.g. high aPID-R) were categorized

more slowly. This is equivalent to saying similar objects were categorized more quickly (as would be expected for effects driven by visual similarity).

	OVERALL	RaPID-R	aPID-R	EO-R	CO-R	rCO-R
cat_b1s_RT	$F(5,106) = 3.00, p = .014^t$	$p = 0.121$	$p = 0.071$	$p = 0.030^t$	$p = 0.905$	$p = 0.747$
cat_b1l_RT	$F(5,114) = 1.65, p = .153$	$p = 0.169$	$p = 0.069$	$p = 0.091$	$p = 0.425$	$p = 0.566$
cat_b2s_RT	$F(5,110) = 3.69, p = .004^*$	$p = 0.124$	$p = 0.004^*$	$p = 0.003^*$	$p = 0.167$	$p = 0.155$
cat_b2l_RT	$F(5,113) = 2.74, p = .022^t$	$p = 0.902$	$p = 0.997$	$p = 0.972$	$p = 0.112$	$p = 0.056$
name_b1s_RT	$F(5, 85) = 0.51, p = .768$	$p = 0.506$	$p = 0.250$	$p = 0.265$	$p = 0.130$	$p = 0.125$
name_b1l_RT	$F(5,114) = 3.02, p = .013^t$	$p = 0.041^t$	$p = 0.142$	$p = 0.122$	$p = 0.176$	$p = 0.618$
name_b2s_RT	$F(5,105) = 1.68, p = .145$	$p = 0.136$	$p = 0.663$	$p = 0.571$	$p = 0.385$	$p = 0.546$
name_b2l_RT	$F(5,114) = 2.64, p = .027^t$	$p = 0.265$	$p = 0.639$	$p = 0.597$	$p = 0.704$	$p = 0.583$

Table 3.5. Summary of results from the eight multiple regression analyses. The “OVERALL” column summarizes the significance of the overall regression. The other columns summarize whether each individual measure of visual similarity was significant in the analysis. Note that the degrees of freedom vary since analysis was done at the item level, and not all items were identified equally accurately in each condition. Further note that significance was evaluated at the $\alpha_{CRIT} = .05 / 8 = .006$, with * to indicate the results that were significant, although values below .05 were marked with a t.

3.16.2 Conclusions & Discussion

A number of conclusions can be drawn from these analyses. First, this result acted to partially reinforce the validity of our derived average pixel intensity difference (aPID), since only this measure and Euclidean overlap were able to significantly explain variance observed in our tasks. Second, this result was consistent with the claim by Laws and Gale (2002b) that pixel-level measures of visual similarity explain variance in identification, but contour overlap measures do not. For comparison, Laws and Gale (2002b) reported their measure explained 4.4% of their variance, while the current significant result explained 10.5% of the variance (for the one significant regression).

Importantly, these analyses showed that even though measures of visual similarity *can* predict some of the variance in our reaction times, they do so for only certain

conditions. That is, these effects were only true during one block of experiment #1 (categorization) but not during experiment #2 (naming). That means, even if we accept visual similarity as a confound, this confound can only be used to explain effects in one of our experiments, and not both. Therefore, the results of this analysis are consistent with our assertion that we need to look beyond visual similarity to explain the effects observed in the current research.

**CHAPTER 4 MODELING A CATEGORIZATION AND NAMING
REVERSAL BASED ON OBJECT MANIPULABILITY:
CONSIDERING THE ROLE OF SEMANTIC ORGANIZATION,
ACTION, & SIMILARITY**

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4.1 ABSTRACT

Recent research has shown that manipulable objects are named more quickly than non-manipulable object-equivalents, despite being categorized more slowly (Salmon, Matheson, & McMullen, in revision). These results raised the question of what mechanism in the human object identification system could lead to such an effect reversal (e.g. faster naming but slower categorization)? The current research sought to evaluate three candidate mechanisms that might explain this ‘reversal effect’: (1) semantic organization, (2) similarity, and (3) a dedicated action model. Computational modeling (an extension of Yoon, Heinke, and Humphrey’s, 2002, Naming Action Model) was employed to test each mechanism independently. Results indicated that a dedicated action module was insufficient to explain these effects: this module led to both faster naming *and* categorization (i.e. *not* a reversal). On the other hand, both semantic organization and similarity were able to simulate the reversal. When manipulable objects were organized into smaller semantic categories relative to non-manipulable objects (i.e. fewer items per category, ‘sparsely’ distributed) the simulations indicated that they would be named more quickly but categorized more slowly. Equivalently, when manipulable objects were made to have lower within-category similarity, the simulations showed faster naming but slower categorization. A visual similarity analysis of the original stimuli suggested that *visual similarity* was not underlying the original naming by categorization reversal effect observed by Salmon et al. (in revision), but that *action similarity* may be playing a role. As a whole, these results suggest two candidate mechanisms that explain both (1) how manipulable objects are perceived/identified differently than non-manipulable ones, and (2) how such differences can lead to manipulability-based effect reversals.

Keywords: computational modeling, semantics, action, manipulability, similarity, identification, naming, categorization

4.2 COMPUTATIONAL MODELING INTRODUCTION

Object identification is a fundamental process of any independent mobile organism. Understanding the mechanisms underlying object identification systems is important not just for cognitive psychologists and neuropsychologists but for engineers and computer scientists trying to build autonomous robots that can successfully navigate and interpret their environment. One interesting feature of the human object identification systems is that not all objects are *created equal*. In particular, object identification tends to be faster and more accurate for objects with which the system/person has high degree of familiarity or exposure (cf. Bonin, et al., 2003; Catling, et al., 2008; Cuetos & Alija, 2003; Dent, et al., 2007; Dent, et al., 2008; Pérez, 2007). For example, the average (north-american) person will identify a photograph of a ‘dog’ much faster than that of a ‘giraffe’ or ‘zebra’. Furthermore, some categories of objects appear to be identified more quickly than others. For example, Thorpe and colleagues have demonstrated an advantage in humans for natural objects and scenes compared to manmade objects when participants are asked to make speeded eye movements toward the natural object or scene (e.g. Bacon-Macé, et al., 2007; Bacon-Macé, et al., 2005; Kirchner & Thorpe, 2006; Rousselet, Macé, & Fabre-Thorpe, 2003; Thorpe, 2009).¹⁶

This advantage for certain categories of object (natural objects, in the above example) could lead a researcher to conclude that the identification system in humans is preferentially tuned to identifying certain kinds of objects (or features in an scene).

Therefore, any reversal in identification effects, such as an advantage for a previously-

¹⁶ Of course, making an eye movement is different than an identification task, but making an eye-movement in the *correct* direction when confronted with two photographs simultaneously requires at least some level of identification of objects or features in the scene.

disadvantaged group is of great interest to the field. The current research explores an example of such a ‘reversal effect’, and the possible mechanisms that could underlie it.

4.2.1 Reversing effects that Object Manipulability play during Identification

In a recent study in our laboratory (Salmon, Matheson, & McMullen, in revision), we uncovered a manipulability effect reversal, when two groups of participants were asked to either Name (identify at a specific level, e.g., “dog”) or Categorize (identify at a higher level, e.g., “natural”) the same sets of manipulable or non-manipulable objects. ‘Manipulable’ objects were defined as those participants could grasp for use, according to ratings obtained by Salmon, McMullen and Filliter (2010). Participants were faster and more accurate when naming manipulable objects, but slower to categorize these same objects relative to non-manipulable objects. Object sets were matched for familiarity (the degree to which participants think about or come into contact with an object on a day-to-day basis) and age of acquisition (the age at which participants first learned the name for the object). The finding that manipulability can influence object identification was *not* completely new. For example, Wolk, Coslett, and Glosser (2005) reported findings from patients with visual agnosia showing they were more accurate at identifying objects considered ‘manipulable’. In addition, Kalénine and Bonthoux (2008) found that during a triad matching task, healthy children and adults were faster to match manipulable objects during thematic-relations triads (e.g. matching ‘coat’ with ‘hanger’), but faster to match non-manipulable objects when triads requiring basic-level taxonomic (e.g. matching ‘coat’ with ‘jacket’) judgements were presented. This result by Kalénine and Bonthoux

(2008) indicated that for certain kinds of tasks manipulable objects are matched more quickly than non-manipulable objects, and for other kinds of tasks the reverse is true.

Thus, our behavioural findings for a manipulability effect reversal based on task were not inconsistent with findings that have been reported from other labs. However, our work was novel in showing effects when effects of object familiarity and age of acquisition were carefully controlled. Also, the categorization by naming reversal based on manipulability was of interest, and is explored in the current research. We believe the literature currently lacks a strong theoretical framework to explain how properties of objects, such as whether or not they can be manipulated, can lead to such identification reversals effects.

4.2.2 The current research: Exploring the mechanisms that could explain behavioural reversals

The current research will explore three different candidate mechanisms that might explain how the same set of (manipulable) objects could be named more quickly but categorized more slowly relative to non-manipulable objects. Theoretical attempts in the past to explain reversals have been focused on differences between manmade and natural objects (cf. Gerlach, 2009; Gerlach, et al., 2006). Differences such as visual similarity and semantic organization based on sensory versus functional features of objects. However, we should be cautious to assume that the same processes will work and apply across manipulability.

In the current research, the following three mechanisms were explored: (1) a dedicated action module for manipulable objects, (2) within category similarity of objects, and (3) semantic organization between item-specific and categorical

representations of objects, or ‘crowded versus sparse’ domains. In order to fully outline what these mechanisms are and how they were explored, this manuscript will follow the following format. First, it will describe the advantages of computational modeling generally, why the Yoon, Heinke, and Humphreys (2002) model was selected, and what modifications needed to be made to their model in the current research. Second, it will go through the theoretical relevance of each of the three models explored, how they were implemented in the model, and what the results looked like. Fourth, it will describe attempts to verify the plausibility of the candidate mechanisms in the original stimulus set itself. Finally, the discussion section will summarize the results and what it means in relation the behavioural result observed in Salmon et al. (in revision), and reversal effects, generally.

Note, throughout this manuscript ‘action’ and the ‘appropriate action’ for a given object will all be treated under one umbrella term. Specifically, no attempt will be made to differentiate between action associated with grasping an object (volumetric gestures) and those associated with its functional use. That is, despite the impressive accumulated evidence to date that computationally and neuroanatomically different action systems exist (cf. Boronat, et al., 2005; Bub & Masson, 2012; Bub, et al., 2008; Buxbaum & Kalenine, 2010; Buxbaum, et al., 2006; Buxbaum & Saffran, 2002; Buxbaum, et al., 2000), the fact still remains that these differences matter most when looking at differences within a set manipulable objects, but are more trivial when the comparison is between non-manipulable and manipulable objects. They are more trivial for this type of comparison between non-manipulable and manipulable objects because these dimensions are hopelessly correlated and confounded. For example, how does one grasp or

functionally use a non-manipulable object? By definition, these kind of objects neither afford grasp (volumetric) or functional gestures, whereas manipulable objects afford both; therefore focusing on the differences between these dimensions can only inform us about differences within manipulable objects, but not about the difference between non-manipulable and manipulable objects, which is the focus of the current research. Thus, this manuscript will not get specific about the flavor of action to which it is referring throughout. However, the issue of different action systems will be revisited in the general discussion along with a statement about which type of action system the construct of the model presumably supports.

4.2.3 Why use computational models?

The mechanisms, described above, could be explored in the real world through careful and considered experimentation. However, one advantage of a good computational model is that it can avoid a lot of the complexity of the real, physical world. That is, the physical world is filled with confounds that can be difficult or impossible to control. A good computational model can exert good control and effectively eliminate many of the confounds that exist in the real world. For example, real-world object identification involves complicated objects presented from a variety of viewpoints, in a variety of colors and sizes, and these can be avoided in a model. The real world also contains other confounds such as object familiarity, object age of acquisition, object size, image complexity, word frequency, word length, etc. Again, a model need not include or be contaminated by such confounds. The signature of good computational modeling is finding a model that is sufficiently complex to study the mechanisms under investigation, but sufficiently simple as to not introduce confusion or confounds to the

interpretation. We believe the model presented in this paper, a modification of Yoon et al.'s (2002) Naming Action model, is of sufficient complexity to explain/illustrate how these mechanisms might work in a real brain, and how they can be used to explain category reversals, such as the naming-categorization reversed effect observed in previous research (Salmon, et al., in revision).

4.2.4 Introducing the current computational model

In 2002, Yoon, Heinke and Humphreys presented their Naming-Action Model (NAM), a computational model that, through lesioning, was able to replicate a number of neuro-psychological deficits during object naming including optic aphasia, anomia, and visual apraxia. The basic layout of their model is shown in Figure 4.1. One key feature of their model is a direction connection between their structural description system (visual input module) and their action output module. This link, as well as the bidirectional link between action and item-specific semantics, implies that action could influence naming by priming items in semantics. The Yoon, Heinke and Humphreys (2002) model compares the time to demonstrate correct action versus the time to name an object. This implies that all objects the model considers had some relevant associated action. To put it another way, this implies that Yoon et al.'s model is designed only to test manipulable objects. Thus, an extension (or modification) to the implementation of Yoon et al.'s model is necessary to test manipulable AND non-manipulable objects.

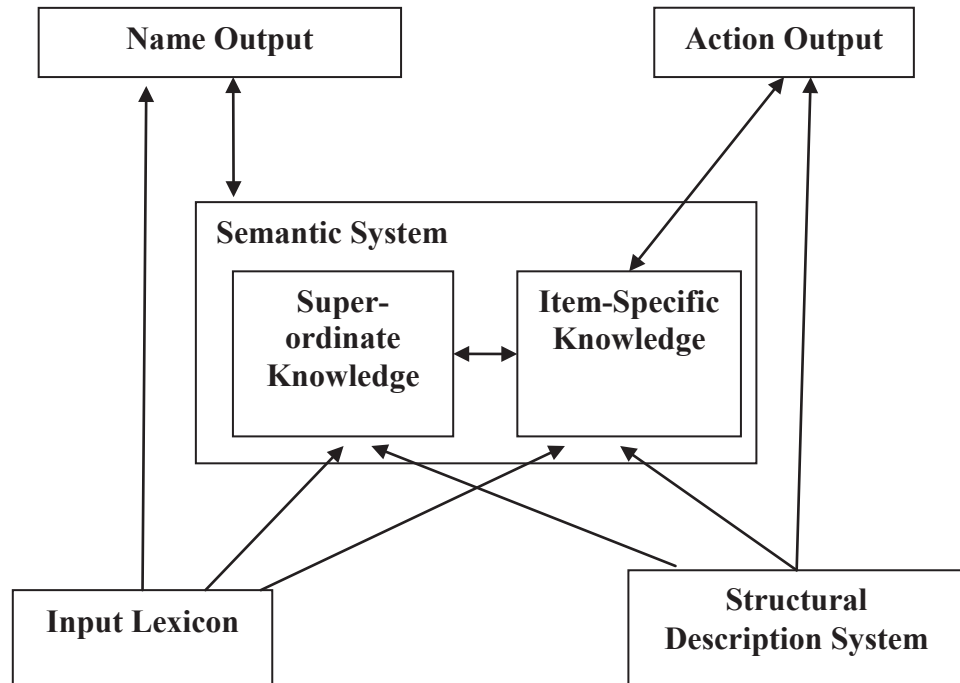


Figure 4.1. Basic schema of the Naming Action model (NAM) as shown in Yoon, Heinke & Humphreys (2002).

The current research used an extension of Yoon et al's (2002) Naming Action model (NAM) to explore three mechanisms that might explain a naming/categorization reversal based on object manipulability (1) a dedicated action module, (2) within-category similarity, and (3) semantic organization. Based on the cooperative/competitive mechanisms in this model it seemed entirely possible that inclusion of an action module alone would be insufficient to explain the full pattern of effects. That is, it was expected that the action module would have a primarily facilitatory effect on object identification. Semantic organization and similarity, on the other hand, seemed like mechanisms that, in the model, could influence object naming and object categorization in different ways.

Before getting into more details about the results obtained from exploring these mechanisms, it is first important to elaborate further on the architecture of Yoon et al's (2002) original model, and the modifications employed in the current research.

4.3 METHODS: THE BASIC ARCHITECTURE OF THE NAMING ACTION MODEL

Yoon et al. (2002) described their Naming-Action (NAM) model as a “dynamic quasi-modular connectionist framework”. Their model accepts two forms of input: pictures (structural description system) and words (input lexicon). It has two forms of output: naming and action. As well as two distinct semantic modules, one for specific item representations (item-specific knowledge) and one for higher level or super-ordinate level knowledge. Each input module has direct connections to an output module, and indirect connections through the two levels of semantics (see Figure 4.1). The modules are built so that the number of nodes (representational units) in each module is equal to the number of items learned by the network, with each node firing maximally to a single item. This architecture is similar to the idea of a ‘grandmother cell’ (cf. Bowers, 2009, 2010; Connor, 2005; Plaut & McClelland, 2010; Rodrigo Quian Quiroga & Kreiman, 2010) for each item, but in principle each node represents a collection of neurons in the real brain and not any individual cell.

The dynamics of the network are such that upon presentation of an item, activity begins to collect in each node of each module with information passed dynamically through time (iterations of the code) between and within each module. Within each module the nodes then compete with more active nodes suppressing less active nodes.

Across each module, representations would support each other, with, for example, the node representing “hammer” in item-specific semantics supporting the node representing the action of “hammering” in the action output module and further supporting the representation of the node for “tools” in the super-ordinate semantic module. Each node has a maximal firing rate of 1, and a minimal firing rate of 0, and over-time the correct representation/response to the item is achieved (in the functioning, unlesioned version of the model). Reaction time of the model can be assessed by determining the amount of time it takes for one of the nodes in an output layer to achieve a certain threshold (say firing rate = 0.7), and accuracy can be determined by the percentage of time the winning node (first node to hit the threshold) represents the correct response to the stimuli (*see Figure 4.2 for a representation of the dynamics of the model*). Note, however, for the purposes of this research, reaction time was focused on as the dependent measure.

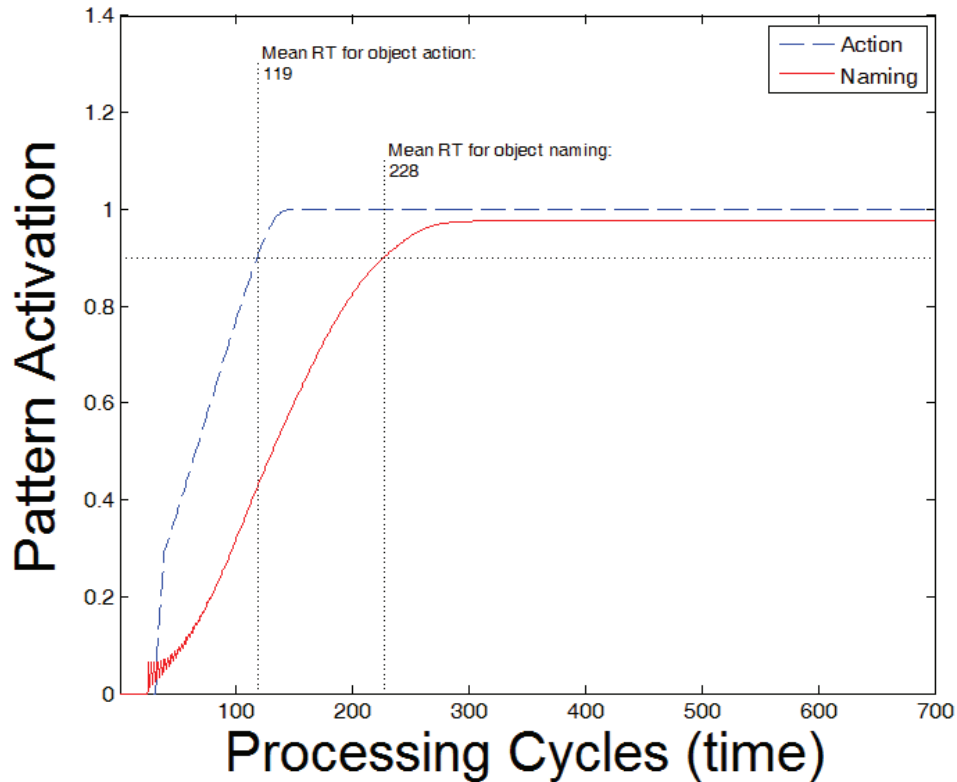


Figure 4.2. Basic dynamics of the Naming Action Model (NAM) in response to a picture (input to structural description system). The black horizontal line represents a threshold set at 0.9. The blue line represents average activity of the winning node in the Action module. The red line represents average activity in the winning node of the Naming module. Vertical lines indicate the amount of time (number of iterations) it took the network before a winner was chosen (equivalent to estimation of reaction time for a human participant). The above figure was generated in MATLAB as a reproduction of the original dynamics of Yoon's et al.'s (2002) NAM.

4.3.1 Extensions to the NAM (changes in implementation)

In order to extend the model to the task used in Salmon et al. (in revision) a number of important modifications were made. First, the Salmon et al. task did not use words (only pictures) so the "input lexicon" was properly removed from the model since it was not used. Second, the NAM model showed naming output connected to both levels of semantics, but in practice, this is not how the model worked. Specifically, Yoon et al.

(2002) would bias the output to either item-specific or super-ordinate level naming depending on the task, so that in any given iteration it was as if only one connection was active. In other words, Yoon et al. (2002) could have drawn their model with a direct line to naming from the item-specific semantics level, and a direct line to categorization from the super-ordinate semantics module. Therefore, our extension illustrated this distinction by connecting the naming output module directly to item-specific semantics, and not super-ordinate semantics. And, a categorization output module was added, connected directly to super-ordinate semantics, since we were directly interested in comparing these two tasks. This gave our model a certain symmetric quality (with the exception of the action output module).

4.4 TESTING THE THREE MECHANISMS

4.4.1 The dedicated Action Module: A Specialized Processor for Manipulable Objects

Salmon et al. (in revision) divided their object set with respect to manipulability (manipulable versus non-manipulable objects). Thus, it seems logical to suppose that an object *action system* might be driving this reversing effect. Such a system would be dedicated to determining possibilities for object action or what Humphreys and others call ‘action affordances’ (cf. Humphreys, 2001). Humphreys and colleagues have proposed and accumulated evidence for such an action system with a direct link from vision to this action ‘output’ system that bypasses semantics (Chainay & Humphreys, 2002; Rumiati & Humphreys, 1998). They have also designed a computational model around how this ‘action output’ module may interact with semantics, and used this model

to explain a number of neuropsychological disorders (i.e. Yoon, et al., 2002). Could their computational model, including a dedicated action module, be used to explain the reversing effects of manipulability we observed in object naming and categorization? In particular, can activation of an action module aid activation of basic-level/item-specific representations of objects leading to faster naming, but at the same time hurt categorization of the same objects? This action module as a potential driver of the reversing categorization-naming effect for manipulable objects was the first of three mechanisms explored in the current research.

4.4.2 Implementing the dedicated Action Module

In Yoon et al.'s (2002) implementation all items presented to the network had a correct action associated with them. In the current implementation we were interested in directly comparing manipulable to non-manipulable objects. By definition, non-manipulable objects would have no correct representation/action in the action module. Thus, for the purposes of this research, we trained the network to have no significant activity during the presentation of a 'non-manipulable' object. This was done by training an ideal action node in the action module for all manipulable objects, but no ideal nodes in response to non-manipulable objects. In practice, the model was told that the ideal firing rate of all nodes in the action module was 0 in response to a non-manipulable object. This modification to the model resulted in a clear winning node in the action output module when the network was shown a manipulable object (see Figure 4.3A) but no clear winner in the action module when the network was shown a non-manipulable objects (Figure 4.3B). *(For full details of the mathematics and equations used in the new Model, as well as sample code, please refer to the Supplementary Appendices).*

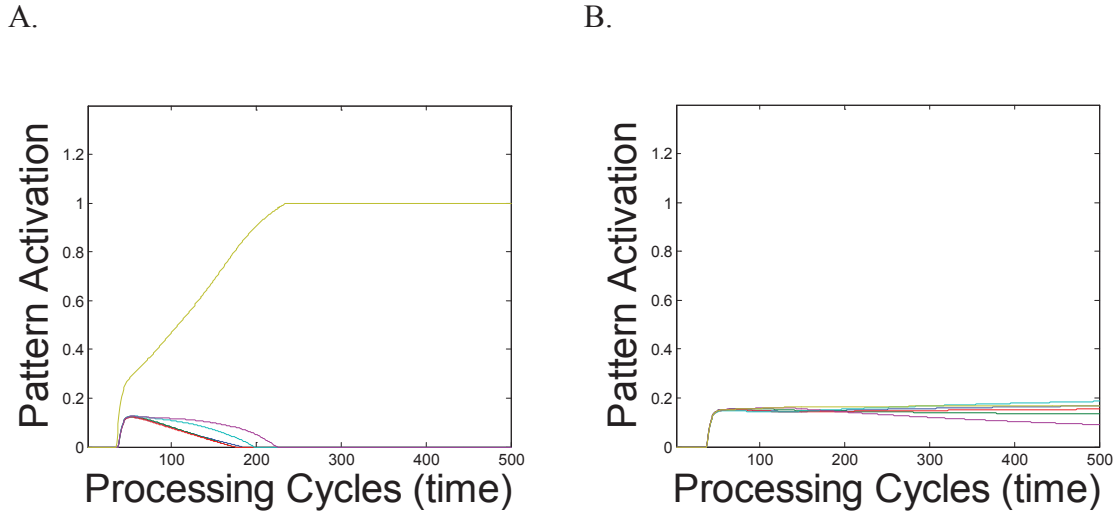


Figure 4.3. Depiction of the dynamics of the action module (each line represents activity within one of the nodes) when shown a manipulable object (A) versus and non-manipulable object (B). Notice that when the action module is shown a manipulable object (A), that over time, one of the nodes will reach a maximum firing rate as the system correctly identifies the action associated with that object. On the other hand, when the action module is shown a non-manipulable object (B) none of its nodes reach maximal firing, regardless of time (although the module retains a base level of low activity that has minimal impact on the other modules of the system).

A key aspect of Yoon et al.'s (2002) model was the Action Output module with a direct link from the input, as well as bidirectional connection to semantics. However, one can clearly see that the model is more symmetric if the module is left out (Figure 4.4A) than if it is included (Figure 4.4B). An important question is whether or not this action module is necessary or sufficient to explain the reversal effects seen in categorizing versus naming manipulable and non-manipulable objects with human participants? There was a concern that, given the cooperative/accumulative nature of the model, action representation would only facilitate naming and categorization of manipulable objects, and never slow them. That is, distinct representations of action held in the action output

module will facilitate distinct representations at semantics leading to faster naming. Further, these distinct representations at the item-specific level may, in turn, facilitate faster categorization of these same objects.

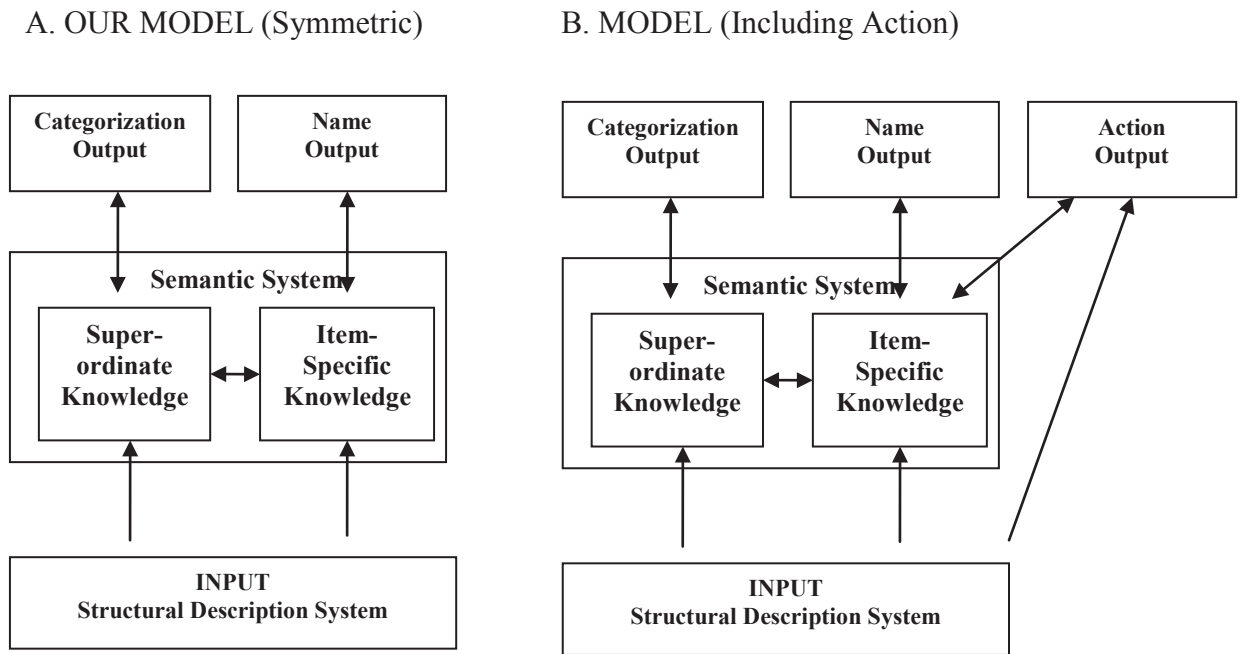


Figure 4.4. The new model architecture with (B) and without (A) the action output module. Note how adding the action output module (B) creates an asymmetry in the model (in the case where only pictures are considered as input).

4.4.3 Results when the Action Module is Included

Unsurprisingly, the symmetric model failed to produce any difference between categorizing and naming manipulable and non-manipulable objects (Figure 4.5, panel 1). This null result is explained by the fact that without the action module, the network had no way to distinguish between manipulable and non-manipulable objects. When the action module was included (Figure 4.5, panel 2), the network produced the naming effect, with faster naming of manipulable objects, but there was no categorization effect.

If anything, there was a tendency towards faster categorization of manipulable objects, inconsistent with the direction of behavioural results achieved by Salmon et al. (as shown Figure 4.5, panel 3).

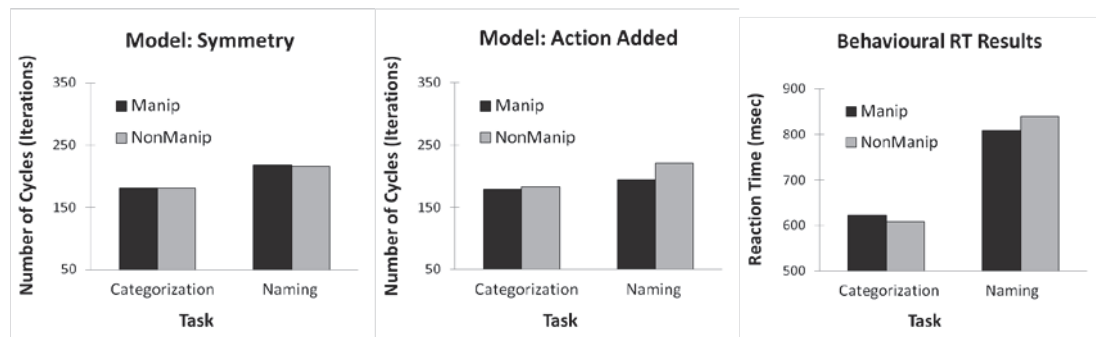


Figure 4.5. Results from the symmetric model show no effect of manipulability (left), the Action Added model shows a manipulability effect for naming (centre), and the original behavioural data shows a cross-over interaction (reversal effect) between manipulability and task (right). Note that these results represent the average of 10 runs for each model with new random ‘stimuli’ generated for each run (to ensure that final results were not artefactually based on one anomalous randomization of input to the model).

These results showed that, under the current implementation of the model, the addition of an action module had a primarily facilitatory role, aiding the identification of manipulable objects (regardless of naming or categorization demands). That is, the addition of the action module was not sufficient to explain the behavioural reversal observed by Salmon et al. (in revision). Thus we explored other factors that could account for the reversal, such as semantic organization and object similarity.

4.4.4 Similarity (Visual & Action)

Typically ‘similarity’ invokes the notion of visual similarity (or how much two objects visually resemble each other), but, when discussing object manipulability *action* similarity cannot be disregarded as a factor. Action similarity would refer to the extent to which two objects require the same or similar action during use, and is not necessarily the same thing as visual similarity. For example, two objects can look very different (e.g. a saw and an iron) but require similar actions during use (e.g. back and forth movement of the hand). Likewise, two objects can look very similar (e.g. fork and spoon) yet have very different actions associated with them (e.g. stabbing and scooping). Further, action similarity may play an important role during object naming and categorizing of manipulable objects (those with many different actions) versus non-manipulable objects (those, by definition, with few or no associated actions).

A recent compelling example of how action similarity can influence object identification was the research conducted by Desmarais, Dixon, and Roy (2007). They used a set of previously generated novel objects (Desmarais & Dixon, 2005) with known level of visual similarity between objects. They then pseudo-randomly assigned each object a novel name, and novel action that participants were required to learn during a training phase of their experiment. Actions were completed on a manipulandum that allowed for three concurrent actions to be completed simultaneously (i.e. sliding, pulling, & twisting). Thus two objects could either be assigned similar actions (e.g. object X assigned sliding-pulling, and object Y assigned pulling only) or dissimilar actions (e.g. object X assigned twisting, and object Y assigned sliding). Their results indicated the same two objects would be confused *more* (incorrectly named) if they had similar

associated actions, but confused *less often* when they had been learned with dissimilar actions (Desmarais, Dixon, et al., 2007). These findings support the idea that action similarity *can* influence object identification. Specifically, objects with similar actions tend to be confused (identified as each other) more often, and objects with distinct actions are confused less often, regardless of the appearance of the objects.

In the past, the argument has been made that similarity can affect the time to name and categorize objects leading to a reversal in effects (cf. Gerlach, 2009). The argument can be articulated as: categories of objects for which items are very similar to each other are named more slowly because the within-category similarity makes it harder for the system to resolve/pick the specific correct identity. On the other hand, if the task requires categorization, all that shared within-category similarity speeds up confidence and decision making so that items are categorized faster. This argument explains how categories with a high degree of inter-item similarity can be named more slowly, yet categorized more quickly. Explanations of models based on effects of visual similarity are common in the literature, for a recent example, see the pre-semantic account of category effects (or PACE model), recently elaborated on by Gerlach (2009; Gerlach, et al., 2004, 2006).

These arguments are usually couched in terms of *visual* similarity, and exemplars of similar items include living, non-manipulable things (e.g. animals), while manmade, manipulable things (e.g. tools) are considered to have low levels of visual similarity. It is generally taken as an accepted assumption that living things have more shared features and are thus more visually similar to each other than manmade things. However, the current research considered manipulable and non-manipulable objects with equal

numbers of natural and manmade objects. Thus, there was no *a priori* expectation of differences based on *visual* similarity in the current research. However, one could predict differences based on *action* similarity, as suggested above.

4.4.5 Implementing stimulus Similarity

In the current research, similarity was adjusted by altering the numeric values of the inputs that represented a structural decomposition or ‘feature’ of each object. Non-manipulable objects were made to be more ‘similar’, in this way, than manipulable objects (in which no ‘features’ were modified to be the same). At face value, it may seem like this method was altering *visual* similarity of input but not *action* similarity of non-manipulable objects. However, it is important to note that certain features of an object (e.g. presence or absence of a handle of some kind) allow it to afford, or not afford, certain kinds of actions. Thus, in principle, manipulating the features of an object will affect both its visual similarity and *action* similarity with other objects.

Similarity in the model was easy to implement. As explained, each object is input into the model as a vector of unique numbers. If all values in the vector share no common numbers with any of the other numbers then there is no similarity between any of the objects. If all ‘non-manipulable’ objects share some numbers in common then they demonstrate a certain amount of input similarity or ‘similarity’ (since the input is intended to represent decomposition of a visually presented photograph). In this way, it is possible to control both which sets of items are similar, and the degree of similarity within a set, with high degree of similarity being related to highly similar input vectors (see Figure 4.6).

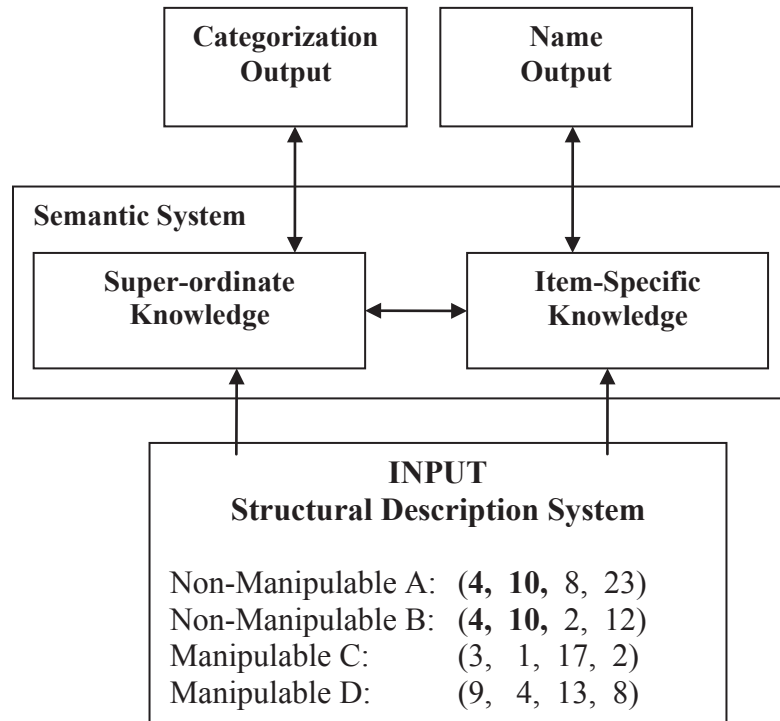


Figure 4.6. A depiction of how similarity appears as input to the model (a vector of random numbers for each unique item). Each number would represent some feature of an object and some associated value. For example, the first number could represent the number of curved lines in an object, the second number could represent number of vertices, etc. Note that for these similarity simulations, non-manipulable objects were set to have more within-category similarity by setting these numbers to be equal. In the example above, note, the two Non-manipulable objects (A & B) begin with the same two values (4, 10) which will make them appear more similar to the model (in this case, the vectors have a length of four, so these objects are 50% similar, or half their features are shared). On the other hand, Manipulable objects C & D have no shared values and therefore have 0% similarity.

4.4.6 Results for Similarity simulations

As predicted, similarity in the model showed the expected reversal effect with similar items being named more slowly but categorized more quickly. Two levels of within-category similarity were tested (30% similarity and 60% similarity), with a much

larger reversal effect for higher within-category similarity (see Figure 4.7). Notably, similarity affected naming to a much larger degree than categorization (see Figure 4.7, Panel 1). That is, compared to a semantic organization, similarity produced smaller categorization effects. These results indicated that a similarity mechanism was sufficient to explain a naming-categorization reversal but the qualitative nature of the effects appeared to be better captured by semantic organization.

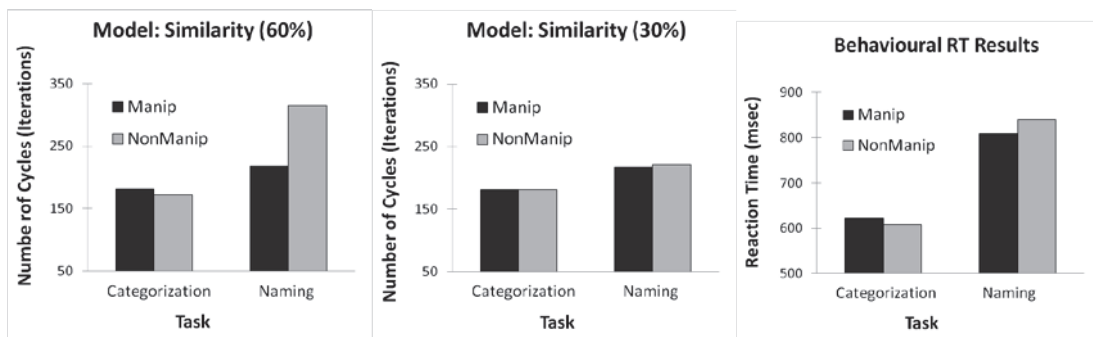


Figure 4.7. Results from Similarity simulations that varied in degree of similarity.

4.4.7 Semantic Organization: Different Numbers of Items per Semantic Category

The terminology of ‘crowded’ versus ‘sparse’ domains has been used to describe differences between natural and manmade objects, and animals and tools, in particular. That is, there are many different types of animals that all have the same features: four legs, fur, tails, a head with a face, yet they all have different names (e.g. horse, zebra, camel, cow, dog, cat, etc.). On the other hand, tools and manmade objects tend to have more structural variety (e.g. hammer, saw, scissors). Thus, animals are said to come from ‘crowded’ domains, with many distinct but visually similar animals all crowded together

in semantic representation. Tools, on the other hand, come from more ‘sparse’ domains with fewer identities represented in a specific semantic space (cf. Allport, 1985; Gale, Done, & Frank, 2001; Humphreys, et al., 1988; Tranel, Logan, Frank, & Damasio, 1997). This phenomenon could also be explained as a ‘semantic organization’ difference. That is, certain kinds (or categories) of objects come to be represented in semantic space shared with many other objects (i.e. ‘crowded’). While other objects are represented in semantic space shared with only a few other objects (i.e. ‘sparse’).

These differences in semantic organization could potentially lead to reversal effects during naming and categorization tasks. In particular, if manipulable objects, such as ‘tools’ tend to belong to smaller (‘sparse’) categories¹⁷, then when their category is activated through presentation of a stimulus, there might be less within-category competition leading to faster naming. Likewise, these same smaller categories of manipulable objects might be categorized more slowly since their representations are more distributed and take longer to accumulate category-level activity¹⁸. Indeed, research by Humphreys and colleagues (in particular the Cascade model and Hierarchical Interactive Theory, Humphreys & Forde, 2001; Humphreys, et al., 1988) suggests that crowded categories, or ‘domains’ (such as the representation of ‘animals’) may be categorized more quickly because there are so many items in the category, but individual items within the category may be named more slowly because there is a high degree of within-category competition to select the correct name (e.g. “camel” not “horse”).

¹⁷ Note, I am making the assumption that ‘sparse’ categories denote those with few exemplars, but another way in which categories can be ‘sparse’ is that the items or ‘exemplars’ might be further apart in semantic space.

¹⁸ These ideas are similar to those of distributed memory theories advocated by Allport (1985). Specifically, manipulable objects may have more distributed and unique representations, creating less overlap among exemplars of manipulable objects, and leaving meaningful categories with fewer exemplars (i.e. more sparse).

Importantly, previous research has focused on the differences between living and non-living objects, or between animals and tools, and not the differences between manipulable and non-manipulable objects (cf. Gaffan & Heywood, 1993; Humphreys, et al., 1988; Laws & Neve, 1999; Turnbull & Laws, 2000). However, with respect to manipulable objects, the case has been made that category differences tend to depend more on the presence or absence of functional properties (see sensory v. functional theories, e.g. Warrington & Shallice, 1984). Thus, given the wide range and variety of manipulable objects that humans are exposed to, and the variety of purposes that they serve, it is reasonable to hypothesize that meaningful categories of manipulable objects are formed with higher frequency and contain fewer items (i.e. more ‘sparse’ compared to non-manipulable objects). Thus, it might be expected that within an experiment with equal numbers of manipulable and non-manipulable objects, the set of manipulable objects would represent objects belonging to more ‘sparse’ categories. Further, because ‘sparse’ categories contain fewer members, by definition, you would need more (high-level) manipulable categories of objects for the same number of non-manipulable objects. That is, the manipulable object would be categorized into many sparse domains, while the non-manipulable objects would be categorized into fewer, and by definition, more crowded domains.

This idea (of semantic organization differences between different categories of objects) is similar to concept of category ‘potency’ or the number of items a participant will generate when asked to think of items that fit in the category. For example, as a part of category norms research, Battig and Montague (1969) collected category potency ratings based on the average number of objects generated by participants in 30 seconds to

a category name. They reported high potency ratings or more objects for non-manipulable objects such as animals (actual potency $F/apf = 9.03$), birds ($apf = 7.35$) and furniture ($apf = 7.25$). In contrast, they reported lower potency ratings or fewer objects for some manipulable object categories such as carpenter's tools ($apf = 6.10$), kitchen utensil's ($apf=6.90$), toys ($apf=6.15$), non-alcoholic beverages ($apf=6.95$), and vegetables ($apf=7.03$). In other words, participants generated more items for non-manipulable categories (crowded domains) and fewer items for manipulable categories (objects from sparse domains). More recent potency ratings from Overschelde, Rawson, & Dunlosky (2004) confirmed this trend of generating more objects in response to non-manipulable category labels. These results, along with the arguments above, provide additional support for the idea of more 'crowded' domains for non-manipulable categories compared to manipulable categories.

Since we have switched terminology throughout to describe basically the same phenomenon (or mechanism) in different ways, the table below (Table 4.1) has been provided as a quick reference for term equivalency, associated predictions, and which category of objects (e.g. manipulable or non-manipulable) we believe the terms describe. The language around semantic organization will become particularly relevant when we explain how this mechanism was implemented and tested in the computational model. Further, this section has used the term 'categories' to represent a collection of similar objects (such as kitchen utensils), but the more precise term 'superordinate' categories will be used, as well, in subsequent sections. The term 'superordinate' is used to define any classification of an object higher than the 'basic' or 'entry' level. Where the basic (or entry) level is defined as the level at which the object is most commonly identified. For

example, during speeded identification tasks, most participants will identify as photo of *golden retriever* as “dog”, and a *Toyota Corolla* as “car”. These terms (car and dog) would be considered the entry level of the object, the more precise term ‘*golden retriever*’ would be considered the subordinate level, and, higher level terms such as ‘mammal’ or ‘animal’ would be considered superordinate-level categories (see Rosch, 1975 for a more detailed account of semantic categories).

Table 4.1. Language around semantic organization mechanism and predictions.

		Semantic Organization (for same # of objects)	Potency	Prediction: Speed to Identify
Non-manipulable	crowded	Fewer categories, Each containing many items	High	Slower Naming Faster Categorization
Manipulable	sparse	More categories, Each containing few items	Low	Faster Naming Slower Categorization

4.4.8 Implementing Semantic Organization differences

In the real world there’s generally a strong correlation between semantic organization differences and visual similarity within a category¹⁹. In a model, however, these mechanisms can be fully decoupled. First we explored the possibility of semantic organization differences, or the organization of connections between the super-ordinate and item-specific semantic systems. Until now, the model assumed that each super-ordinate node mapped onto an equal number of items in semantics (that is, it assumed all objects belonged to categories of equal sizes). But is that assumption valid? For example, it may be true that all natural/non-manipulable things are animals, but

¹⁹ Reminder: This is because domains with many similar objects tend to crowd together (many items per category) and domains with more visual distinctiveness tend to form more sparse representations (fewer items per category).

manmade/manipulable things can properly be categorized into multiple categories including toys, tools, utensils, clothing, dishes, etc. In other words, it may be that manipulable objects have more super-ordinate level categories (each containing fewer members, i.e. ‘sparse’).

In cognitive object-identification studies it is very common to control for the number of items in each super-ordinate category, for example Gale, Laws, and Foley (2006) when exploring categorization/naming differences based on the visual crowding hypothesis, tested 10 super-ordinate categories of objects (animals, birds, body parts, fruit, vegetables, clothing, furniture, musical instruments, tools, and vehicles) with 10 items chosen from each category. In Salmon et al. (in revision) membership control was done at a higher level (natural/manmade & manipulable/non-manipulable) and not at the ‘super-ordinate’ levels like animals, furniture and clothing. For example, Salmon et al.’s (in revision) stimulus set contained 32 animals, but only 3 articles of clothing. This imbalance may have resulted in the observed pattern of faster categorization for items belonging to large super-ordinate categories (i.e. ‘crowded’), but faster naming times for items belonging to small super-ordinate categories (i.e. ‘sparse’).

This hypothesis about differences in semantic organization (depicted in the right panel of *Figure 4.8*) can be easily implemented in the model by changing the ideal mapping from the item-specific knowledge to super-ordinate knowledge such that some items get low-ratio mapping from item to super-ordinate knowledge. This low-ratio mapping compared to a high-ratio mapping is somewhat simplistic compared to the real world, but it captures the idea that some super-ordinate categories contain very few specific items while others contain many. An easy example would be the super-ordinate

category of ‘utensils’ which contains relatively few items, specifically: spoons, forks, and knives. On the other hand, the super-ordinate category of ‘animals’ contains many more items. See also *Figure 4.9*²⁰, and the supplementary Appendix for more details on how semantic organization was implemented in the model.

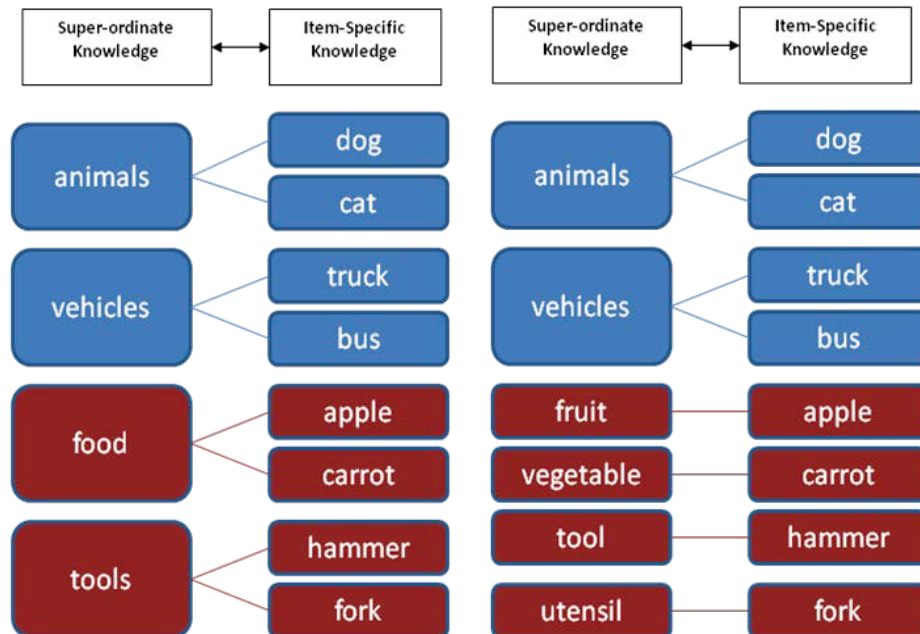


Figure 4.8. The left panel shows a representation of non-manipulable (blue) and manipulable (red) objects with equal/balanced semantic organization between the two categories of objects. The right panel shows an unbalanced mapping, with manipulable (red) objects mapping to more super-ordinate semantic categories than non-manipulable (blue) objects. This results in more low-ratio mappings (or super-ordinate categories) for the same number of manipulable objects.

²⁰ Note: In the current simulation, the same number of objects (items) was always used, so semantic differences were introduced by increasing or decreased the number of super-ordinate categories that the objects were associated with.

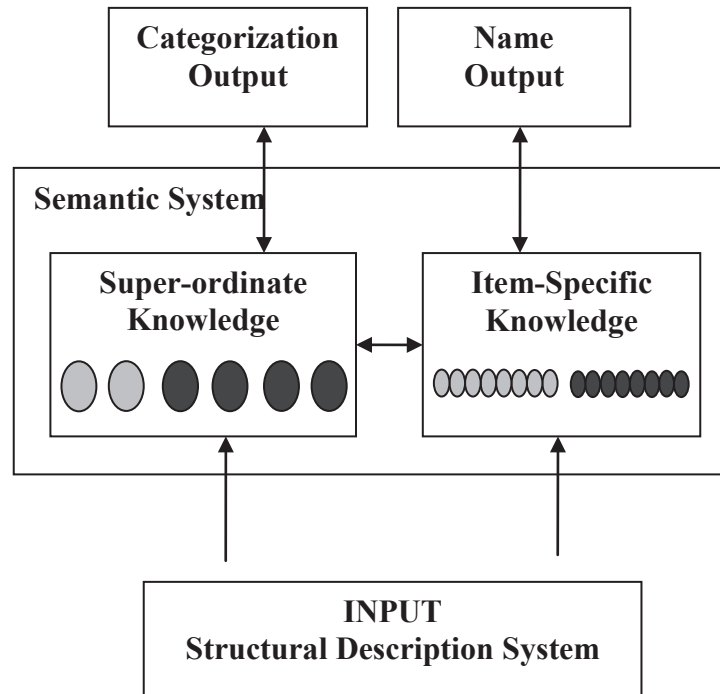


Figure 4.9. Another depiction of the semantic organization differences hypothesis is shown in the context of the overall model where the circles in the super-ordinate knowledge represent nodes that fire maximally for manipulable categories of objects (dark grey) or non-manipulable categories of objects (light grey). Circles in the item-specific knowledge represent nodes that fire maximally to the presentation of an object. Notice, to test the semantic organization differences hypothesis, there are more super-ordinate manipulable categories for the same number of manipulable objects (but each of those categories would contain fewer items – i.e. a greater number of sparse categories).

4.4.9 Results with Semantic Organization differences

With semantic organization differences, the reversed effects of manipulability for categorizing and naming were finally observed. In order to more fully explore the effects, the effect was considered in two strengths, (1) the stronger case where with 24 items (12 manipulable, and 12 non-manipulable) the manipulable objects would be equally divided among 6 super-ordinate (sparse) categories, compared to 2 super-ordinate (crowded)

categories for non-manipulable objects, and (2) the weaker case where the same number of objects were divided into 6 super-ordinate categories (sparse) for manipulable objects compared to 4 super-ordinate categories (crowded) for non-manipulable objects. Again, for more details on the implementation of this, please refer to the Supplementary Appendix.

The results were consistent with the behavioural data, and showed faster categorization of items from crowded categories mapping, but slower naming. Likewise, items from sparse categories had faster naming but slower categorization. Further, the reversal effects were more pronounced when the differences were larger (i.e. larger effects for a 6:2 ratio than a 6:4 ratio of super-ordinate categories). This structure, and reversal, is similar to the reversal predicted by the PACE model and visual crowding hypothesis (cf. Gale, et al., 2006; Gerlach, 2009), except the effects are based on the semantic organization of the system and not on the input (visual similarity).

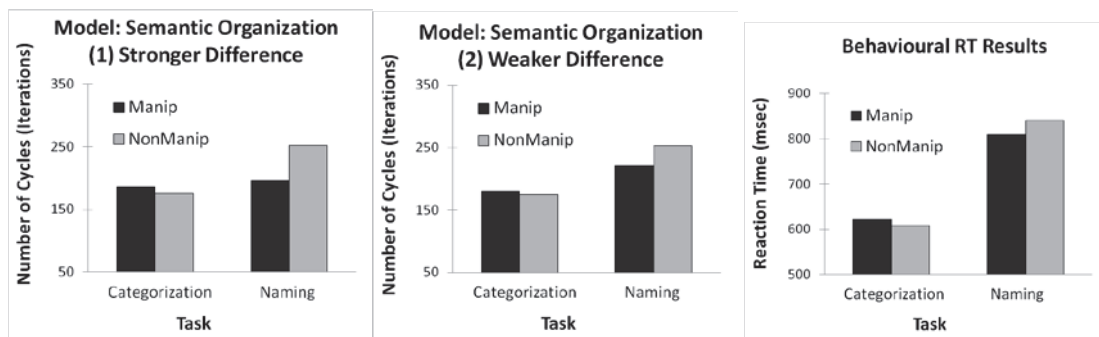


Figure 4.10. Results from semantic organization differences of different strengths. Note: Larger effects of manipulability reversal when differences in organization are more pronounced.

The mechanism can be explained by considering the model dynamics for each possible item presentation.

Naming

1. Non-Manipulable (crowded) naming: Each non-manipulable object (e.g. dog) activates the super-ordinate level representation (e.g. animal) which in turn activates all items within that category (e.g. cat, elephant, giraffe). This activation then creates competition at the item level between items within the category. This competition slows down resolution of the model and leads to slower naming relative to items objects from more sparse categories.
2. Manipulable (sparse) naming: Each manipulable object (e.g. fork) activates the super-ordinate level (e.g. utensil) which activates few item-specific competitors. This smaller competition allows the item-specific representation to accumulate evidence faster. Thus, the model resolves more quickly, and names the item faster relative to items that belong to larger/crowded categories.

Categorization

3. Non-Manipulable (crowded) categorization: Each category label for non-manipulable objects (e.g. animal) activates all of the items within that category (e.g. cat, elephant, giraffe, etc.). This collective activity then feeds back, allowing greater confidence that the item belongs to that category. In other words, the collective activity from all members of the category help the category accumulate evidence faster. Thus, these types of objects are categorized more quickly in comparison to categories with fewer members (relative to more sparse categories).
4. Manipulable (sparse) categorization: Each category label for manipulable objects (e.g. utensil) activates only a few item(s) in item-specific semantics (e.g. fork). This item then feeds back to support category membership. However, because the category is so small the support is minimal (relative to larger more crowded categories) and the object is not categorized as quickly as those from crowded categories.

In other words, the semantic organization (or crowded versus sparse domains) leads to reversed effects in naming and categorization (see *Figure below*). Importantly, these effects were in a direction consistent with behavioural effects found by the authors, and consistent with theory.

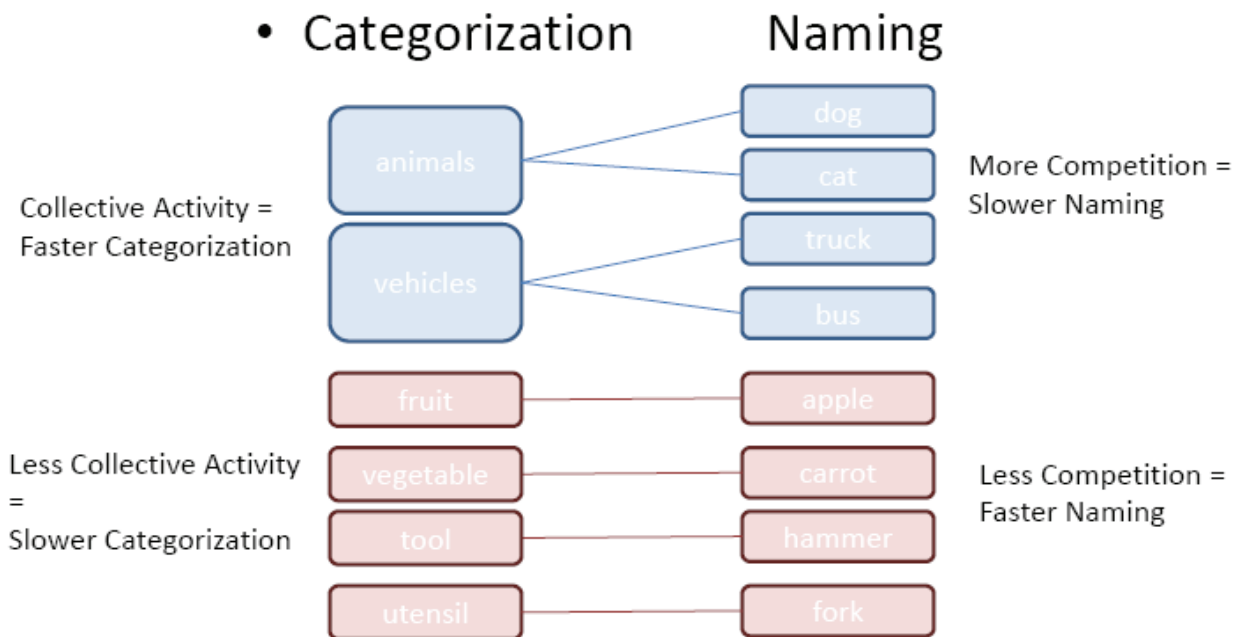


Figure 4.11. A depiction of semantic organization differences that can lead to super-ordinate category-based reversals.

4.4.10 Similarity versus Semantic Organization

Interestingly, although perhaps unsurprisingly, the predictions based along the lines of similarity mirror those of semantic organization. Specifically, categories containing high inter-stimuli visual similarity should be named more slowly due to high inter-item competition. On the other hand, the high precedence of shared visual properties could help the entire category of objects to be categorized more quickly. This could also be true for *action* similarity, with items with highly similar actions (or in the case of non-

manipulable objects: no actions) being categorized more quickly, but named more slowly.

Typically, little effort has been put forth to distinguish between effects of similarity and the semantic organization, as described above. This is probably due to the fact in the real world these two mechanisms are highly related: Categories that contain many similar items tend to crowd together, while categories with fewer or less similar items tend to form smaller more sparse representations. Some would say meaningful superordinate categories or classifications of the world are developed *based* on similarity of the objects in the environment (i.e. similar objects group together semantically)(cf. Rosch, 1975). In other words, object similarity is the mechanism that drives the semantic organization (crowded or sparse) in a system. Thus, discussions about similarity versus semantic organization may be considered attacking two ends of the same phenomena.

However, similarity and semantic organization are *not* the same thing, and it is important to emphasize their differences. Similarity is related to the early effects during processing/structural encoding of the object. Semantic organization, on the other hand, is related to the semantic structure of the semantic system after the organism has effectively developed. In the processing stream this is the difference between an early-stage stimulus-driven and mid-stage system-organization effects. Although it may be difficult to separate these two things in the real world, it can be done with models that include at least two-levels of semantic representation, such as the Naming Action Model presented by Yoon et al. (2002). Thus, with a model one can properly distinguish effects based on similarity versus those based on semantic organization.

4.5 EXPLORING THE PLAUSIBILITY OF THESE MECHANISMS: BACK TO THE STIMULUS SET

As two of the three mechanisms offered plausible accounts of the manipulability effect reversal, it made sense to revisit the real world objects to determine if they could offer a clue about which mechanism was the likeliest. That is, analyses were performed on the original stimulus set (black & white photographs of real-world objects) to determine the extent to which similarity or semantic organization differences could be measured in the stimulus set itself.

An analysis of visual similarity (on the photographs of the objects used) is described in detail in the Salmon, et al.'s (in revision) behavioural manuscript, but the basic finding was that when the object-set was analyzed based on pixel-intensity differences²¹, there was a suggestion of larger visual similarity for manipulable objects as compared to non-manipulable, $F(1,3538) = 42.075, p < .001$. This result was in direct contrast to the direction that would be expected if visual similarity were driving the reversal effect observed between the time to name and categorize manipulable objects. That is, this visual similarity analysis on the real-world objects suggested that visual similarity was not a likely candidate for explaining this reversal effect.

On the other hand, an analysis of semantic organization of the 120 objects had more success. Specifically, when each of the 60 manipulable and 60 non-manipulable objects were categorized into super-ordinate categories, by the experimenter, it was observed that the manipulable objects belonged to significantly more categories than the non-manipulable objects. In order to rule-out experimenter bias, 14 naïve participants

²¹ A method that was akin to measures of Euclidean distance described by Laws & Gale, 2002a, 2002b; Laws, et al., 2002.

were asked to categorize the 120 objects (each participant was presented the object set in a new random order). Participants were not told which categories to use, just to pick super-ordinate categories such that categories would contain more than one object, and to use more than two categories (i.e not to use high-level categories like living/non-living, or manmade/natural). Further, participants were given the following examples to help define a super-ordinate category: a piano and trumpet are ‘musical instruments’ while a nose and arm are ‘body parts’. These were considered good examples, because the set of 120 objects contained no photos of musical instruments or body parts. Although there was variance in the categories chosen by the 14 naïve participants (for example, for “fork” one said “utensil” where another said “kitchen”) all participants agreed, on average, that the 60 manipulable objects belonged to more categories than the 60 non-manipulable objects. This result was significant, $F(1, 13) = 55.615, p < .001$, with the most number of super-ordinate categories being generated for manmade-manipulable objects ($M = 14.4$), and the fewest for natural-non-manipulable objects ($M = 7.4$), see table 4.2.

Table 4.2. Average number of categories generated for 30 objects.

	Manmade	Natural
Manipulable	14.4	11.9
Non-Manipulable	7.5	7.4

These results suggested that when examining the original stimulus set used by Salmon, et al. (in revision) to find a behavioural reversal, a semantic organization difference could be found, in a direction that could explain the reversal effect. On the other hand, the visual similarity differences observed were in the opposite direction than would be expected if visual similarity were driving the reversal. Thus, these analyses of the original stimulus set suggested that semantic organization differences were a more probable mechanism that could underlie this reversal effect.

4.6 GENERAL DISCUSSION

In this paper we explored three mechanisms that might explain a behavioural reversal effect on naming and categorization objects, based on their manipulability (specifically, the effect that manipulability appears to facilitate object naming while hindering object categorization). The three mechanisms that were explored using computational modelling were: (1) a dedicated action module, (2) similarity and (3) semantic organization. Results from the computational model simulations showed that the mechanisms of semantic organization and similarity were each *sufficient*, but not *necessary*, predictors of the pattern of effects of manipulability across the two tasks. They were *sufficient* predictors because each, on their own, simulated the reversing patterns of effects of manipulability across the two tasks; yet they were not *necessary* predictors because each was capable of predicting the pattern without the other. These results imply that either semantic organization or similarity, or both together, play a role in creating the reversal effects observed in behavioural data. In contrast, the model including an action module was neither *necessary* nor *sufficient* to explain this reversal pattern. The action

module was not *necessary*, because the other mechanisms on their own were sufficient to explain the pattern. Nor was it *sufficient*, because it failed to produce categorization results in the correct direction. Instead, the dedicated action model primarily served a facilitatory role in both object naming and categorization.

From these results we can conclude that the action module, as advocated by Humphreys and colleagues (e.g. Chainay & Humphreys, 2002; Humphreys, 2001; Rumiati & Humphreys, 1998; Yoon, et al., 2002), is not sufficient to explain a categorization-naming reversal as was observed in the behavioural data. On the other hand, semantic organization (when non-manipulable objects represent a more crowded domain) *can* sufficiently explain the observed behavioural pattern. Importantly, semantic organization can explain these differences even when no visual similarity differences exist in the object set. This result is particularly important as it suggests that although meaningful semantic categories may form based on object similarity, similarity is not *necessary* for explaining the reversal effects. Instead, the hierarchical category organization of the semantic system, on its own, is sufficient for creating an advantage for naming certain objects that, in turn, reduces how quickly these same objects can be categorized. This illustration is especially poignant given the research by Desmarais and colleagues (2007) showing that action similarity can be an important predictor of the organization and representation of novel objects, independent of visual similarity.

4.6.1 Semantic Organization versus Similarity

As stated at the outset of this article, there are many reasons we might predict smaller and sparser categories for manipulable objects. First, the functional importance. That is, different manipulable objects are used for different purposes (e.g. crayons and

pencils for writing, forks and spoons for eating). As an individual develops, he or she begins to develop different higher-level terminology/categories associated with meaningful categories (“cups” for drinking, “utensils” for eating, “writing tools” for writing). This semantic division into many small (sparse) meaningful functional units likely happens to a much higher degree for manipulable, as there are many different actions and many different contexts, leading to many smaller meaningful categories for manipulable objects (i.e. sparse categories, containing fewer exemplars).

Alternatively, semantic organization differences may be related to the underlying neuroarchitecture activated when processing manipulable objects (cf. Chao & Martin, 2000; Grèzes, et al., 2003). That is, representation of manipulable objects may be more sparse because these objects require more brain areas to build a representation / their representation is more distributed in the brain (cf. Allport, 1985). Either way, cursory evidence, such as research on category potency (Battig & Montague, 1969; Overschelde, et al., 2004), and the re-analysis of our stimulus set outlined in section 4, suggests that these assumptions about manipulable objects may be true. In any event, the results of modeling simulations put forth in this research demonstrates that semantic organization differences create naming by categorization reversal effects. Thus, this mechanism is a strong candidate to explain the categorization-naming reversal effect observed in Salmon et al.’s (in revision) behavioural research. Moreover, this mechanism can explain a reversal independent of stimulus similarity.

As for similarity, it’s easy to imagine a mechanism driven purely by *visual* similarity creating this effect. In which case, our hypothesis would be that the non-manipulable objects judged in the original behavioural study were more visually similar

to each other than the manipulable objects were. However, our re-analysis of the original stimulus set did not support visual similarity in this direction. In fact, the results appeared to suggest differences in the opposite direction (higher similarity of manipulable objects). On the other hand, it's impossible to rule out the importance action similarity may play here. Non-manipulable objects, by definition, have no (or very little) action associated with them. Manipulable objects, on the other hand come with a wide-range of possible actions. Therefore, it could be considered that the set of manipulable objects represented a set with a low degree of action similarity. For instance, the set used by Salmon et al. (in revision) contained a wide range of manipulable objects including fruit and vegetables like a banana or celery and manmade objects like balloon, scissors or paintbrush, all containing very different actions. Thus, it could be said that manipulable objects represent a set of low action similarity relative to non-manipulable objects (that all the same lack of action associated with them). Thus, standard similarity predictions based on *action* similarity would predict faster naming but slower categorization of manipulable objects, as observed by Salmon et al. (in revision). Further, as articulated in the Introduction, Desmarais and colleagues (2007) showed that action similarity can influence object identification. Specifically, assigning objects dissimilar actions causes them to be confused in an identification task less often. Thus, there is support from other laboratories that *action similarity* differences can lead to differences in identification of objects.

In summary, this research suggested the differences observed by Salmon et al. (in revision) were more likely related to either (a) differences in semantic organization or (b) differences in action similarity. In fact, it could be that these are two ways of describing

the same thing. Or rather, mechanisms underlying action similarity and functional use lead to differential organization of semantics for manipulable objects relative to non-manipulable objects. After all, we come to know the world by how we interact with it, and we interact with different objects in different ways. Part of understanding (and ultimately semantics itself) is derived from coming to know which objects can be used for drinking with, which for eating with, which for drawing with, etc.

4.6.2 Limitations & Further Considerations

There are a number of noteworthy limitations of this research. First, although this research shows that the semantic organization mechanism *can* work to explain this behavioural reversal of effects of manipulability, it cannot *prove* that this is the causal mechanism. For example, we've shown at least one other mechanism (similarity) that can also independently generate this effect, and it's probably possible to imagine others. Second, the similarity results suggested that even though visual similarity did not appear to drive the reversal effect underlying the behavioural data, action similarity might play role. However, it was difficult to conceive of a measure of 'action similarity' for objects for which there was no action (i.e. non-manipulable objects). In the section above the argument was made that manipulable objects could be considered a set of objects with low action similarity relative to a set of non-manipulable objects. But the argument that non-manipulable objects are similar compared to manipulable objects based on an attribute they lack (i.e. associated action) is, if nothing else, a little dissatisfying.

Third, this research was focused on explaining the behavioural results obtained between objects which were split in terms of their 'manipulability', or the ease with which an object could be '*grasped and used with one hand*'. However evidence,

especially from Buxbaum and colleagues (Buxbaum & Kalenine, 2010; Buxbaum, et al., 2006; Buxbaum & Saffran, 2002), suggests that there are at least two distinguishable types of manipulability (graspability or functional use), which were necessarily confounded in the behavioural research presented by Salmon et al. (in revision) (see also Bub & Masson, 2012; Bub, et al., 2008 for exploration of the different types of manipulability). If we had to hypothesize about which type of manipulability (graspability or functional use) was driving the reversal effect, based on this model we might predict *functional use* manipulability, since functional use knowledge requires semantics ('are the actions made to use this object different from those made to pick it up') and the semantic organization mechanism is entirely a semantic-based explanation of the effects. Certainly, future research will need to be employed to attempt to further disambiguate the role of *functional use* manipulability from that of the standard definitions, which tend to be along the lines of 'graspability' or 'volumetric' gestures.

4.6.3 Conclusion

Using an extension of Yoon, Heinke and Humphreys' (2002) computational Naming Action Model, we were able to simulate a manipulability-based reversal effect across the tasks of object naming and categorization based on semantic organization in the system and similarity of the objects. However, implementation of a dedicated action module did not appear to capture the nature of this reversal effect, suggesting that a dedicated action module was not necessary to re-capture the behavioural pattern observed by Salmon et al. (in revision).

In contrasting the remaining possibilities (semantic organization versus similarity), an analysis of the original stimulus set suggested that visual similarity

differences were not consistent with the observed effect, but semantic organization effects were. This indicated that semantic organization differences (in particular, more sparse categories for manipulable objects and more crowded for non-manipulable) were a probable mechanism for explaining the naming/categorization reversal observed by Salmon et al. (in revision). However, this analysis was unable to completely rule the possible influence of action similarity. Action similarity differences may be underlying this reversal effect, or at the very least, be related to the mechanism that leads to semantic organization differences in the first place.

4.7 REFERENCES

- Allport, D. A. (1985). Distributed memory, modular subsystems and dysphasia. In S. K. Newman & R. Epstein (Eds.), *Current Perspectives in Dysphasia* (pp. 32-60). Edinburgh: Churchill Livingstone.
- Bacon-Macé, N., Kirchner, H., Fabre-Thorpe, M., & Thorpe, S. J. (2007). Effects of task requirements on rapid natural scene processing: From common sensory encoding to distinct decisional mechanisms. *Journal of Experimental Psychology: Human Perception and Performance*, 33(5), 1013-1026.
- Bacon-Macé, N., Macé, M. J. M., Fabre-Thorpe, M., & Thorpe, S. J. (2005). The time course of visual processing: Backward masking and natural scene categorisation. *Vision Research*, 45(11), 1459-1469.
- Battig, W. F., & Montague, W. E. (1969). Category norms for verbal items in 56 categories: A replication and extension of the Connecticut category norms. *Journal of Experimental Psychology Monograph*, 80(3), 1-46.
- Bonin, P., Peereman, R., Malardier, N., Méot, A., & Chalard, M. (2003). A new set of 299 pictures for psycholinguistic studies: French norms for name agreement, image agreement, conceptual familiarity, visual complexity, image variability, age of acquisition, and naming latencies. *Behavior Research Methods, Instruments & Computers*, 35(1), 158-167.
- Boronat, C. B., Buxbaum, L. J., Coslett, H. B., Tang, K., Saffran, E. M., Kimberg, D. Y., et al. (2005). Distinctions between manipulation and function knowledge of objects: Evidence from functional magnetic resonance imaging. *Cognitive Brain Research*, 23(2-3), 361-373.

- Bowers, J. S. (2009). On the Biological Plausibility of Grandmother Cells: Implications for Neural Network Theories in Psychology and Neuroscience. [Article]. *Psychological Review*, 116(1), 220-251.
- Bowers, J. S. (2010). More on Grandmother Cells and the Biological Implausibility of PDP Models of Cognition: A Reply to Plaut and McClelland (2010) and Quian Quiroga and Kreiman (2010). [Article]. *Psychological Review*, 117(1), 300-308.
- Bub, D. N., & Masson, M. E. J. (2012). On the dynamics of action representations evoked by names of manipulable objects. *Journal of Experimental Psychology: General*, 141, 502-517.
- Bub, D. N., Masson, M. E. J., & Cree, G. S. (2008). Evocation of functional and volumetric gestural knowledge by objects and words. *Cognition*, 106(1), 27-58.
- Buxbaum, L. J., & Kalenine, S. (2010). Action knowledge, visuomotor activation, and embodiment, in the two action systems. *Annals of the New York Academy of Sciences*, 1191, 201-218.
- Buxbaum, L. J., Kyle, K. M., Tang, K., & Detre, J. A. (2006). Neural substrates of knowledge of hand postures for object grasping and functional object use: Evidence from fMRI. *Brain Research*, 1117, 175-185.
- Buxbaum, L. J., & Saffran, E. M. (2002). Knowledge of object manipulation and object function: Dissociations in apraxic and nonapraxic subjects. *Brain and Language*, 82(2), 179-199.
- Buxbaum, L. J., Veramonti, T., & Schwartz, M. F. (2000). Function and manipulation tool knowledge in apraxia: Knowing 'what for' but not 'how.'. *Neurocase*, 6(2), 83-97.

- Catling, J. C., Dent, K., & Williamson, S. (2008). Age of acquisition, not word frequency affects object recognition: Evidence from the effects of visual degradation. *Acta Psychologica, 129*(1), 130-137.
- Chainay, H., & Humphreys, G. W. (2002). Privileged access to action for objects relative to words. *Psychonomic Bulletin & Review, 9*(2), 348-355.
- Chao, L. L., & Martin, A. (2000). Representation of manipulable manmade objects in the dorsal stream. *NeuroImage, 12*, 478-484.
- Connor, C. E. (2005). Neuroscience: Friends and grandmothers. [Article]. *Nature, 435*(7045), 1036-1037.
- Cuetos, F., & Alija, M. (2003). Normative data and naming times for action pictures. *Behavior Research Methods, Instruments & Computers, 35*(1), 168-177.
- Dent, K., Catling, J. C., & Johnston, R. A. (2007). Age of acquisition affects object recognition: Evidence from visual duration thresholds. *Acta Psychologica, 125*(3), 301-318.
- Dent, K., Johnston, R. A., & Humphreys, G. W. (2008). Age of acquisition and word frequency effects in picture naming: A dual-task investigation. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 34*(2), 282-301.
- Desmarais, G., & Dixon, M. J. (2005). Understanding the structural determinants of object confusion in memory: An assessment of psychophysical approaches to estimating visual similarity. *Perception & Psychophysics, 67*(6), 980-996.
- Desmarais, G., Dixon, M. J., & Roy, E. A. (2007). A role for action knowledge in visual object identification. *Memory & Cognition, 35*(7), 1712-1723.

- Gaffan, D., & Heywood, C. A. (1993). A spurious category-specific visual agnosia for living things in normal human and nonhuman primates. *Journal of Cognitive Neuroscience*, 5(1), 118-128.
- Gale, T. M., Done, D. J., & Frank, R. J. (2001). Visual crowding and category specific deficits for pictorial stimuli: A neural network model. *Cognitive Neuropsychology*, 18(6), 509-550.
- Gale, T. M., Laws, K. R., & Foley, K. (2006). Crowded and sparse domains in object recognition: Consequences for categorization and naming. *Brain and Cognition*, 60(2), 139-145.
- Gerlach, C. (2009). Category-specificity in visual object recognition. *Cognition*, 111(3), 281-301.
- Gerlach, C., Law, I., & Paulson, O. B. (2004). Structural similarity and category-specificity: A refined account. *Neuropsychologia*, 42(11), 1543-1553.
- Gerlach, C., Law, I., & Paulson, O. B. (2006). Shape configuration and category-specificity. *Neuropsychologia*, 44(7), 1247-1260.
- Grèzes, J., Tucker, M., Armony, J., Ellis, R., & Passingham, R. E. (2003). Objects automatically potentiate action: An fMRI study of implicit processing. *European Journal of Neuroscience*, 17(12), 2735-2740.
- Humphreys, G. W. (2001). Objects, affordances...action! *The Psychologist*, 14(8), 408-412.
- Humphreys, G. W., & Forde, E. M. E. (2001). Hierarchies, similarity, and interactivity in object recognition: 'Category-specific' neuropsychological deficits. *Behavioral and Brain Sciences*, 24(3), 453-509.

- Humphreys, G. W., Riddoch, M. J., & Quinlan, P. T. (1988). Cascade processes in picture identification. *Cognitive Neuropsychology*, 5(1), 67-104.
- Kalénine, S., & Bonthoux, F. (2008). Object manipulability affects children's and adult's conceptual processing. *Psychonomic Bulletin & Review*, 15(3), 667-672.
- Kirchner, H., & Thorpe, S. J. (2006). Ultra-rapid object detection with saccadic eye movements: Visual processing speed revisited. *Vision Research*, 46(11), 1762-1776.
- Laws, K. R., & Neve, C. (1999). A 'normal' category-specific advantage for naming living things. *Neuropsychologia*, 37(11), 1263-1269.
- Overschelde, J. P. V., Rawson, K. A., & Dunlosky, J. (2004). Category norms: An updated and expanded version of the Battig and Montague (1969) norms. *Journal of Memory and Language*, 50, 289-335.
- Pérez, M. A. (2007). Age of acquisition persists as the main factor in picture naming when cumulative word frequency and frequency trajectory are controlled. *The Quarterly Journal of Experimental Psychology*, 60(1), 32-42.
- Plaut, D. C., & McClelland, J. L. (2010). Locating Object Knowledge in the Brain: Comment on Bowers's (2009) Attempt to Revive the Grandmother Cell Hypothesis. [Article]. *Psychological Review*, 117(1), 284-290.
- Quiroga, R. Q., & Kreiman, G. (2010). Measuring Sparseness in the Brain: Comment on Bowers (2009). [Article]. *Psychological Review*, 117(1), 291-299.
- Rosch, E. (1975). Cognitive representations of semantic categories. *Journal of Experimental Psychology: General*, 104(3), 192-233.

- Rousselet, G. A., Macé, M. J. M., & Fabre-Thorpe, M. (2003). Is it an animal? Is it a human face? Fast processing in upright and inverted natural scenes. *Journal of Vision*, 3(6), 440-455.
- Rumiati, R. I., & Humphreys, G. W. (1998). Recognition by action: Dissociating visual and semantic routes to action in normal observers. *Journal of Experimental Psychology: Human Perception and Performance*, 24(2), 631-647.
- Salmon, J. P., Matheson, H. E., & McMullen, P. A. (in revision). The influence of object manipulability on categorization and naming of backward-masked photographs shown for brief durations: A reversal effect for object manipulability. *Visual Cognition*.
- Salmon, J. P., McMullen, P. A., & Filliter, J. H. (2010). Norms for two types of manipulability (graspability and functional usage), familiarity, and age of acquisition for 320 photographs of objects. *Behavior Research Methods*, 42(1), 82-95.
- Thorpe, S. J. (2009). The speed of categorization in the human visual system. *Neuron (Previews)*, 62, 168-170.
- Tranel, D., Logan, C. G., Frank, R. J., & Damasio, A. R. (1997). Explaining category-related effects in the retrieval of conceptual and lexical knowledge for concrete entities: Operationalization and analysis of factors. *Neuropsychologia*, 35(10), 1329-1339.
- Turnbull, O. H., & Laws, K. R. (2000). Loss of stored knowledge of object structure: Implications for 'category-specific' deficits. *Cognitive Neuropsychology*, 17(4), 365-389.

- Warrington, E. K., & Shallice, T. (1984). Category specific semantic impairments. *Brain*, *107*, 829-854.
- Wolk, D. A., Coslett, H. B., & Glosser, G. (2005). The role of sensory-motor information in object recognition: Evidence from the category-specific visual agnosia. *Brain and Language*, *94*, 131-146.
- Yoon, E. Y., Heinke, D., & Humphreys, G. W. (2002). Modelling direct perceptual constraints on action selection: The Naming and Action Model (NAM). *Visual Cognition*, *9*(4-5), 615-661.

4.8 SUPPLEMENTARY APPENDIX SA1. NAMING ACTION MODEL EXTENSION DETAILS

The original technical details used by Yoon, Heinke and Humphreys (2002) Naming Action Model (NAM) are included in great detail in their Appendices, and thus this Appendix will focus on elaborating the differences between their model and the current extension.

Input Vectors

In Yoon, Heinke and Humphreys' (2002) model, they described a structural- featural decomposition method for decoding real-world objects that involved something like: counting the number of each feature and using those counts as input to network/model. This method would create a vector (list) of numbers that would be different for each object. In the current model, it was decided that beginning with random vectors of numbers (to represent each object) would be both (a) simple, and (b) free of confounds. Thus, for the current model, each object was created by generating a random vector of numbers with a default of 15 values (15 features) and whole-number values that would vary between the range of 0 and 20.

4.8.1 The Action Module

Another key difference between the current model and that of Heinke and Humphreys' (2002) NAM was that their model only examined manipulable objects, but the current model was meant to analyse both manipulable and non-manipulable objects.

Thus, for the current model, the action module needed to be turned off for non-manipulable objects.

In addition, our extension included versions of the model in which the action network was entirely absent. That is, during testing of the symmetry model, semantic organization, and similarity, the action module was not used at all. Therefore the item specific semantics module ($y^{item}(t)$) equation needed to be updated to:

$$y^{item}(t) = ITEM(y^{input} + y^{o_item}(t) + a^{ci} \cdot w^{sup_itemT} \cdot y^{sup}(t))$$

where y^{input} was the input from the structural description system, $y^{o_item}(t)$ was the feedback from the name output layer, and $a^{ci} \cdot w^{sup_itemT} \cdot y^{sup}(t)$ was the feedback from the superordinate knowledge layer. This was identical to the equation used in the NAM, with the exception of the exclusion of feedback from the action module ($a^{al} \cdot y^{act}(t)$)²². The original equation (eqn 7 from Yoon, Heinke and Humphreys) looked like this:

$$y^{item}(t) = ITEM(y^{input} + y^{o_item}(t) + a^{ci} \cdot w^{sup_itemT} \cdot y^{sup}(t) + a^{al} \cdot y^{act}(t))$$

4.8.2 New Categorization (Output Module)

The NAM depicted a single output naming layer with a state that would bias towards naming at the specific or at a higher-level superordinate level. The equation NAM used for this module (equation 8) was:

$$[y^{o_item}(t), y^{o_sup}(t)] = OUT([y^{item}(t) + y^{word} + c_1, y^{sup}(t) + c_2])$$

where the notation $[. , .]$ stated the fact that two sets of units were combined to be part of one Winner-Take-All layer. y^{word} was set to zero if objects were used, and c_1 and c_2 were

²² Note: a^{ci} and a^{al} were both constants values set to control the strength of the connection between two modules in the network. w^{sup_itemT}

control units whose values determined if naming operated at a superordinate level ($c_1 = 0$ and $c_2 = 1$) or an item-specific level ($c_1 = 1$ and $c_2 = 0$). In the current model, we wanted to directly compare time to identify at both levels, so we, instead, separated and depicted the item-specific output and super-ordinate output as two separate modules. Thus, the item-specific output (or naming output) module could be represented with the equation:

$$y^{o-item}(t) = ITEM_OUT(y^{item}(t))$$

where there was never any word input (and not worth including in the equation), and no need for bias (and therefore no c_1 and c_2). Instead, this module simply got input from semantics. The corresponding new super-ordinate output (or categorization output layer) could be represented similarly with the equation:

$$y^{o-sup}(t) = CAT_OUT(a^{scat} \cdot y^{sup}(t))$$

where a^{scat} was a constant that could specify the strength of the connection between semantics and categorization output layer (its default value was 1.5, which was similar in strength to the constants used in the other modules).

4.8.3 Semantic Organization

Semantic organization differences were modeled in these simulations not by changing the equations and connections in the models, but by changing the ideal-mapping between two modules. Specifically, the item-specific semantic module and superordinate semantic module always had a different number of nodes (more item-specific) and the network needed to ‘learn’ weights to do the proper computation between them. In addition, the model needed to ‘learn’ the correct mapping between input to correct answer. The learning algorithm used in this model was described in detail by

Yoon, Heinke & Humphreys (2002), but, an important element of the process was specifying to the network the IDEAL output at each node for a given input pattern (object).

Thus, if we wanted 24 objects (12 manipulable, 12 non-manipulable) completely balanced across semantics, we could set an ideal matrix as such:

```

1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1

```

where each object (column) maximally fires one of four super-ordinate categories, and six objects activate the first category, six the second, and so on.

If, instead, we wanted to create an imbalance where manipulable objects activate more super-ordinate categories than non-manipulable categories, that would just increase the number of super-ordinate categories/nodes, and set the ideal mapping between item and category to be the following (for 3:1 mapping):

```

1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1

```

where objects 1 through 6, and 13 through 18 are manipulable objects, and a total of eight super-ordinate categories now exist. In the above example, you could say that each manipulable category contains 2 items, and each non-manipulable category contains 6 items (1:3). You could also say, in the above example, that there is a total of 6

manipulable categories for which the same number of non-manipulable items only belong to two categories.

Using this method of specifying the ideal mapping between item-specific and superordinate semantic modules, it was possible to control precisely the ratios and therefore explore stronger and weaker effects of semantic organization on object naming and object categorization.

4.8.4 Similarity

As described in the text, objects could be made more ‘similar’ to each other by directly making a % of the numbers representing the objects equal to each other. If, to use Yoon, Heinke & Humphrey’s analogy of each number representing a feature (e.g. number of straight lines, number of curvy lines, number of vertices) then doing so would be akin to making features of objects very similar to one another. The exact code to make objects similar was pretty straight-forward, and therefore won’t be elaborated on here, but can be found in the MATLAB code supplementary Appendix.

4.8.5 Force Choice Model

Finally, the superordinate output module ($y^{o_sup}(t)$) was modified one final time for the force-choice simulations, this meant changing the equation to:

$$y^{o_sup}(t) = CAT_OUT(a^{scat} \cdot w^{o_CAT} \cdot y^{sup}(t))$$

which included the addition of w^{o_CAT} : a vector of weights to convert the superordinate semantic module down to a module with only two nodes (force-choice). w^{o_CAT} was

calculated with the same learning algorithm used to calculate the rest of the weights, and an ideal matrix that specified the correct mapping. For example, the ideal matrix used in the balanced case (4 categories, would have been):

$$\begin{array}{cccc} 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 \end{array}$$

where each column represents the correct choice (force-choice) for each superordinate group. For example, column1 could show that the first category was manipulable, the second non-manipulable, third manipulable, and fourth manipulable.

To use another example, the ideal for a 3:1 ratio (3 manip categories for each 1 non-manip category) from the example before, if categorization was based on manipulability would be:

$$\begin{array}{cccccc} 1 & 1 & 1 & 0 & 1 & 1 & 1 & 0 & \text{(manipulable)} \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & \text{(non-manipulable)} \end{array}$$

However, our simulations were based on behavioural data in which the categorized dimension was orthogonal to manipulability (manmade vs natural) and thus, the ideal we used would more likely look balanced like this:

$$\begin{array}{cccccc} 1 & 1 & 1 & 0 & 1 & 0 & 0 & 0 & \text{(manmade)} \\ 0 & 0 & 0 & 1 & 0 & 1 & 1 & 1 & \text{(natural)} \end{array}$$

with each force-choice answer (manmade vs. natural) being correct an equal number of times across the entire set of objects.

4.9 SUPPLEMENTARY APPENDIX SA2. MATLAB SYNTAX FOR MODIFIED NAMING ACTION MODEL

In addition to the main program, there were 3 functions (dependencies) that were required, listed below.

Functions Called By Program (dependencies)

LA2.m

```
function LA2=LA2(x, input, tau, a)

% WTA layer (LA)
% leaky integrator... inhibition
LA2 = x + tau*(-x-(a*(sum(y(x))-1))+input); % equation 3 from Yoon
et al. (2002)

return
```

y.m

```
function y=y(x)
% Modified sigmoid function (piecewise linear)
m=0.5;
s=0.95;

%y=x;
y=4*m*(x-s)+0.5;
y=y.*(y>0);
y=y.*(y<1)+(y>=1);
return
```

Gaussian.m

```
function Gaussian = Gaussian(x, StdDev)

% Simplify bottom of equation (-2*StdDev^2)
Divide = -2 * (StdDev^2);

Gaussian = exp((x).^2)./Divide);

return;
```


Main Program

Note that the program presented below can be used to simulate all three mechanisms described in the paper by changing the values in “MODEL OPTIONS”. For example, to turn on the dedicated action module while leaving semantic organization differences and similarity off, parameters should be set:

```
ActionOn = 1; % 0=no action module, 1=action module on, 2=grouped action (natural same action)
ImbalanceOn = 0; % 0 = no semantic imbalance, 1= 1:3 ratio, 2 = 2:3 ratio
SimilarityOn = 0; % 0 = no similarity, 1 = Non-manip Similar...
```

Likewise, semantic organization difference can be set using the options:

```
ActionOn = 0; % 0=no action module, 1=action module on, 2=grouped action (natural same action)
ImbalanceOn = 1; % 0 = no semantic imbalance, 1= 1:3 ratio, 2 = 2:3 ratio
SimilarityOn = 0; % 0 = no similarity, 1 = Non-manip Similar...
```

There is also an option to control the level of similarity (when similarity is turned on), which needs to be a value between 0 and 1:

```
SimilarityAmount = 0.60; % percent similarity (only matters if similarity turned on).
```

Control for how many simulations (# of iterations to conduct upon execution of the code):

```
% Number of iterations (controls how many simulations to run).
iterations = 4; %iterations = 10;
```

Control over whether or not do use the model default or a force-choice categorization²³

(where `SmallerCats = 1` indicates to use of force-choice categorization):

```
SmallerCats = 1; % 0 = No, 16 each. 1= Yes (2 categories...)
```

And, control over whether or not to use the same random input on each simulation or to generate new input on each iteration:

```
RandInput = 1; % 0 = calls the same random input, 1= New rand input every time
```

Thus, the code below contains the options/building blocks to simulate all simulations/results presented in this research.

Main program here:

```
% -----  
%  
% Modifications of the Yoon, Heinke and Humphreys (2002) Naming Action  
% Model (NAM) as done by Joshua Paul Salmon.  
%  
% Version 51 - Added option to choose between 16 and 2 superO categories  
% Extended Model - fixed some of the learning and dependencies  
%  
%     @@@ Most recent modifications, June 2011  
%  
% NOTE: These simulations represent visually presented objects (only)  
% -----  
  
% This program calls (requires) the following functions:  
% Gaussian.m  
% y.m  
% LA2.m  
  
% This program, further, grabs (requires) data from the following files:  
% itemINPUT2.txt  
% IdealACT.txt  
% IdealACT2.txt  
% IdealSUP_manip4.txt  
% IdealSUP_m4a.txt  
% IdealSUP_Balanced.txt  
%  
  
clear; clf; % clear previous states & variables  
  
% #####  
% MODEL OPTIONS  
% -----  
RandInput = 1; % 0 = calls the same random input, 1= New rand input every time  
  
% Action Module Options
```

²³ Note that “force-choice” model was a model to describe categorization between only two-categories. This model is no longer described in the manuscript.

```

ActionOn = 0; % 0=no action module, 1=action module on, 2=grouped action (natural same
action)

% Semantic Organization Options
ImbalanceOn = 0; % 0 = no semantic imbalance, 1= 1:3 ratio, 2 = 2:3 ratio
SmallerCats = 0; % 0 = No, 16 each. 1= Yes (2 categories...)

% Similarity Options
SimilarityOn = 1; % 0 = no similarity, 1 = Non-manip Similar...
SimilarityAmount = 0.60; % percent similarity (only matters if similarity turned on).

% Number of iterations (controls how many simulations to run).
iterations = 4; %iterations = 10;

% #####
% MODEL PARAMETERS / DEFAULT VALUES
% -----

vector_size = 18; % how many distinct features for each object
nitems      = 24; % total number of items (used to be 32)
nsupcat     = 16; % total number of superordinate categories(in semantics)
nACT        = 6;  % total number of distinct ACTIONS identified by network

% ncat = # of Super-ordinate categories
% If SmallerCats==1, ncat=2, else ncat=16 (code below).
ncat = ((SmallerCats==0)*16)+(SmallerCats*2);

tic; % time code (start clock)

% #####
for iters = 1:iterations;

% #####
% LOAD / RANDOMIZE INPUTS (based on options)

% Loading the Input Vectors for each item.
fid3 = fopen('itemINPUT2.txt'); % this is input is random (but the same random every
time.
inputMATRIX = fscanf(fid3, '%g %g %g %g %g %g %g %g %g %g %g %g %g %g', [vector_size
inf]);
if RandInput==1; % overwrite if this option set
    inputMATRIX = round(20*rand(vector_size,nitems)); % set to something new (randomly)
end;

% Load Similarity (if its turned on).
if SimilarityOn==1; % set 12 of the items (non-manip) to be within-cat similar
    similarRows = floor(SimilarityAmount*vector_size);

    for row = 8:12;
        inputMATRIX(1:similarRows,row) = inputMATRIX(1:similarRows,7);
        inputMATRIX(1:similarRows,row+12) = inputMATRIX(1:similarRows,19);
    end;
end;

% Load Action Output Module - IDEAL values
if ActionOn==1;
    fid = fopen('IdealACT.txt');
else
    fid = fopen('IdealACT2.txt'); % natural objects non-unique actions
end;
ACT_ideal = fscanf(fid, '%g %g %g %g %g %g', [6 inf]);

% Load Semantics (Ideal mapping between super-ordinate and item-specific)
if ImbalanceOn==1;
    fid2 = fopen('IdealSUP_manip4.txt'); % this is 1:3 effect
elseif ImbalanceOn==2;

```

```

    fid2 = fopen('IdealsUP_m4a.txt'); % 2:3 ratio here!!
else
    fid2 = fopen('IdealsUP_Balanced.txt');
end;
ySUP_orbfIDEAL = fscanf(fid2, '%g %g %g %g %g %g %g %g %g %g %g %g %g %g %g', [nsupcat
inf]);
ySUP_orbfIDEAL = ySUP_orbfIDEAL';

% Switch to force-choice categorization (if turned on).
% Need weights from SUP(semantic) to CAT (2 levels)
if SmallerCats==1;
    yCAT_orbfIDEAL = [1,1,1,1,1,1,1,1,0,0,0,0,0,0,0,0;
                    0,0,0,0,0,0,0,0,1,1,1,1,1,1,1,1];

    % set weights to ideal (pre-learned).
    W_o_CAT = yCAT_orbfIDEAL;
end;

fclose('all');
% Now the following have been loaded:
% inputMATRIX, ACT_ideal, & ySUP_orbfIDEAL

% #####
%   OBJECTS & WEIGHTS
% #####

% Now I want to set the weights for the hidden layer equal to input vector
x_feature = inputMATRIX;
wgt_hObject = x_feature;

% Want to do input using a radial basis function.
StdDevObject = 13; StdDevWord = 1; lamda = 0.2;
StdDevCat = 6; % StdDev of category
str = 0.5; %strength of input to model
catStr = 1/16;

% Also want to construct weights between hidden & output layer.
for input = 1:nitems;
    %The Euclidean distance d between two vectors X and Y is:
    %d = sum((x-y).^2).^0.5
    for compare = 1:nitems; %This caculates Euclidean distance between current and others
        Euclidean(compare,input) = sum((x_feature(:,input)-
wgt_hObject(:,compare)).^2).^0.5;
    end %Finish calculating distances for this input

    % Gaussian(input, stdDev) % y_hrbf represents firing of hidden layer
    y_hrbf = Gaussian(Euclidean, StdDevObject); %y_hrbf is a 32x32 matrix (with 1 across
diag)

end; %stop running for all 32 input.

%But... want to use the identity matrix to calculate W_o
% W_o = Ycat_orbfIDEAL' * inv(y_hrbf + lamda*I)
W_o = ySUP_orbfIDEAL' * inv(y_hrbf + lamda*eye(nitems));
% (this is doing the learning)

% W_sup_item = is the mapping from Semantics Item to SUPERORDINATE module
W_sup_item = W_o; % !!!

% calculate weights to action network
W_o_ACT = ACT_ideal * inv(y_hrbf + lamda*eye(nitems));

SupCat_input = ySUP_orbfIDEAL'; % !!!

Ycat_orbf = W_o * y_hrbf; % at the category level (16)

y_orbf = y_hrbf; % at the item level (32)

% #####

```

```

% EVALUATE THE OBJECTS (one at a time)
% #####

% -----
% Setting up WTA networks defaults
%defaults: a_al = 1.5; a_ci = 2;
a_al = 1.5; a_ci = 2; a_scat = 1.5;
threshold = .7; %threshold = .9;
MAX_time = 500; % max iterations to search for a winner % 700

% -----
% PARAMETERS (strengths of each module)
tau_ACT = 0.0025; a_ACT = 8;
tau_SUP = 0.0038; a_SUP = 8;
tau_CAT = 0.0025; a_CAT = 8;
tau_ITEM = 0.0038; a_ITEM = 13;

% LOOP: Setting which object the system is evaluating
for object = 1:nitems; % 18 last of manipulable... 19 non-manip (when N=24)

% set input based on current item (* activity in network)
input = str*y_orbf(:,object)'; % set item level input
sup_input = str*SupCat_input(:,object)'; % set category level input

% -----
% ZEROing each module/layer at the start (no activation to start)
x_ACT=zeros(MAX_time,nACT); % ACT for action output
y_ACT=zeros(MAX_time,nACT);
x_SUP=zeros(MAX_time,length(sup_input)); % SUP for superordinate semantics
y_SUP=zeros(MAX_time,length(sup_input));
x_ITEM=zeros(MAX_time,length(input)); % ITEM for item-specific semantics
y_ITEM=zeros(MAX_time,length(input));
x_CAT=zeros(MAX_time,ncat); % CAT for CATEGORIZATION module (modification by JPS)
y_CAT=zeros(MAX_time,ncat);

% SEMANTIC (Naming & Categorization) modules
%(seperate ones for naming at the specific OR superordinate level)
x_o_item=zeros(MAX_time,length(input));
y_o_item=zeros(MAX_time,length(input));
x_o_sup=zeros(MAX_time,length(sup_input));
y_o_sup=zeros(MAX_time,length(sup_input));

% SUPERordinate stuff
% figure out output of category that is suppose to win
[Y,correctSUP] = max(ySUP_orbfIDEAL(object,:));

% CATEGORICAL stuff
if SmallerCats==1;
    Y2cat_temp = yCAT_orbfIDEAL';
    [Y,correctCategory] = max(Y2cat_temp(correctSUP,:));
else
    correctCategory = correctSUP;
end;

% Figure out correct action
[Y,correctACT] = max(ACT_ideal(:,object));

% calculate whether object is manipulable
manipulable(object) = sum(ACT_ideal(:,object));

% -----
%
% WTA (Winner-Take-All), run the network through time...
%
% -----

for t=2:MAX_time

% -----
% LA2(x,input) = x + tau*(-x-(a*(sum(y(x))-1))+input);

```

```

% where x is the what the layer is currently doing
% where input is the object/word representation

% -----
% ACTION (OUTPUT) layer/module
% -----

% Since this is an object, the direct route to action is included.
if ActionOn>=1; % if manipulable, compute as normal
    % need mapping mechanism for input
    x_ACT(t,:) = LA2(x_ACT(t-1,:),a_al*input*W_o_ACT' + y_ITEM(t-1,)*W_o_ACT',
tau_ACT, a_ACT);

    %xt2(t-1,:) = y_act(t,:);
    y_ACT(t,:) = y(x_ACT(t,:));
end;

% -----
% ITEM (SEMANTICS) layer/module
% -----

if ActionOn>=1; % incorporate action input
    x_ITEM(t,:) = LA2(x_ITEM(t-1,:),input + y_o_item(t-1,:) +
a_ci*(W_sup_item*y_SUP(t-1,:))' + a_al*y_ACT(t-1,)*W_o_ACT, tau_ITEM, a_ITEM);
else % otherwise act as if action is not there
    x_ITEM(t,:) = LA2(x_ITEM(t-1,:),input + y_o_item(t-1,:) +
a_ci*(W_sup_item*y_SUP(t-1,:))', tau_ITEM, a_ITEM);
end;
% input - (object), y_o_item - Naming output layer, y_SUP - superordinate, y_ACT -
action layer

y_ITEM(t,:) = y(x_ITEM(t,:));

% -----
% SUPERORDINATE (SEMANTICS) layer/module
% -----

if SmallerCats==0;
    x_SUP(t,:) = LA2(x_SUP(t-1,:),sup_input + (a_scat*y_CAT(t-1,:)) + (a_ci *
W_sup_item * y_ITEM(t-1,:))',tau_SUP,a_SUP);
else
    x_SUP(t,:) = LA2(x_SUP(t-1,:),sup_input + (a_scat*(W_o_CAT*y_CAT(t-1,:))' +
(a_ci * W_sup_item * y_ITEM(t-1,:))',tau_SUP,a_SUP);
end;

y_SUP(t,:) = y(x_SUP(t,:));

% -----
% CATEGORIZING (OUTPUT) layer/module
% -----

% Link only through semantics
if SmallerCats==1;
    %x_CAT(t,:) = LA2(x_CAT(t-1,:), (W_o_catSup*sup_input)' + (W_o_catSup*y_SUP(t-
1,))', 0.0025, 8);
    x_CAT(t,:) = LA2(x_CAT(t-1,:), (a_scat*(W_o_CAT*y_SUP(t-1,))'), tau_CAT, a_CAT);
else
    x_CAT(t,:) = LA2(x_CAT(t-1,:), (a_scat*y_SUP(t-1,)), tau_CAT, a_CAT);
end;
% update overall model
y_CAT(t,:) = y(x_CAT(t,:));

% -----
% NAMING (OUTPUT) layer/module
% -----

% [y_o_item(t), y_o_sup(t)] = OUT([ y_ITEM(t) + y_word + c1, y_SUP(t) + c2]
x_o_item(t,:) = LA2(x_o_item(t-1,:),y_ITEM(t-1,),tau_ITEM,a_ITEM);
y_o_item(t,:) = y(x_o_item(t,:));

```

```

% #####
% Calculate CORRECT output for each network
PhonOut(t,object) = y_o_item(t,object); % Item-specific name
ActionOut(t,object) = y_ACT(t,correctACT); % Action (appropriate action)
CatOut(t,object) = y_CAT(t,correctCategory); % Category Network Output
CategoryOut(t,object) = y_o_item(t,correctSUP); % Superordinate Name

end %t ... iterate through time

end % object ... iterate through objects

%#####
% PLOTTING: 'MANIPULABLE' & 'NON-MANIPULABLE' naming & categorizations RTs

% Grab network values for manipulable/non-manipulable objects
manip_PhonOut = PhonOut(:,manipulable==1);
nonmanip_PhonOut = PhonOut(:,manipulable==0);
manip_CatOut = CatOut(:,manipulable==1);
nonmanip_CatOut = CatOut(:,manipulable==0);
m_PhonMean = mean(manip_PhonOut');
m_CatMean = mean(manip_CatOut');
nm_PhonMean = mean(nonmanip_PhonOut');
nm_CatMean = mean(nonmanip_CatOut');

% CAPTURE the point at which network passes threshold (RTs)
[value,mPhon_Point] = min((m_PhonMean>=threshold).*m_PhonMean + (m_PhonMean<threshold));
[value,mCat_Point] = min((m_CatMean>=threshold).*m_CatMean + (m_CatMean<threshold));
[value,nmPhon_Point] = min((nm_PhonMean>=threshold).*nm_PhonMean +
(nm_PhonMean<threshold));
[value,nmCat_Point] = min((nm_CatMean>=threshold).*nm_CatMean + (nm_CatMean<threshold));

% Save the points at which they crossed threshold (RTs) into 'IterDat'
IterDat(itors,:) = [mCat_Point, nmCat_Point, mPhon_Point, nmPhon_Point];
itors % count the iterations (print) so user can watch progress

end; % end META loop

% Fix values for any non-resolved conditions
IterDat2 = IterDat; IterDat2(IterDat2<2)=MAX_time;

% plot averages across iterations
sumPlot = mean(IterDat2);
bar(sumPlot, 'g')
xlabel(['Manip Cat ', 'NonManip Cat ', 'Manip Name ', 'NonManip Name '])

% print data (and timings) at the end
IterDat
sumPlot
toc
iterations

return

```

**CHAPTER 5 EFFECTS OF OBJECT MANIPULABILITY
(GRASPABILITY AND FUNCTIONAL USAGE) ON MASKED AND
UNMASKED OBJECT IDENTIFICATION**

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5.1 ABSTRACT

Two properties that must be mentally represented when objects can be physically manipulated are that: 1) they can be grasped and how and 2) they can be used for some function and how. Neuroimaging indicates that these traits are represented in different parts of the brain (cf. Buxbaum et al., 2006). The current research explored the influence of these traits of manipulable objects on their identification as assessed by naming and picture-word matching tasks. Stimuli used were masked and unmasked photographs of objects. Results from two experiments indicated that the greater the ease with which objects could be grasped for use (Graspability), the faster they were named and matched. Importantly, these effects were found over and above any contributions made to speed of naming and matching by the factors of Age-of-Acquisition and Familiarity. Similarly, the degree to which the actions associated with the functional use of objects was different from the actions associated with grasping (Functional Use) also predicted faster identification times. Critically the effect of a concurrent mask interacted with both of these “action” traits, but in different directions. Graspability effects were larger for objects shown without a mask. In contrast, Functional Use effects were largest for masked objects. Thus, these results indicated that not only is object manipulability (in general) an important predictor of object identification, but that the effects of these two types of manipulability (graspability versus functional usage) are dissociable in healthy normal participants.

Keywords: manipulability, action, grasping, functional use, naming, matching

5.2 INTRODUCTION

5.2.1 Action and Identification

In our environment there are two things humans primarily do with objects: use and identify them. Perhaps not coincidentally, the human brain appears to have two distinct visual streams, one that is engaged during the identification of objects (the ventral visual stream), and one that is associated with action (the dorsal visual stream) (Goodale & Milner, 1992, 1994). For example, brain activity in the ventral stream is particularly active during the viewing and identification objects and faces (Gauthier, et al., 2000; Grill-Spector, 2003; Grill-Spector & Sayres, 2008; Haxby, et al., 2001), whereas objects with action associations (i.e. ‘manipulable’ objects) activate areas in the dorsal stream (Chao & Martin, 2000; Grèzes, et al., 2003). Given two apparently distinct visual streams for identification and action, one might expect relative independence between these two streams; however, there are many examples of action-identity interactions (for a good review see Goodale, 2008; see also Matheson & McMullen, 2010).

Specifically, perception can affect action. For example, Creem and Proffitt (2001) found that during a dual-task which involved moving objects from one spot to another, participants naturally grasped an object in a manner that would most potentiate object-use, even though using the object was not required for the task. Similarly, Tucker and Ellis (1998) showed that the presentation of a manipulable object can potentiate (i.e. speed-up) manual button-press responses regarding the orientation of the object when the handle of the object points toward the response hand. In another study, Tucker and Ellis (2004) showed, more specifically, that the presentation of an object affording a precision

grasp will potentiate precision movements (i.e. making a pincer grasp in response to a clothes pin) and the presentation of an object affording a power grip will potentiate power movements (e.g. making a power grasp in response to a bottle). Thus, object perception can influence the action system.

Research shows that the action system can also influence the object identification system. For example, Wolk, Coslett, and Glosser (2005) showed that patients with agnosia could more accurately identify (name) objects with associated action-properties (so-called ‘manipulable objects’). Similarly, Filliter, McMullen, and Westwood (2005) found healthy participants matched pictures and words more quickly for manipulable objects than non-manipulable ones, although the direction of this advantage reversed when the familiarity of objects was carefully controlled. Inconsistency in the direction of these effects is not uncommon. For example, Kalénine and Bonthoux (2008) showed that children and adults were faster to match thematic triads of manipulable objects, but faster to match basic-level taxonomic triads of *non*-manipulable objects. Similarly, research in our lab (chapters 3 & 4) found that participants *named* the same set of manipulable objects more quickly, despite *categorizing* them more slowly than non-manipulable. Thus, these studies, taken together, indicate that the role action plays during identification may be task-dependent.

The reasons for these task-related dependencies might lie partially in the fact that *more than one* action system is at work. For example, Buxbaum and colleagues (2006; 2002; 2000) have, with the aid of neuroimaging techniques, identified two, and possibly three structurally distinct object-actions areas subserving different roles. Other researchers have also explored the roles of different action systems and how they interact

with the identification (e.g. Bub & Masson, 2012; Bub, et al., 2003; Bub, et al., 2008), and evidence is accumulating to show that in addition to being neuroanatomically distinct these action systems are also computationally distinct (for a recent example see Bub & Masson, 2012 and their comparison of the role of "functional" versus "volumetric" grasps). Thus, different "action" effects during identification across different studies might be related to multiple action systems being involved. The next section will outline the differences between these action systems and how to define them.

5.2.2 Multiple Types of Action Systems (i.e. types of Manipulability)

As suggested, Buxbaum and colleagues (2006; 2002; 2000) have been careful to note that there is more than one type of relevant action information (see Buxbaum & Kalenine, 2010, for a recent review of their findings). Their evidence comes partly from patients with apraxia: those that can identify objects but have trouble demonstrating skilled actions with objects. Buxbaum and colleagues (2010; 2006; 2002; 2000) noted that while most apraxics perform normally when reaching to and grasping visible objects, they showed substantial deficits in pantomiming object-related gestures, and reduced, although still significant impairments when using objects (Poizner et al., 1990; see also Buxbaum and Kalenine, 2010). This pattern of better online grasping than pantomiming object use was found to doubly dissociate from the performance of patients with optic ataxia, who are frequently impaired in grasping objects, but perform normally in gesture tasks (Buxbaum & Coslett, 1997; 1998).

These observations led Buxbaum and colleagues (2010; 2006; 2002; 2000) to propose different neuro-substrates for action related to grasping²⁴, than for action related to functional use. Salmon, McMullen and Filliter (2010) tried to capture these two types of action by asking participants to rate photographs of objects on (1) how easy it is to grasp and use the object with one hand (which we hereafter refer to as “Graspability”), and (2) the extent to which the hand movements that participants would make while using the objects differed from those involved in picking it up (which we hereafter refer to as “Functional Use”). The idea was that the ratings collected would tap Buxbaum and colleagues’ (2010; 2006; 2002; 2000) notion of the Graspability /and Functional Use distinction.

However, recent research suggests a further division. In particular, Buxbaum and colleagues (2010; 2006; 2002; 2000) noted a double-dissociation between *knowledge of object manipulation* and *object function* in apraxic and nonapraxic patients. This, along with supporting neuroimaging research, indicates a further significant distinction within the dorsal stream: the dorso-dorsal, and dorso-ventral processing stream. Specifically, the dorso-dorsal action system is associated more with the ‘structure’ of objects, whereas the ventro-dorsal is related to the ‘function’. More specifically the dorso-dorsal system is (1) more about action ‘affordances’, is (2) activated without motor intention, and (3) may be activated outside conscious awareness. On the other hand, the ventro-dorsal system is (1)

²⁴ Note, the term “volumetric” grasp has come to be preferred by some researchers (cf. Bub & Masson, 2012; Bub, et al., 2003; Bub, et al., 2008). It was our intent that the “graspability” ratings collected by Salmon et al. (chapter 2) would be equivalent or at least conceptually very similar to “volumetric” grasps as described by Bub, Masson and colleagues. One obvious difference between these two was that the Salmon et al. (chapter 2) definition included the word “grasp and use” implying some kind of function / purpose or tool-ness quality associated with our “graspability” ratings, whereas Bub, Masson and colleagues describe “volumetric” more in terms of picking the object up to move it to a new location (i.e. no implication of object function).

more concerned with appropriate action, (2) and requires a relative intention or goal, (3) similar to their concept of ‘functional use’.

Buxbaum and colleagues (2010; 2006; 2002; 2000) further characterized activation in the dorso-dorsal stream as having a weak relationship to conceptual knowledge, and being short acting/lasting (lasting milliseconds), whereas the ventro-dorsal stream was characterized as having a strong relationship to conceptual knowledge and being longer lasting (lasting minutes). Importantly, this ventro-dorsal stream is separate from the ventral stream in the temporal lobe, to which knowledge of function/purpose is still attributed²⁵ (see Buxbaum & Kalenine, 2010; for a more exhaustive review of these theories). That is, depending on what one considers ‘action’, these three divisions could be considered a 3-stream action theory (two dorsal streams, and one ventral).

It is outside of the scope of this research to conduct an exhaustive search for all independent and distinct types of action processes that might play a role during identification. In fact, Buxbaum and Kalenine (2010) have noted, themselves, that the effects of manipulability can wax and wane as a function of task demands (Buxbaum and Kalenine, 2010, p. 204; see also Salmon, McMullen, & Trappenberg, 2011). Thus, the current research will focus on the original two types identified by Buxbaum and colleagues (2006; 2002; 2000), and collected for this purpose by Salmon et al. (2010): Graspability and Functional Use, collected conveniently in an object set by Salmon, McMullen & Filliter (2010). Specifically, this research will use the “Graspability” and “Functional Use” ratings and object set collected by Salmon et al. (2010).

²⁵ For example, the ventro-dorsal stream would code the appropriate gesture for “ironing”, where the ventral stream would code “an iron is for ironing”.

5.2.3 Measuring Object “Manipulability”: Continuous versus Discrete scales”

Wolk, et al. (2005) explored the influence of manipulability as measured by ratings that were defined in terms of (1) unambiguous pantomiming: whether or not participants could mime the action so that a person looking at them could decide which object goes with the actions (norms developed by Magnié, et al., 2003, p. 524), and (2) form-manipulation ratings: the degree to which the shape of the object implies how it should be used (Wolk, et al., 2005, p. 135). In both cases, Wolk, et al. (2005) found better recognition of manipulable than non-manipulable objects in a patient with mild visual agnosia and more recognition difficulty particularly for visually presented living things compared to non-living things. However, as noted in previous research (Salmon, et al., 2010), the pantomiming definition used by Wolk, et al. (2005) is quite different than that established by Buxbaum and colleagues (2000, 2002, 2006), and leads to unusual and sometimes unintuitive classifications of objects. For example, with Wolk, et al.’s (2005) definition a ‘car’ got classified as ‘strongly manipulable’ and ‘celery’ and ‘strawberry’ were both classified as ‘strongly unmanipulable’. This was due to the fact that it is easy to pantomime driving a car, but hard to pantomime celery and strawberries.

Most recent research on manipulability effects on object identification in neurologically normal participants has dichotomized objects as either manipulable or non-manipulable (e.g. Filliter, et al., 2005; Kalénine & Bonthoux, 2008; Salmon, McMullen, & Matheson, submitted). One drawback to this method of dichotomizing objects into two categories (manipulable or not) is that many items have a medium or ambiguous level of manipulability. For example, ‘blender’, ‘toaster’, ‘bicycle’ and even

‘piano’ have medium levels of manipulability (depending on the definition applied by the rater). Each of the items mentioned above have a manipulable element, despite being objects that you don’t ‘pick up’ to use. Natural examples include ‘leaf’, ‘shell’, ‘ant’, ‘rock’, and ‘cat’; these are all things that you *can* pick up and *manipulate* (to a certain extent) with your hands, despite the fact that there is no necessity or functional use in doing so. That is, the goal when picking up a ‘leaf’ is less clear than the goal when picking up a carrot or piece of celery (to eat it). Capturing these continuous effects of manipulability, by treating manipulability as a continuous variable could yield new insight into the role object manipulability plays during object recognition. Fortunately, the published ratings we have collected (Salmon, et al., 2010) exist in a continuous form, which capitalizes on the power of emerging statistical methods and software, such as R, and linear mixed-effects regressions, which, in addition to being more powerful, let you measure both item and subjects effects simultaneously (Agresti, 2002; D. Bates, 2007).

Another disadvantage of dichotomizing manipulability is that the two types of manipulability become somewhat confounded. As explained in Salmon et al. (2010), the two manipulability scales: Graspability and Functional Use, ‘did not correlate significantly with each other ($r = -.012, p = .875, [n=178]$), indicating that they were indeed measures of two different dimensions of manipulability’ (p. 87). However, it is worth pointing out that only half (178) of the items had ‘functional use’ ratings while all of the objects (321) had ‘graspability’ ratings. That is, the correlation in question was based only on items with existing ‘functional use’ ratings, and by definition, only items with high (>3 on 5-point scale) ratings on ‘graspability’. In other words, only ‘manipulable’ (graspable) items have ‘functional use’ ratings, therefore, the lack of

correlation is only true within the set of “manipulable” objects (i.e. there is nothing to correlate for non-manipulable objects). That is, across the *full* set of 321 objects, ‘functional use’ and ‘grasping’ ratings are properly confounded, with only objects already high on ‘grasping’ having valid ‘functional use’ ratings. To illustrate this point, if we were to redo the correlation by assigning all non-manipulable objects a ‘functional use’ rating = 0²⁶, such that a correlation across all objects could be done, we find, instead a significant correlation ($r = .876, p < .001, n = 321$) with all items rated low on ‘grasping’ having low (=0) ‘functional use’. This result is not surprising, given the nature and construct of these scales. However, it does illustrate that any manipulability results that dichotomize manipulability are naturally confounded, and one does not know if the ‘grasping’ or ‘functional use’ nature of the objects drive any effects that are found.

5.2.4 The Current Research

The current research sought to disambiguate the role of these two types of manipulability in object identification: Grasability and Functional Use. Two different experiments (tasks) were conducted with both types of manipulability analyzed as continuous predictors in mixed-effects linear regression models. One advantage of these mixed-effect regression models, besides the ability to use continuous predictors, is that they allow the experimenter to account for the random effects of both the participants and items simultaneously (without the need for separate subjects and items analyses). This new method for analysis of linguistic data has been advocated by other linguistic researchers (e.g. Baayen, 2008; Kliegl, Masson, & Richter, 2010) and researchers

²⁶ Note, this would turn the ‘functional use’ rating scale into a 6-point scale (0-6), while the original scale was a 5-point Likert scale (0-5) with a high number indicating a high rating on functional use.

interested in stimulus-driven effects (e.g. Lawrence & Klein, 2012; Malcolm, Lanyon, Fugard, & Barton, 2008).

5.2.5 Manipulability Ratings & Definitions

The current research used the object set and manipulability ratings based on definitions collected previously (Salmon, et al., 2010). These definitions included two types of manipulability: (1) graspability, as the ability to “grasp and use the object with one hand” and (2) functional usage, as the extent to which hand movements made to “use the object differ from hand movements [made] to pick it up” (Salmon, et al., 2010, p. 85), hereafter referred to as Manip1 and Manip2, respectively. These manipulability definitions were slightly different from those applied by Wolk, et al. (see also Magnié, et al., 2003; 2005), but similar to those employed by Buxbaum and colleagues (cf. 2006; 2002; 2000).

One advantage of this new object set (besides being large and having recent ratings) was that it also included Familiarity and Age of Acquisition (AoA) ratings for each object. Familiarity and Age of Acquisition (AoA), or the age at which a participant first acquires the vocabulary for the word, have both been shown to strongly predict object identification times (E. Bates, et al., 2003; Bonin, et al., 2003; Cuetos & Alija, 2003; Pérez, 2007). Thus, one primary goal of the research was to determine if both types of manipulability affect naming above and beyond the effects of familiarity and AoA.

5.2.6 Experimental Design & Rationale

The current research was designed to test the role of two types of object manipulability during two standard object identification tasks: Naming (Experiment #1)

and Picture-Word Matching (Experiment #2). Object Naming was chosen because manipulability effects have been observed with Naming in other experiments (e.g. Salmon, McMullen, & Trappenberg, 2011; Wolk, et al., 2005). Picture-Word matching was chosen as a comparison task to the findings of Filliter, et al. (2005). In addition, picture-word matching task shared similarities to the categorization task used by Salmon et al. (2011), specifically (1) it required two-choice button press, and (2) it created the possibility of judgments based on very superficial properties of the objects. On the other hand, the two tasks differ in that categorization is done at the super-ordinate level while picture-word matching (like naming) is done at the basic or entry level of semantics. Thus, it was important to see if manipulability effects on picture-word matching tasks were reversed the same way they were for categorization tasks in Salmon et al. (chapter 3).

In addition, the effect of a concurrent visual mask was investigated. Recent research suggests that manipulability effects may be larger when object presentations are degraded with a visual mask (chapter 3, Salmon, et al., 2011). This increased effect size might just be a general effect of the entire process of identification being slowed down, or it may be related to the fact that action properties of objects may be processed very early during identification. For example, the action-specific perception account elaborates on how all objects are perceived based on the viewer's ability to act on it (cf. Witt, 2011; Witt, Kemmerer, Linkenauger, & Culham, 2010). A clear example of this, is that baseball players with better batting averages will subjectively perceive a baseball as larger than do other players on the team (Witt & Proffitt, 2005). Alternatively, slowing processing down

may involve recruiting semantic memory and in effect cause deeper processing. Deeper processing could be expected to affect functional use (or Manip2), in particular.

Given that potential for action can influence basic perceptual qualities such as the *size* of the object, it seems reasonable to presume that the influence of action-potential occurs early during perceptual processing. Thus, it makes sense that something like a visual mask could disrupt this influence. Therefore, the current research sought to test this by showing both masked and unmasked versions of the photographs in Experiment #1 and #2. Of note, Salmon, et al. (2011; in revision) found no difference according to exposure duration for either a categorization or naming task and exposure duration could be considered a means of degrading input. However, it also possible that their failure to find a difference was related to too small a contrast between their two exposure conditions (35 ms versus 105 ms). Thus, it is possible that a larger contrast (e.g. masked versus not-masked), as employed in this research, will succeed at finding an interaction where Salmon, et al. (2011; in revision) did not.

5.3 EXPERIMENT #1: OBJECT NAMING

Experiment #1 was designed to test a full range of objects benefitting from recently collected norms on Familiarity, Age of Acquisition and the two types of manipulability (Salmon, et al., 2010). The primary goal was to determine whether or not effects of object manipulability could contribute to object naming above and beyond that explained by age of acquisition and familiarity. Given recent support for the influence of object manipulability on identification in patients with agnosia (e.g. Wolk, et al., 2005) and healthy normals (Filliter, et al., 2005; Kalénine & Bonthoux, 2008; Salmon, et al.,

submitted) it was hypothesized that significant effects of manipulability would be found above and beyond the effects of both object Familiarity and Age of Acquisition (hypothesis 1). Also, a visual Mask covering the objects was expected to affect the two types of manipulability differently (hypothesis 2), given the evidence for an early role of action information in perception (cf. Witt, 2011; Witt, et al., 2010; Witt & Proffitt, 2005). And, in general the effects of graspability/Manip1 and functional usage/Manip2 were expected to be dissociable (hypothesis 3) given both the functional and neurological underlying differences between these two types of manipulability (Buxbaum, et al., 2006; Buxbaum & Saffran, 2002; Buxbaum, et al., 2000).

Data were analyzed using linear mixed effects regression analysis, and results from this experiment (to foreshadow section 2.2) indicated support for most of our hypotheses. In particular, the effects of graspability (Manip1) and functional use (Manip2) were both in the direction of higher manipulability ratings predicting faster identification times. However, only for graspability were these effects significant above and beyond effects of the covariates. Further, both types of manipulability interacted with the Mask but in different directions with graspability effects larger for unmasked objects, and functional use effects larger for masked items, suggesting independence of these two types of manipulability, and providing support for our second and third hypothesis (see section 2.3 for additional interpretation of these results).

5.4 METHODS

5.4.1 Participants

Thirty-eight students (8 males) enrolled in Dalhousie University participated in Experiment #1. All participants had English as a first language, normal or corrected-to-normal vision, and no known history of neurological or visual disorders. The average age of participants was 21.25 years (range: 18-35) and only three reported being left-handed.

5.4.2 Materials

Greyscale photographs from the set developed by Salmon, McMullen, and Filliter (2010) were used. This included the entire 320 objects from their set plus one of their practice items (window) for a total of 321 items. Each of the items had recently been rated on Familiarity, Age of Acquisition (AoA), and the two forms of Manipulability (Graspability and Functional Usage) by fellow Dalhousie University students. For a complete list of the objects used in this experiment please refer to the Appendix A.

A visual mask was created from the stimulus set using the program GIMP 2.6 (GNU Image Manipulation Program). Portions of 64 representative photographs (equal numbers of manmade/natural and manipulable/non-manipulable objects) were taken and overlaid together in an 8x8 grid. A section of the grid was superimposed over each object with 60% transparency, and a reduction in mask *contrast* so that the Mask appeared less defined and blended with the image (Figure 5.1). Also, the axis of elongation was maintained (tall objects were masked with a tall section of the mask, wide objects with a wide mask). For examples of the photographs with and without the mask applied, see Figure 5.1.

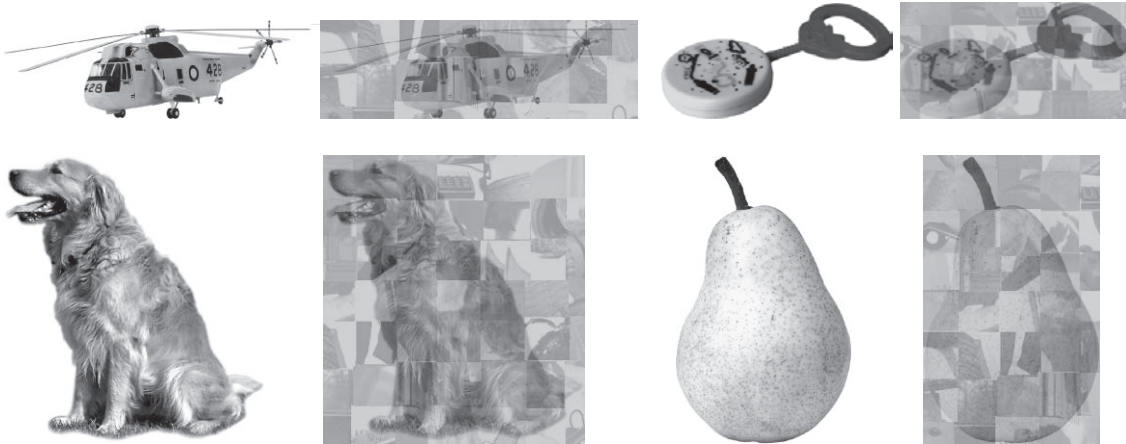


Figure 5.1. Masked and Unmasked versions of some of the objects.

The stimuli were presented on a 17-inch View Sonic screen vertically and horizontally centered in the middle of the screen. All pictures were designed to be no bigger than 300 x 300 pixels, or 11 cm (range: 4-11 cm). The unrestrained viewing distance of approximately 53 cm resulted in visual angles of 4.3-11.7 degrees of any direction. Direct RT © was used to present the images and to record responses.

Participants responded verbally into a microphone sitting on the table in front of them. The experimenter was present for all trials and used a keyboard to record participant naming-errors.

5.4.3 Procedure

Each participant performed one practice block (with different objects), prior to starting the main experimental block of 321 randomized trials. For each participant, half (160 or 161) of the images were masked and half were not masked. Masking was counterbalanced across participants. For example, half participants saw the masked dog, and half the participants saw the unmasked dog. Each object was seen only once. Each trial started with a central “+” fixation that appeared for 1000 ms. The object appeared

and stayed visible until the participant made a vocal response loud enough to be picked up by the microphone. Participants were instructed to make their responses as “quickly and as accurately as possible” and to emphasize the first sound in the word to ensure that the microphone registered a response. At the end of each trial the words “please wait” appeared on the screen and remained until the experimenter recorded accuracy for the trial by using the keyboard. The experimenter recorded (1) accurate responses, (2) incorrect/wrong word responses (e.g. “cat” instead of “dog”), and (3) microphone misfires, (including coughing, laughing, smacking of lips, responding too softly, or anything else that may have triggered the voice-key on the microphone too early or too late). Once the experimenter coded the accuracy of the trial, a new fixation appeared indicating the start of the next trail. Participants were given trial-by-trial feedback during the practice trials, but no feedback during the main block of trials. The entire experiment, including informed consent and debriefing lasted no more than 1 hour.

5.4.4 Data Analysis

Accuracies for naming were generally very high (with correct responses for 88 % of the trials). Of the errors, 7 % were participant errors (i.e. wrong words) and 5 % were equipment errors (e.g. microphone not hearing voice). The primary analyses were on reaction time, and only accurate RTs were analyzed. Further, very short (< 300ms) and very long (> 3000 ms) RTs were eliminated from the analysis (2.47 % of the data), and a log-transformation was performed to help normalize the RT data. Finally, four items with accuracies less than 25% were excluded from the RT analysis (i.e. CD-ROM, diaper, peach, pitcher). Accuracies were analyzed only to ensure no speed-accuracy trade-offs.

To test the first hypothesis (significant main effects for graspability and functional usage above and beyond the effects of familiarity and AoA) and second hypothesis (interaction between mask and manipulability) mixed-effects models were tested against each other; That is, models with and without manipulability were compared to determine if including manipulability significantly increased the predictive power of the model (Analysis 1.1). This first analysis was similar to a stepwise regression analysis in SPSS, but it was conducted as a Mixed-Effects regression analysis (Agresti, 2002) using the lme4 package (D. Bates, 2007) in R (www.r-project.org). Likewise, the third hypothesis (differences between the two types of manipulability) was analyzed with Mixed-Effects regression models that explored the interaction between the two manipulability variables. This analysis was different from the previous because it included both variables in the model simultaneously (it was necessary to conduct this analysis separately because all items had Manip1 ratings, but not all items had Manip2 ratings).

5.5 RESULTS

5.5.1 Analysis 1.1 (RT). Manipulability versus Covariates & Masking

Testing Hypothesis 1. Significant effects of manipulability during naming (above and beyond effects of familiarity and AoA) for Manip1 (graspability), and Manip2 (functional usage).

Testing Hypothesis 2. The effect of the visual mask will disrupt (interact with) the two types of manipulability.

In the first RT analysis, two models were compared against each other. In the first model (1.0) the two known covariates, object familiarity (fam_{si}) and object age of acquisition (aoa_{si}) were entered as continuous predictors, as well as the presence or

absence of the mask ($Mask_{si}$) which was coded 0=No Mask, 1=Masked. In the second model (1.1) Manipulability ($Manip1_{si}$) was included as a predictor, as well as the interaction between Manipulability and the Mask. This allowed for a direct comparison between the models before and after the inclusion of manipulability as a predictor. Further, because the number of items with valid Manip2 ratings was smaller, Manip2 was looked at separately (1.2) from Manip1. Thus, the construct of these scales required separate analyses on the two types of manipulability.

The full regression equations are shown below.

$$\Pr(\log(y_{RT})) = b_0 + b_1 \cdot aoa_{si} + b_2 \cdot fam_{si} + b_3 \cdot Mask_{si} + subject_s + item_i + \epsilon_{si} \quad (1.0)^{27}$$

$$\Pr(\log(y_{RT})) = b_0 + b_1 \cdot aoa_{si} + b_2 \cdot fam_{si} + b_3 \cdot Mask_{si} + b_4 \cdot Manip1_{si} + b_5 \cdot Mask_{si} \cdot Manip1_{si} + subject_s + item_i + \epsilon_{si} \quad (1.1)$$

$$\Pr(\log(y_{RT})) = b_0 + b_1 \cdot aoa_{si} + b_2 \cdot fam_{si} + b_3 \cdot Mask_{si} + b_4 \cdot Manip2_{si} + b_5 \cdot Mask_{si} \cdot Manip2_{si} + subject_s + item_i + \epsilon_{si} \quad (1.2)$$

Where $\Pr(\log(y_{RT}))$ is the “probability of obtaining the log of a given RT”. The variables b_0, b_1 , through b_4 are the fixed effects predictors for the main effects, i.e. the group average effects induced by the variables $aoa_{si}, fam_{si}, Mask_{si}, Manip1_{si}$, and $Manip2_{si}$. The variables b_5 in 1.1 and 1.2 represent the fixed effects for the two-way interactions between the Mask and Manipulability variables. (The interactions between familiarity and AoA were not explored since these variables were considered merely as covariates.) The random effect term, $subject_s$, represents each subject’s deviation from the group RT average. Likewise, the random effect $item_i$ represents each item’s deviation from the item group RT average. Finally, ϵ_{si} is the residual term representing remaining unexplained variance.

²⁷ There were actually two versions of this first model, one to compare against Manip1 ($n = 320$), and one to compare against Manip2 ($n = 178$).

5.5.2 Results for Manip1 (Graspability)

Each model was evaluated for significance based on t -values, where $t_{crit} = 1.96$. In other words, $t > 1.96$ were considered significant at $\alpha = 0.05$. The initial model (1.0) significantly predicted naming latencies (RTs) with the Mask and higher AoAs, predicting slower RTs ($b_3 = 0.169$, $t = 34.02$, and $b_1 = 0.144$, $t = 10.22$, respectively) and a small significant Familiarity effect, $b_2 = -0.020$, $t = -2.42$, with expected effect of faster RTs for more familiar objects.

Critically, the second model (1.1) was shown to be a significant improvement over the initial model with $\text{Diff-}\chi^2(2) = 20.58$, $p < 0.001$, $\text{AIC} = 1866.1$ compared to $\text{AIC} = 1882.7$ for model 1.0. This result indicated that adding Manip1 significantly increased the predictive power of the model. Further, it was found that both Manip1, and the interaction between Manip1 and the Mask, were significant ($b_4 = 0.169$, $t = 34.02$, and $b_5 = -0.021$, $t = -2.42$ respectively), with the overall effect of higher Manip1 ratings speeding up RTs, but this effect was bigger for non-masked items. See Table 5.1 for the full breakdown of effects from this analysis.

5.5.3 Results for Manip2 (Functional Use)

Again, the initial model (1.0) significantly predicted naming latencies (RTs) with the Mask and higher AoAs, predicting slower RTs ($b_3 = 0.186$, $t = 28.69$, and $b_1 = 0.113$, $t = 5.09$, respectively) as well as a significant effect of familiarity ($b_2 = -0.062$, $t = -4.58$), with faster RTs for familiar objects. Critically, the second model (1.2) was shown to be a significant improvement over the initial model with $\text{Diff-}\chi^2(2) = 18.02$, $p < 0.001$, $\text{AIC} =$

791.14 compared to AIC = 805.16 for model 1.0. This result indicated that adding Manip2 significantly increased the predictive power of the model. Interestingly, the main effect of Manip2 on its own was not significant ($b_4 = -0.012$, $t = -0.56$), but the interaction between Mask and Manip2 was ($b_5 = -0.038$, $t = -4.00$), with bigger effects of Manip2 on *Masked* items. This suggested that the influence of Manip2 on object Naming depended on the presence or absence of the Mask. Importantly, the direction of this interaction was the *opposite* from the one obtained by Manip1, indicating that the Mask was affecting Manip1 and Manip2 ratings in different ways. See Table 5.2 for the full breakdown of effects from this analysis.

Table 5.1. Linear Mixed-Effects Regression effect sizes for model including Manip1 (Model 1.1), $n = 320$.

	Beta Label	Beta Value (Estimate)	t-value ($t_{crit} = 1.96$)
(Intercept)	b0	6.583	115.49
AoA	b1	0.144	10.22
Fam	b2	-0.020	-2.26
Mask	b3	0.125	11.04
Manip1	b4	-0.017	-2.53
Mask * Manip1	b5	0.014	4.25

Table 5.2. Linear Mixed-Effects Regression effect sizes for including Manip2 (Model 1.2), $n = 178$.

	Beta Label	Beta Value (Estimate)	t-value ($t_{crit} = 1.96$)
(Intercept)	b0	6.714	73.71
AoA	b1	0.125	5.30
Fam	b2	-0.059	-4.40
Mask	b3	0.292	10.72
Manip2	b4	-0.012	-0.56
Mask * Manip2	b5	-0.038	-4.00

5.5.4 Analysis 1.1 Summary & Hypothesis Testing

The significant model improvement in both cases supported *hypothesis 1*, indicating that both types of object manipulability (Manip1 and Manip2) were significant predictors in naming latency times (RTs). In particular, Manip1 (grasping) had the main effect of speeding up RT, e.g., a 1-point increase in this rating scale predicting RTs that were 18 ms faster for regular photos (refer to Appendix 5.14 for a visual depiction of these results). Manip2 also predicted faster RTs (e.g. 51 ms faster for masked photos), although this difference was not statistically significant ($t = -0.56$). These results are consistent with previous findings of faster naming for manipulable objects (e.g. Salmon, et al., 2011).

Further, supporting *hypothesis 2*, both Manip1 and Manip2 interacted with the Mask. This suggested that the presence of a Mask disrupted/changed the nature of these manipulability effects. Interestingly, the direction of the interaction effect was different for the two types of manipulability, with Manip1 (graspability) having larger effects on naming RT when items were non-Masked, and Manip2 (functional use) having larger effects on naming RT when items were Masked. The difference was illustrated by *post hoc* analyses of the masked and unmasked data separately. These *post hoc* analyses indicated significant Manip1 (Graspability) RT effects for non-masked but not masked items. In contrast, Manip2 (functional use) had significant effects for masked, but not non-masked photographs (see Figure 5.2 for an illustration of this cross-over effect of Manipulability x Mask). This meant that Manip1 (graspability) effects were larger for non-masked objects, but Manip2 (functional usage) effects were larger for *masked* objects. So the ability to grasp an object had a greater effect on object naming times when

objects were not masked. The direction of this effect was such that being more graspable decreased naming time. Conversely, the degree to which an object's functional use was different from its grasping action influenced naming time more when objects were masked. The direction of this effect was also that greater values decreased naming time.

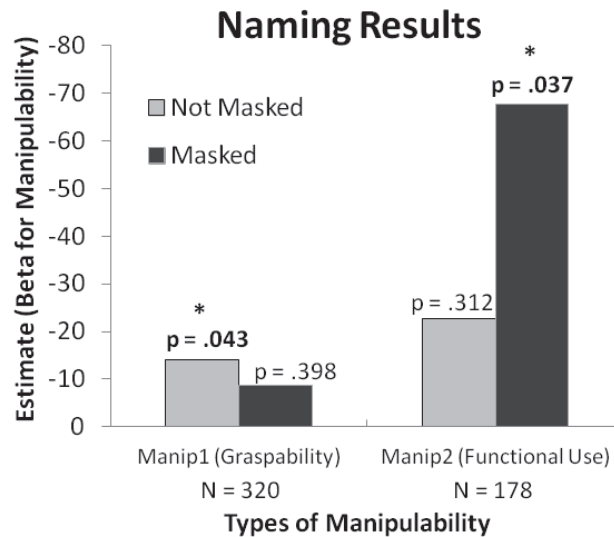


Figure 5.2. Manipulability effect sizes (betas) during object Naming for Masked and non-Masked conditions (simple effects analyses). Note that negative betas are plotted up, and indicate a relationship between higher scores on manipulability and faster RTs, with each beta coming from a different analysis. Also note that masking interrupts these effects in different ways for the two types of manipulability. For Manip1 (graspability), effects are larger for non-masked items, but for Manip2 (functional use), effects are larger for masked items.

5.5.5 Analysis 1.2 (RT). Mixed Effects with Interactions

Testing Hypothesis 3. Differential effects of the two types of manipulability on RT.

Hypothesis 3 was supported by the analyses from 1.1 and 1.2, by showing differences in direction of the Manipulability by Mask effects that depended on the type of manipulability. Planned comparisons between the subset of items containing both

Manip1 and Manip2 ratings were conducted (to further explore differences between these two types of manipulability). The results of these additional analyses showed that a model containing the 3-way interaction between Mask and the two types of Manipulability (1.4) explained significantly more variance than model 1.3, which contained only the 2-way interactions ($\chi^2(1) = 9.91, p < 0.01, AIC = 769.62$ compared to $AIC = 856.23$). In this same, more complex model, there was also a significant 2-way interaction between the Mask and both Manip variables ($t = 4.00, b_6 = 0.205$ and $t = 2.65, b_7 = 0.216$ respectively) but no 2-way interaction between the two Manip variables ($t = -0.56, b_8 = -0.022$). And, neither the main effect of Manip1 nor Manip2 was significant, $t = 0.79, b_4 = 0.0.89$ and $t = 0.50, b_5 = 0.089$ respectively.

$$\Pr(\log(y_{RT})) = b_0 + b_1 \cdot \text{aoa}_{si} + b_2 \cdot \text{fam}_{si} + b_3 \cdot \text{Mask}_{si} + b_4 \cdot \text{Manip1}_{si} + b_5 \cdot \text{Manip2}_{si} + b_6 \cdot (\text{Mask}_{si} \times \text{Manip1}_{si}) + b_7 \cdot (\text{Mask}_{si} \times \text{Manip2}_{si}) + b_8 \cdot (\text{Manip1}_{si} \times \text{Manip2}_{si}) + \text{subject}_s + \text{item}_i + \epsilon_{si} \quad (1.3)$$

$$\Pr(\log(y_{RT})) = b_0 + b_1 \cdot \text{aoa}_{si} + b_2 \cdot \text{fam}_{si} + b_3 \cdot \text{Mask}_{si} + b_4 \cdot \text{Manip1}_{si} + b_5 \cdot \text{Manip2}_{si} + b_6 \cdot (\text{Mask}_{si} \times \text{Manip1}_{si}) + b_7 \cdot (\text{Mask}_{si} \times \text{Manip2}_{si}) + b_8 \cdot (\text{Manip1}_{si} \times \text{Manip2}_{si}) + b_9 \cdot (\text{Mask}_{si} \times \text{Manip1}_{si} \times \text{Manip2}_{si}) + \text{subject}_s + \text{item}_i + \epsilon_{si} \quad (1.4)$$

The 3-way interaction (**Mask_{si} X Manip1_{si} X Manip2_{si}**) in model 1.4 was significant ($t = -3.15, b_9 = -0.057$), suggesting that any interaction between **Manip1_{si} X Manip2_{si}** depended on the presence or absence of the Mask. Follow up *post hoc* analyses suggested that the 2-way interaction between **Manip1_{si} X Manip2_{si}** was explained by a reversal in the direction on Manip1 (with higher values predicting slower RTs) but only for manipulable items (>3 on Manip1) and only when masked.

This reversal in Betas for Manip1 depending on whether it was considered over the whole set, or just the subset of items with Manip2 ratings was investigated with a follow-up regression analysis with polynomial fit. For Masked items, a curvilinear fit for Manip1 explained more variance in RT than a linear model, while there was no big

difference for Non-Masked items (See Appendix Figures). This suggested that although the trend across the entire object set (of masked items) was for higher values of Manip1 to predict faster RTs, in the high Manip1 ratings (≥ 3) the direction of this effect reversed.

5.5.6 Accuracy Results

Mixed-effects regression (logit) predicting accuracy was done to ensure no speed-accuracy trade-offs. For Manip1, no significant accuracy effects were found ($z = -1.07, p = .283$). For Manip2 ratings there was a trend towards higher Manip2 (functional usage) ratings to lead to more accurate identification, $z = -1.65, p = .100$, which did not interact with the mask effect. In addition, there was a strong main effect of mask on accuracy, with higher accuracy for non-masked items, $z = -5.55, p < .001$; in fact, one item (the diaper) was never correctly identified when masked. There was also a strong accuracy effect for AoA, $z = -5.55, p < .001$, with late acquired items being identified less accurately, and there was no effect of familiarity in accuracies, $z = -5.55, p < .001$. Importantly, these results suggested no speed-accuracy trade-offs.

5.6 DISCUSSION

These results supported the hypotheses, with both Manip1 (graspability) and Manip2 (functional use) increasing the predictive power of the base covariate model (hypothesis 1). The results also showed that the Mask had a disruptive effect on Manipulability, supporting the notion that manipulability effects depend on early visual processing stages (hypothesis 2). Finally, an investigation of the combined effects of

Manip1 and Manip2 together showed that the direction of Manip1 effects appear to reverse for Manip1 ratings >3 , but only for Masked items. This interaction, along with the general finding that overall Manip1 effects were larger for non-masked items supported the idea that Manip1 and Manip2 really do have differential effects on object recognition.

Why would Manip1 effects be larger for Non-Masked items, while Manip2 effects are larger for Masked items? This surprising result could be explained by considering the type of Mask (concurrent with the object) and the definitions of each type of Manipulability. Manip1 (grasping) ratings would depend on the overall shape/outline of an object. Therefore, it makes sense that these effects would be largest in a non-degraded presentation of the stimulus, and significantly diminished for Masked stimuli. This result also indicates an effect of Manip 1 (grasping) that is early in visual processing, fast and transient. Manip2 (functional use) ratings, on the other hand, would depend more on the semantic system, a deeper level of processing. Presumably, Masked stimuli engage deeper processing (they certainly take longer to name), and therefore, effects of Manip2 would have more time to exert their influence on Masked stimuli, since it is likely a more semantic variable.

In general, these results are consistent with the naming advantage observed by previous research in our lab (cf. Salmon, McMullen & Trappenberg, 2011; and Salmon, et al., in revision), for faster naming of manipulable objects. The reversed effect of the mask, however, gives further insight into which aspect of manipulability might have been causing the effects in Salmon, McMullen and Trappenberg (2011). Specifically, the study by Salmon et al. (2011) contained a mask and a brief exposure duration. The current

study indicated bigger effects of Manip2 (functional usage) for masked objects. Thus, the results of this research suggest that the manipulability effects observed by Salmon, McMullen and Trappenberg (2011, see also Salmon, McMullen and Matheson, in revision) were more likely related to functional (Manip2) differences between manipulable and non-manipulable objects than to graspability (Manip1) differences.

5.7 EXPERIMENT #2: PICTURE-WORD MATCHING

The primary reason for testing picture-word matching on the same photograph set of objects from Experiment #1 was to maximize comparability to the data collected by Filliter et al. (2005). Filliter et al. (2005) showed faster picture-word matching of non-manipulable objects on a set of familiarity-controlled line-drawings. On the other hand, Experiment #1 showed faster naming of *manipulable* objects on a set of photographs (with the effects of both familiarity and age of acquisition covaried). That is, one experiment showed an advantage for non-manipulable (Filliter et al., 2005) and the other experiment showed an advantage for manipulable objects (experiment #1). If the different results between the two experiments were based on task, then one would expect to replicate Filliter et al.'s (2005) result and show faster picture-word matching of non-manipulable objects. On the other hand, if the different results of these two experiments were based on something else (e.g. different level of stimulus control, or different stimuli) then one would predict a replication of Experiment #1 (faster identification of manipulable objects).

The key differences between the current research and that of Filliter et al.'s (2005) were that first, the current research controlled for AoA as well object familiarity, and second, the current research compared a larger controlled set of objects: 321 versus 144

objects in Filliter et al.'s (2005). Furthermore, the current research drew objects from more categories. That is, Filliter et al. (2005) drew their objects from one of eight categories (i.e. fruit, vegetable, office supply, kitchen utensil, bird, dog, watercraft, or land vehicle), but the current research not limit selection of category membership in this way (i.e. the current research included these categories, and many others). Other differences included that the word appeared before the photo (instead of at the same time) in the current research, and the proportion of match trials in the current research was higher (66.7% match compared to 50% match) to increase the number of trials that could be analyzed. However, since we had no *a priori* reasons to suspect that these differences would matter enough to change our effects the current research hypothesized that Experiment #2 (picture-word matching) would replicate Filliter et al.'s (2005) advantage for non-manipulable objects (hypothesis 4).

In addition, Experiment #2 afforded the opportunity to re-test the manipulability differences observed in Experiment #1. In particular, would Picture-Word matching show the same Mask by Manipulability interactions with bigger effects of Manip2 on Masked items and bigger effects of Manip1 on Non-Masked items? To test this, the same Mixed-Effects Regression models from before were tested on the new data from the new task. Additionally, the same basic hypotheses from before were tested including: significant effects of both types of manipulability over and above the covariates (hypothesis 5), a disrupting effect of the mask, or Mask by Manipulability interaction (hypothesis 6), and differential effects of manipulability (hypothesis 7).

Again, data were analyzed using linear mixed effects regression analyses. Our results with picture-word matching (to foreshadow section 2.2) appeared to replicate the

effects observed during picture naming. In particular, high ratings of both types of manipulability still predicted faster identification times. As before, however, only for graspability (Manip1) was this effect significant above and beyond the covariates. Also, the same interaction between mask the two types of manipulability were observed – with bigger graspability effects for unmasked items and bigger functional use effects for masked items. Again, these results provided support for independent roles of these two types of manipulability during object identification (see section 3.2 for additional interpretation of these results).

5.8 METHODS

5.8.1 Participants

Thirty-six new students (4 males) enrolled in Dalhousie University participated in Experiment #2. All participants had English as a first language, normal or corrected-to-normal vision, and no history of neurological or visual disorders. The average of participants was 19.92 years (range: 18-29) and six reported being left-handed.

5.8.2 Materials

The same 321 photographs from Experiment #1 were used in Experiment#2. In addition, a list of foil words was generated, with foil words chosen to match the objects at the basic level, e.g. “stork” for “eagle,” and “clarinet” for “harmonica.” For some of the items, names were matched at the associate-level due to difficulty matching appropriately at the basic level (e.g. “driveway” for “fence”). For a list of all the foil words and actual objects used please refer to Appendix A. The words appeared in black,

Times New Roman font centered on the screen just prior to the appearance of the photographs. Participants were instructed to respond on a keyboard by pressing one button for a ‘match’ between photograph and preceding word and another for ‘mismatch’ trials. Participants were asked to make their responses as quickly and as accurately as possible. Keys were counterbalanced across participants.

Three object subsets A, B, C (balanced on AoA, familiarity and Manipulability) were generated (107 items each). These subsets were then used to design three conditions in which two thirds of the items were match trials. That is, List A contained: A-mismatch, B-match, C-match, List B: B-mismatch, List C: C-mismatch. Thus, across the three possible orders, each object was matched twice and mismatched once. In addition, approximately half of the items in each subset were masked, and the other half was not. This made for 2 (keyboard keys) x 3 (lists) x 2 (masking) = 12 different orders/conditions participants could participate in. Again, DirectRT © software was used to present the stimuli with the same visual angles as in experiment #1.

5.8.3 Procedure

Participants were assigned randomly to a condition, and given practice trials before commencing their block of 321 trials. Each trial began with a fixation “+” that stayed on the screen for 300 ms. Participants were presented with a written word and asked to match it with the photograph when it appeared. The word remained on the screen for 1500 ms, and then a blank screen was shown for 500 ms before the picture of the object appeared. This seemed like adequate time for participants to read even the longer words. The photographs remained on the screen until the participant pressed (either match or mismatch), and then the program advanced to the next trial. Practice

trials were completed with a different set of objects, and each trial was unique (no participant saw the same object twice). The entire experiment, including informed consent and debriefing, lasted no more than 1 hour.

5.8.4 Data Analysis

Accuracies for matching were generally very high with 96.7 % (7450 / 7704) of the matched trials correctly matched, and 87.6 % (3376 / 3852) of the mismatch trials correctly rejected. Two thirds of the total trials were match trials, and only those trials were analyzed. As in Experiment #1, only accurate RTs within a certain range were analyzed, and log transformation was applied. A more conservative time window was analyzed for matching trials (between 300 and 2000 ms, or 1.83 % of trials rejected) given that matching trials were generally faster than naming trials (*mean RT* = 748 ms for picture-word matching compared to *mean RT* = 1120 ms for naming). In addition, results from items with accuracies less than 60% (matched correctly by fewer than 50% of the participants) were excluded from analysis (chance was at 50%). This resulted in the rejection of 3 items (diaper, iron, and Dalhousie's Rowe Building), which were not matched correctly when masked. Accuracies were analyzed only to ensure no speed-accuracy trade-offs.

The same Mixed-Effects Regression analyses from before were conducted on the new data, again, using R and lme4 package. The first set (Analysis 2.1) allowed for simultaneous testing of the hypotheses about the significance of manipulability, its direction, and interactions with the Mask (hypotheses 4 through 6). The second set (Analysis 2.2) allowed for further explorations of any interactions between the two ratings of manipulability within the set of manipulable objects (hypothesis 7).

5.9 RESULTS

5.9.1 Analysis 2.1 (RT). Manipulability versus Familiarity and AoA

Testing Hypothesis 4. Manip1 (graspability) will predict slower picture-word matching times (significant negative Beta for Manip1), a result that would be consistent those of Filliter et al. (2005).

Testing Hypothesis 5. Significant effects of manipulability during picture-word matching (above and beyond effects of familiarity and AoA) for Manip1 (graspability), and Manip2 (functional usage).

Testing Hypothesis 6. The effect of the visual mask will be to disrupt (interact with) the effects of the two types of manipulability.

As before, two models were compared against each other. In the first model (2.0) the two known covariates, object familiarity (fam_{si}) and object age of acquisition (aoa_{si}) were entered as continuous predictors, as well as the presence or absence of the mask ($Mask_{si}$). In the second model (2.1) manipulability ($Manip1_{si}$) was included as a predictor, as well as the interaction between this measure of Manipulability and the Mask. This allowed for a direct comparison between the models before and after the inclusion of manipulability as a predictor. Further, because the number of items with valid Manip2 ratings was smaller, this variable was looked at separately from Manip1 (2.2). The full regression equations are shown below (see methods from Experiment #1 for a full explanation of the terms in these equations).

$$\Pr(\log(y_{RT})) = b_0 + b_1 \cdot aoa_{si} + b_2 \cdot fam_{si} + b_3 \cdot Mask_{si} + subject_s + item_i + \epsilon_{si} \quad (2.0)^{28}$$

$$\Pr(\log(y_{RT})) = b_0 + b_1 \cdot aoa_{si} + b_2 \cdot fam_{si} + b_3 \cdot Mask_{si} + b_4 \cdot Manip1_{si} + b_5 \cdot Mask_{si} \cdot Manip1_{si} + subject_s + item_i + \epsilon_{si} \quad (2.1)$$

$$\Pr(\log(y_{RT})) = b_0 + b_1 \cdot aoa_{si} + b_2 \cdot fam_{si} + b_3 \cdot Mask_{si} + b_4 \cdot Manip2_{si} + b_5 \cdot Mask_{si} \cdot Manip2_{si} + subject_s + item_i + \epsilon_{si} \quad (2.2)$$

²⁸ There were actual two versions of this first model, one to compare against Manip1 ($n = 320$), and one to compare against Manip2 ($n = 178$).

5.9.2 Results for Manip1 (Grasping)

The initial model (1.0) significantly predicted naming latencies (RTs) with the Mask and higher AoAs predicting slower RTs ($b_3 = 0.064$, $t = 5.86$, and $b_1 = 0.183$, $t = 29.51$, respectively). Interestingly, familiarity was also significant but in the opposite direction than would be predicted, with more familiar items being matched more slowly ($b_2 = 0.019$, $t = 2.86$). Critically, the second model (1.1) was shown to be a significant improvement over the initial model with $\text{Diff-}\chi^2(2) = 25.39$, $p < 0.001$, $\text{AIC} = 1965.1$ compared to $\text{AIC} = 1986.5$ for model 1.0). This result indicated that adding Manip1 significantly increased the predictive power of the model. Further, it was found that both Manip1 and the interaction between Manip1 and the Mask were significant ($b_4 = 0.169$, $t = 34.02$, and $b_5 = -0.021$, $t = -2.42$ respectively), with faster RTs for higher values of Manip1, as found in Experiment #1. See Table 5.3 for the full breakdown of effects from this analysis.

Notably, these effects did not support the *hypothesis 4* prediction of slower RTs for manipulable objects, which would have replicated the non-manipulable advantage reported by Filliter et al. (2005). However, Filliter et al. (2005) controlled for object Familiarity, but not Age of Acquisition, and the current observed advantage was consistent with the advantage observed in Experiment #1 for object naming.

5.9.3 Results for Manip2 (Functional Use)

Again, the initial model (1.0) significantly predicted naming latencies (RTs) with the Mask and higher AoAs predicting slower RTs ($b_3 = 0.203$, $t = 24.48$, and $b_1 = 0.035$, $t = 2.41$, respectively), however, for this subset of items, the effect of familiarity was not significant ($b_2 = -0.006$, $t = -0.67$). Critically, the second model (1.1) was shown to be a

small but significant improvement over the initial model with $\text{Diff-}\chi^2(2) = 6.37, p < 0.05$, $\text{AIC} = 1071.0$ compared to $\text{AIC} = 1073.3$ for model 1.0). This result indicated that adding Manip2 significantly increased the predictive power of the model. Interestingly, despite overall improvement in the model, neither the main effect of Manip2, nor the interaction between Manip2 * Mask were significant ($b_4 = -0.025, t = -1.68, b_5 = -0.013, t = -1.09$, respectively). Although, the trends for both variables were in the direction of replicating Experiment #1, with a trend towards bigger effects Manip2 for Masked objects. See Table 5.4 for the full breakdown of effects from this analysis.

Table 5.3. Linear Mixed-Effects Regression effect sizes for model including Manip1 (Model 2.1)

	Beta Label	Beta Value (Estimate)	t-value ($t_{\text{crit}} = 1.96$)
(Intercept)	b_0	6.170	115.49
AoA	b_1	0.063	10.22
Fam	b_2	0.022	3.24
Mask	b_3	0.131	9.21
Manip1	b_4	-0.022	-4.27
Mask * Manip1	b_5	0.016	4.09

Table 5.4. Linear Mixed-Effects Regression effect sizes for model including Manip2 (Model 2.2)

	Beta Label	Beta Value (Estimate)	t-value ($t_{\text{crit}} = 1.96$)
(Intercept)	b_0	6.264	99.46
AoA	b_1	0.047	3.06
Fam	b_2	-0.004	-0.47
Mask	b_3	0.239	7.11
Manip2	b_4	-0.025	-1.68
Mask * Manip2	b_5	-0.013	-1.09

5.9.4 Analysis Summary and Hypothesis Testing

The first hypothesis for this experiment, that we would replicate Filliter et al.'s (2005) advantage for non-manipulable objects (hypothesis 4), was not supported. In fact,

the results suggested a significant pattern in the opposite direction (faster matching of more highly manipulable objects). These results replicated the advantage for manipulable (high Manip1) items during Naming (Experiment #1). The results further replicated Experiment #1 by showing a significant increase in predictive power of the model when both types of object manipulability were included (support for hypothesis 5), and showed a significant Mask by Manipulability effect for Manip1, that was not significant for Manip2 (partial support for hypothesis 6, that the mask would interact with the effects of manipulability).

Even though the Manip2 * Mask interaction was not significant, it was still of theoretical interest to examine the extent to which the pattern of Masking by Manipulability interaction replicated the results from Experiment #1. Thus, the same *post hoc* analyses from Experiment #1 were conducted to chart the associated *Betas* for the two types of Manipulability with and without a Mask. Again, the results appeared to indicate that Manip1 (grasping) results were largest for Non-Masked stimuli, while Manip2 (functional use) results were largest for Masked stimuli (see Figure 5.3 for a depiction of this reversing effect of manipulability based on the Mask).

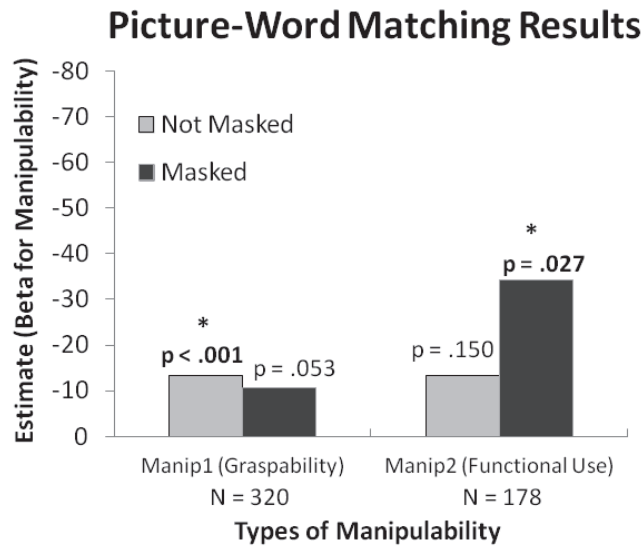


Figure 5.3. Manipulability effect sizes (betas) during Word-Picture Matching for Masked and non-Masked conditions (simple effects analysis). Note that negative betas are plotted up, and indicate a relationship between higher scores on manipulability and faster RTs. Also note that masking interrupts these effects in different ways for the two types of manipulability. For Manip1 (graspability), effects are larger for non-masked items, but for Manip2 (functional use), effects are larger for masked items. These findings are consistent with those from Experiment #1 (Picture Naming).

5.9.5 Analysis 2.3 (RT). Mixed Effects with Interactions

Testing Hypothesis 7. Differential effects of the two types of manipulability on RT.

Again, hypothesis 7 was partially supported by the different effects of manipulability based on the Mask shown in analysis 2.1, but a full analysis pitting the two types of manipulability against each other was again considered (analysis 2.2). This time, adding the 3-way interaction between the Mask and both types of Manipulability did not significantly improve the predictive power of the model ($\chi^2(1) = 2.17, p = 0.141$, AIC = 1068.4 for model 2.4 compared to AIC = 1068.6 for model 2.3, equations below).

$$\Pr(\log(y_{RT})) = b_0 + b_1 \cdot \text{aoa}_{si} + b_2 \cdot \text{fam}_{si} + b_3 \cdot \text{Mask}_{si} + b_4 \cdot \text{Manip1}_{si} + b_5 \cdot \text{Manip2}_{si} + b_6 \cdot (\text{Mask}_{si} \times \text{Manip1}_{si}) + b_7 \cdot (\text{Mask}_{si} \times \text{Manip2}_{si}) + b_8 \cdot (\text{Manip1}_{si} \times \text{Manip2}_{si}) + \text{subject}_s + \text{item}_i + \varepsilon_{si} \quad (2.3)$$

$$\Pr(\log(y_{RT})) = b_0 + b_1 \cdot \text{aoa}_{si} + b_2 \cdot \text{fam}_{si} + b_3 \cdot \text{Mask}_{si} + b_4 \cdot \text{Manip1}_{si} + b_5 \cdot \text{Manip2}_{si} + b_6 \cdot (\text{Mask}_{si} \times \text{Manip1}_{si}) + b_7 \cdot (\text{Mask}_{si} \times \text{Manip2}_{si}) + b_8 \cdot (\text{Manip1}_{si} \times \text{Manip2}_{si}) + b_9 \cdot (\text{Mask}_{si} \times \text{Manip1}_{si} \times \text{Manip2}_{si}) + \text{subject}_s + \text{item}_i + \varepsilon_{si} \quad (2.4)$$

A lack of significant improvement in model 2.4 suggested no reason to analyze the 3-way interaction, and the model including it. Instead, the results from model 2.3 were considered. This model (shown in equation 2.3) showed only one significant 2-way interaction between the Mask and Manip1 ($t = 2.403$, $b_6 = 0.040$). Again, the Mask by Manip2 interaction was not significant, nor was the Manip1 by Manip2 interaction ($t = -1.09$, $b_7 = -0.013$ and $t = -1.38$, $b_8 = -0.035$, respectively). Also, within this range of selected stimuli ($n = 176$), neither the main effect of Manip1 nor Manip2 was significant ($t = 1.27$, $b_4 = 0.092$ and $t = 1.16$, $b_5 = 0.132$, respectively), nor, surprisingly, was the main effect of Mask ($t = 0.718$, $b_3 = 0.059$), meaning that the Mask effect was effectively partialled out by the Manip1 by Mask interaction.

These results, again, provide support for hypothesis 7: differential effects of the two types of manipulability. In particular, on the same restricted stimulus set, the interaction with the Mask was significant for one manipulability variable (Manip1) and not for the other (Manip2). More critically, the directions of the interactions were reversed, with, as before, bigger Manip1 effects for Non-Masked items, and bigger Manip2 effects for masked items.

Further, although it was not significant in this analysis, there was a trend towards Manip1 predicting longer RTs ($t = 1.274$, $b_5 = 0.092$), for these already ‘graspable’ items. This trend, as before, suggested some curvilinearity in the overall relationship between Manip1 and the dependent variable (matching response times). This curvilinearity in Manip1, although interesting, was difficult to interpret. Thus, discussion in this

manuscript will focus on the Mask by manipulability interactions that reversed for the two types of manipulability.

5.9.6 Accuracy Analysis

In general, the effects of accuracy did not contradict the main RT findings (as measured with mixed-effects regression analysis on the accuracy for match trials). Specifically, there were no significant accuracy effects of Manip1 or Manip2. There was a significant masking effect, $z = -4.28, p < .001$, and a significant effect of AoA, $z = -4.22, p < .001$, but these were in the expected direction of more errors for masked and late acquired objects. There was also a small accuracy effect for object familiarity, $z = -2.25, p < .05$, which suggested, counter-intuitively, lower accuracy for high familiarity items. These results, taken with the reaction time data, suggest an interesting effect whereby unusual (low familiarity) objects were actually picture-word matched better than high familiarity ones.

5.10 DISCUSSION

Overall, the current picture-word matching experiment did not replicate the non-manipulable picture-word matching advantage reported by Filliter et al. (2005), and therefore did not support our initial hypothesis for this experiment (hypothesis 4). On the other hand, our picture-word Matching results did replicate our Naming results from experiment #1, by showing an advantage for identifying (Matching or Naming) manipulable objects. Further, the current Matching results also replicated experiment #1 by: (1) showing significant effects of both types of manipulability above and beyond other confounds like Familiarity and Age of Acquisition (supporting hypothesis 5), and

(2) showing significant interactions between manipulability and the Mask, (supporting hypothesis 6). In particular, the finding that graspability (Manip1) effects were larger for Non-Masked items, and functional use (Manip2) effects were larger for Masked items suggests that masking diminishes the effect of one type of manipulability effect (graspability) while strengthening the effect of the other (functional use). This difference in effects based on masking, supports the notion that our two definitions of manipulability really do tap two different constructs with differing effects on object identification.

In the current research there was no reversal in effects between naming and picture-word matching like the reversal observed by Salmon, McMullen and Trappenberg (2011; see also Salmon et al., in revision) between naming and categorization. This suggests that the picture-word matching task is more similar to a naming task than a categorization one, despite the surface similarities to a categorization task (i.e. both categorization and picture-word matching require force-choice button press responding instead of a verbal response). At its essence, the picture-word matching task requires identification at the basic or entry-level: like a naming task, even though it may be performed with a button press like the categorization task (see Table 5.5 for a comparison between the tasks). Thus, these findings suggest that it's the level of representation (and not the response effector) driving these effects. This idea is consistent with the semantic branching explanation explored in Salmon, McMullen and Trappenberg (2011). That is, manipulability effects are related to semantic organization, with organization of manipulable objects being sparser and less clustered than non-manipulable objects. This leads to faster identification of manipulable objects at a 'basic' level (cf. Rosch, 1975) ,

but slower identification of manipulable objects at a super-ordinate / category level (see chapter 4 for a more in depth review of this theory, and computational support for it).

Table 5.5. A comparison between the tasks used in the current research to those used by Salmon, McMullen and Matheson (submitted), and the results. The cells matching characteristics of the Picture-Word matching task are highlighted in grey. Notably, although the picture-word matching task requires the same type of response as the categorization task (two button on the keyboard), the level at which the object is identified is more equivalent to a naming task and so are the corresponding results.

	The Current Research		Salmon, McMullen & Matheson	
	Naming	Picture-Word Matching	Naming	Categorization
type of response	verbal	manual (button press)	verbal	manual (button press)
# of options	infinite	two: match or mismatch	infinite	two: manmade or natural
level of identity	basic	basic	basic	super-ordinate
mean RTs	1120 ms	748 ms	826 ms	615 ms
faster RTs for:	manipulable	manipulable	manipulable	non-manipulable

5.11 GENERAL DISCUSSION

The current research sought to disambiguate the role of two types of manipulability (graspability versus functional use) during object identification, and did so by showing a differential effect of a concurrent Mask on these variables. In particular, both Experiment #1 (Naming) and Experiment #2 (Picture-Word Matching) showed larger effects of graspability (Manip1) on unmasked items, and larger effects of functional use (Manip2) on Masked items. Where “graspability” was defined as the extent to which an object could be picked up a used with one hand, and “functional use” was defined as the extent to which actions for using the object differed from those made to grasp it. The current results indicated that these manipulability ratings/scales really do capture two independent action systems. In other words, these results were consistent

with notions expressed by Buxbaum and colleagues (2006; 2002; 2000) as well as those by Bub, Masson and colleagues (2012; 2003; 2008), that ‘grasping’ and ‘functionally using’ objects are subserved by two computationally and neuro-anatomically different action systems.

Another aspect of the current research was to show significant effects of these action systems on object identification above and beyond the effects predicted by covariates such object familiarity, and object age of acquisition. Research in this area has been criticized in the past for lack of control of potentially confounding variables such as age of acquisition which has been well established as a strong predictor in identification times (e.g. E. Bates et al., 2003; Bonin, Peereman, Malardier, Méot, & Chalard, 2003; Cuetos & Alija, 2003; Pérez, 2007). In the current research, observed effects of Age of Acquisition (AoA) were very large, and in many cases much larger and more consistent than those of manipulability. Thus, it was a particular success of this research that we were able to show significant effects of manipulability above and beyond effects of AoA. Further, research from our lab (unpublished) has shown the effects of manipulability to sometimes be elusive, and demanding of larger object sets, many participants, and powerful statistical techniques to measure their effects.

5.11.1 Two Action Systems: Two Different Effects on Identification

As discussed in the introduction, Buxbaum and Kalenine (2010) have elaborated on their “Two Action Systems” model, which really is a model for explaining an additional action distinction within the dorsal pathway. In the current research, we used ratings collected by Salmon, McMullen and Filliter (2010), for Graspability and

Functional Use. The definition applied and results obtained from Graspability (Manip1) align clearly with what Buxbaum and Kalenine (2010) referred to as the ‘dorso-dorsal’ or action ‘structure’ stream, a fast, short-acting system focused on action affordances that are short acting. In particular, the current results indicated an effect of Graspability (Manip1) for un-masked but not masked items. Given that masked items take longer to identify, this result could be related to transient effects of Graspability that only appear in early stages of processing and wash out by later ones (cf. Bub & Masson, 2012 who observed transient effects of "volumetric" gestures during a task that required processing the name of manipulable object while making a gesture). Also, the lack of Graspability effects when objects are masked may reflect that this aspect of object-action is only activated in the presence of a clear outline, texture and contour, such as was the case with non-masked objects.

Our results and definition of Functional Usage (Manip2) could pertain either to the ventro-dorsal ‘function’ stream or be a part of processing of an object in the ventral stream. Buxbaum and Kalenine (2010) clearly would place ‘functional usage’, using their definitions, as a ventro-dorsal function. However if we look at the ‘functional use’ ratings collected by Salmon, McMullen and Filliter (2010) and then used in this research, this de-facto classification may not be perfectly apt. In particular, the definition used by Salmon, McMullen and Filliter (2010) asked participants to rate the extent to which ‘the action made when using the object differed from those made when grasping the object’. This definition explicitly requires participants to think in depth about using the object, both how it is used, and how is it grasped. It is therefore, perhaps, a more semantic definition than that used by Buxbaum and colleagues’ (2010; 2006; 2002; 2000). However,

Buxbaum and Kalenine (2010) did make the point that this ventro-dorsal stream might be considered part of the semantic system or the ‘embodied’ representation of the object.

As stated in the introduction, in Buxbaum and Kalenine’s (2010) model, the ventro-dorsal stream processes specific object-appropriate action or actions associated with ‘functional use’ (i.e. these are the movements for ironing my shirt). On the other hand, the ventral stream processes the knowledge of the objects’ functional purpose (i.e. the iron is for ironing). Thus, the Salmon, McMullen and Filliter (2010) ratings likely represent part of the process related to the ventral stream, even though at their core, these ratings were designed to capture ‘functional use’ of the kind described in Buxbaum and Kalenine’s (2010) ventro-dorsal ‘function’ stream. Certainly, the current results are at least consistent with characteristics attributed to this ventro-dorsal ‘function’ stream. In particular, Functional Usage (Manip2) effects in this research were larger for masked objects. This is consistent with the slower and longer lasting attributes attributed to the ventro-dorsal stream. These streams may have been particularly active during masked-representations of the objects as a means of aiding in the deciphering the content of the image behind the mask. Similarly if this ‘function’ stream is slower acting and longer lasting, it makes sense that the effects of this stream will be more noticeable for tasks in which the entire process is slowed down (as in the case with a concurrent mask).

In summary, these results offer further support that the ratings collected by Salmon, McMullen, and Filliter (2010) align with the ‘Two Action Systems’ model of Buxbaum and Kalenine (2010). In particular, Graspability ratings correspond to the fast acting, fleeting effects of dorso-dorsal action ‘structure’ stream; while, Functional Usage ratings correspond mostly to the slower acting, longer lasting ventro-dorsal ‘function’

stream. The one caveat to this pairing is that the Functional Usage ratings by Salmon, McMullen, and Filliter (2010) may also be partly confounded with ventral stream ‘knowledge of functional purpose’ involvement. However, future research will be required to determine the extent to which these Functional Usage ratings represent a pure measure of the “function” in Buxbaum and Kalenine’s (2010) ventro-dorsal ‘function’ stream.

5.11.2 Disambiguating Functional Use (Manip2) from Graspability (Manip1)

The most interesting finding about our *functional use* (Manip2) ratings was that their effects were actually *stronger* for masked items. As stated at the outset, most research comparing manipulable to non-manipulable objects confound these two types of action systems (e.g. this was true of the research conducted by Salmon, McMullen and Matheson, submitted). That is, all “manipulable” items have, by definition, higher functional use ratings. This means that for any significant manipulability effect between objects categorized as “manipulable” or “non-manipulable,” it’s difficult or impossible to say whether it is Graspability (Manip1) or Functional Use (Manip2) driving these effects. However, if the relative size of manipulability effects can be judged based on the presence or absence of a Mask, then this gives a good rubric for determining which manipulability is driving a given effect.

For example, the research presented by Salmon, Matheson and McMullen (chapter 3) showed a reversing manipulability effect (based on categorizing versus naming) for briefly presented and backward masked stimuli. Although the nature of the Mask was different from the one used in the current experiments (backward, versus

concurrent), it seems reasonable to assume that a backward Mask combined with a brief exposure duration would disrupt the visual system in a similar way. Thus, it seems reasonable to conclude that the Salmon, et al. (chapter 3) results were driven largely by *functional use* ratings, at least to a greater extent than Graspability. This assumption would also be consistent with the computational model presented in Salmon, McMullen and Trappenberg (chapter 4) that purported semantic branching effects based on super-ordinate categorization. In particular, this model suggests that manipulable objects, according to their highly specific learned function, form smaller super-ordinate categories than the non-manipulable objects. As a result, this differential semantic organization can then lead to manipulability-related advantages for basic-level identification (e.g. naming or picture-word matching) and disadvantage during super-ordinate level identification (e.g. object categorization).

Whatever the mechanism behind these effects, it is the case that the current research indicated effects of both Graspability and Functional Usage on object identification. In particular, these effects were found with healthy normal participants, without the aid of neuroimaging techniques. To our knowledge, this is the first simultaneous demonstration of these two effects in healthy participants during behavioural identification tasks. These results clearly show the interactivity between the identification and action systems in the brain.

5.11.3 Conclusions

In conclusion, the current research demonstrated that action systems have an influence during simple object identification tasks (i.e. naming and picture-word matching), and more specifically, two types of manipulability or action systems

(Graspability and Functional Use) differentially affect object identification. Specifically, observed *graspability* effects were largest for unmasked items, suggesting that these relate to a quick acting short-lasting system during object identification. Functional use effects were largest for masked items suggesting these effects relate to a slower acting, longer lasting action system, with a semantic element. Further, these effects were significant above and beyond the role of both object Familiarity and Age of Acquisition, suggesting that, with the right design, effects of these action systems can be observed during object identification. These findings are important for any researcher interested in the mechanisms underlying object identification and action systems, as well as those interested in rehabilitation strategies for patients. They also speak to the dynamic and parallel, interactive nature of the identification and action systems.

5.12 APPENDIX A – OBJECT AND FOIL LIST

1	Accordion	~bagpipes	108	Eagle	~stork	215	Plate	~muffin tin
2	Administrati on Building	~dunn building	109	Easter Egg	~easter basket	216	Pliers	~vise
3	Airplane	~blimp	110	Egg	~cheese	217	Plug	~fuse
4	Anchor	~sail	111	Elephant	~hippopotamus	218	Police Car	~ambulance
5	Animal Crackers	~teddy grahams	112	Envelopes	~folder	219	Pool Table	~air hockey table
6	Ant	~caterpillar	113	Etch-A- Sketch	~coloring book	220	Popsicle	~ice cream
7	Ashtray	~candy dish	114	Fax Machine	~printer	221	Pot	~whisk
8	Axe	~crowbar	115	Fence	~driveway	222	Potato	~parsnip
9	Baby Bib	~baby booties	116	Filing Cabinet	~office chair	223	Present	~party hat
10	Baby Bottle	~baby hat	117	Fire	~furnace	224	Prison	~fire station
11	Baby Carriage	~baby monitor	118	Fire Hydrant	~mailbox	225	Protractor	~abacus
12	Baby Cradle	~rocking chair	119	Fish	~otter	226	Purse	~wallet
13	Baby Food	~teething ring	120	Floor Tiles	~doormat	227	Rabbit	~ferret
14	Baby Powder	~skin cream	121	Flower	~shrub	228	Raccoon	~porcupine
15	Baby Rattle	~baby jumper	122	Fly	~praying mantis	229	Raspberry	~blueberry
16	Backpack	~fanny pack	123	Football	~hockey puck	230	Refrigerator	~air conditioner
17	Balloon	~streamers	124	Forest	~lake	231	Remote Control	~keyboard
18	Banana	~orange	125	Fork	~chopsticks	232	Ring	~brooch
19	Bank	~museum	126	Fox	~shrew	233	Road	~driveway
20	Bank Machine	~vending machine	127	Frog	~chameleon	234	Rocking Horse	~seesaw
21	Barn	~silo	128	Frying Pan	~crockpot	235	Rolodex	~agenda
22	Barrel	~bucket	129	Garbage Can	~garbage bag	236	Roof	~porch
23	Basket	~grocery bag	130	Gas Station	~restaurant	237	Rooster	~sparrow
24	Bathtub	~linen basket	131	Gazebo	~arbor	238	Roulette Wheel	~poker chips
25	Bear	~wolf	132	Giraffe	~hyena	239	Rowe	~CS Building
26	Bee	~mosquito	133	Glasses	~contact lens	240	Building	building
27	Beetle	~grasshopper	134	Glove	~sweatband	241	Ruler	~push pin
28	Bell	~pipe organ	135	Goat	~warthog	242	Sailboat	~speedboat
29	Belt	~sneaker	136	Gorilla	~orangutan	243	Salt Shaker	~can opener
30	Bicycle	~skateboard	137	Grapes	~watermelon	244	Sandbox	~toy truck
31	Binder	~clipboard	138	Grass	~bush	245	Sandwich	~granola bar
32	Blender	~microwave	139	Guitar	~saxophone	246	Santa Claus	~easter bunny
33	Blocks	~teddy bear	140	Gun	~whip	247	Saw	~spade
34	Book	~magazine	141	Hair Dryer	~hair straightener	248	Scarf	~slippers
35	Boots	~sandals	142	Halifax Citadel	~discovery centre	249	Scissors	~glue
36	Bottle	~travel mug	143	Hammer	~pickaxe	250	Screw	~tack
37	Bow	~sash	144	Harmonica	~clarinet	251	Screwdriver	~clamp
38	Bowl	~spatula	145	Harp	~cello	252	Seagull	~pelican
39	Box	~jar	146	Hat	~ earmuffs	253	Seahorse	~starfish
40	Bread	~muffin	147	Helicopter	~hang glider	254	Seal	~dolphin
41	Bridge	~traffic light	148	High Chair	~bean bag chair	255	Sewing Machine	~breadmake r
42	Broom	~mop	149	Hole Punch	~post-it note	256	Sheep	~llama
							Shell	~shrimp

43	Brush	~washcloth	150	Horse	~buffalo	257	Shovel	~hoe
44	Bus	~camper	151	House	~igloo	258	Shower	~hand soap
45	Butterfly	~ladybug	152	Ice Scraper	~tire pump	259	Sink	~medicine cabinet
46	Cake	~cookies	153	Iron	~clothes steamer	260	Sppy Cup	~baby mobile
47	Camel	~moose	154	Ironing Board	~laundry basket	261	Skirt	~capris
48	Camera	~camcorder	155	Jacket	~shawl	262	Sled	~snowmobile
49	Candle	~incense	156	Jack-O-Lantern	~halloween mask	263	Slide	~monkey bars
50	Candy Cane	~peanut brittle	157	Jelly Beans	~licorice	264	Slot Machine	~arcade
51	Cannon	~sword	158	Kangaroo	~koala	265	Snail	~clam
52	Cap	~toque	159	Kettle	~toaster oven	266	Snake	~eel
53	Car	~jeep	160	Key	~key chain	267	Snowflake	~raindrop
54	Carpet	~hardwood floor	161	Kite	~boomerang	268	Sock	~long underwear
55	Carrot	~beet	162	Knife	~taser	269	Spider	~scorpion
56	Car Seat	~seatbelt	163	Ladder	~scaffolding	270	Spider Web	~bird nest
57	Cash Register	~adding machine	164	Lamp	~chandelier	271	Stairs	~hallway
58	Cassette	~speakers	165	Lawn Mower	~whipper snipper	272	Staple Gun	~graph paper
59	Castle	~sky scraper	166	Leaf	~seaweed	273	Stapler	~paperclip
60	Cat	~hamster	167	Lego	~puzzle	274	Staple Remover	~twist tie
61	CD-ROM	~record	168	Lemon	~plum	275	Statue	~mural
62	Celery	~cucumber	169	Leopard	~dingo	276	Stocking	~valentine
63	Cell Phone	~pager	170	Lettuce	~broccoli	277	Stool	~footrest
64	Chain	~rope	171	Light Bulb	~battery	278	Stove	~barbecue
65	Chair	~hammock	172	Lion	~cheetah	279	Strawberry	~cranberry
66	Chalkboard	~bulletin board	173	Lobster	~stingray	280	Stroller	~shopping cart
67	Cherry	~apricot	174	Lock	~safe	281	SUB	~halifax shopping centre
68	Chest	~bookcase	175	LSC	~killiam library	282	Suitcase	~garmet bag
69	Chickadee	~blue jay	176	Manhole Cover	~subway	283	Sweatshirt	~snow pants
70	Chicken	~pig	177	Maracas	~wind chimes	284	Swing Set	~carousel
71	Chisel	~clamp	178	Marker	~crayon	285	Table	~countertop
72	Christmas Tree	~yule log	179	Milk	~yogurt	286	Tambourine	~cowbell
73	Church	~library	180	Mitten	~leg warmer	287	Tape Measure	~level
74	Cigar	~lighter fluid	181	Mixer	~hot plate	288	Telephone	~answering machine
75	Cigarette	~lighter	182	Monkey	~skunk	289	Television	~radio
76	Clock	~fire alarm	183	Monument	~fountain	290	Thread	~wool
77	Closet	~hatstand	184	Moon	~sun	291	Tie	~cummerbund
78	Clothespin	~safety pin	185	Motorcycle	~scooter	292	Tiger	~cougar
79	Clouds	~earth	186	Mountain	~glacier	293	Toaster	~waffle iron
80	Clown	~mime	187	Mouse	~guinea pig	294	Toilet	~bath mat
81	Coffee Pot	~urn	188	Movie Theatre	~casino	295	Toilet Paper	~hand towel
82	Comb	~facecloth	189	Mr. Potatohead	~g.i. joe	296	Tomato	~radish
83	Compass	~sundial	190	Mushroom	~garlic	297	Toothbrush	~dental floss
84	Computer	~CD player	191	Nails	~bolts	298	Tractor	~bulldozer
85	Couch	~ottoman	192	Necklace	~earring	299	Train	~trolley
86	Cow	~gazelle	193	Onion	~asparagus	300	Tree	~flowerbed
87	Crab	~shrimp	194	Orange	~grapefruit	301	Truck	~van
88	Crocodile	~iguana	195	Ornament	~holly	302	Turtle	~gecko
89	Crown	~sceptre	196	Ostrich	~goose	303	Umbrella	~rain coat
90	Cup	~glass	197	Owl	~hawk	304	Vase	~flower pot

91	Deer	~squirr	198	Pacifier	~lollipop	305	Vest	~poncho
92	Desk	~wardrobe	199	Paintbrush	~paint roller	306	Violin	~flute
93	Diaper	~baby wipe	200	Pants	~shorts	307	Wagon	~tricycle
94	Dice	~cards	201	Parking Meter	~stop sign	308	Wall	~air vent
95	Dinosaur	~mammoth	202	Parrot	~flamingo	309	Washing Machine	~washing board
96	Dish Washer	~vacuum	203	Peach	~lime	310	Watch	~bracelet
97	Dog	~badger	204	Peacock	~swan	311	Water Fountain	~hedge
98	Doll	~easy bake oven	205	Pear	~kiwi	312	Well	~resevoir
99	Donkey	~coyote	206	Pen	~highlighter	313	Wheels	~handlebars
100	Door	~awning	207	Penguin	~emu	314	Whistle	~recorder
101	Dragonfly	~moth	208	Pepper	~peas	315	Wickwire	~point pleasant park
102	Dress	~cape	209	Photocopier	~typewriter	316	Windmill	~watermill
103	Dresser	~hanger	210	Piano	~xylophone	317	Window	~mirror
104	Drill	~flashlight	211	Pigeon	~crow	318	Wreath	~mistletoe
105	Drums	~gong	212	Pineapple	~cantaloupe	319	Wrench	~mallet
106	Dryer	~clothes line	213	Pipe	~cigarette papers	320	Yarn	~fabric
107	Duck	~turkey	214	Pitcher	~grater	321	Zebra	~antelope

5.13 REFERENCES

- Agresti, A. (2002). *Categorical data analysis*. Hoboken, NJ: A John Wiley & Sons, Inc.
- Baayen, R. H. (2008). *Analyzing Linguistic Data: A practical introduction to statistics*: Cambridge University Press.
- Bates, D. (2007). lme4: Linear mixed-effects models using S4 classes (Version R package version 0.99875-9).
- Bates, E., D'Amico, S., Jacobsen, T., Székely, A., Andonova, E., Devescovi, A., et al. (2003). Timed picture naming in seven languages. *Psychonomic Bulletin & Review*, *10*(2), 344-380.
- Bonin, P., Peereman, R., Malardier, N., Méot, A., & Chalard, M. (2003). A new set of 299 pictures for psycholinguistic studies: French norms for name agreement, image agreement, conceptual familiarity, visual complexity, image variability, age of acquisition, and naming latencies. *Behavior Research Methods, Instruments & Computers*, *35*(1), 158-167.
- Bub, D. N., & Masson, M. E. J. (2012). On the dynamics of action representations evoked by names of manipulable objects. *Journal of Experimental Psychology: General*, *141*, 502-517.
- Bub, D. N., Masson, M. E. J., & Bukach, C. M. (2003). Gesturing and naming: The use of functional knowledge in object identification. *Psychological Science*, *14*(5), 467-472.
- Bub, D. N., Masson, M. E. J., & Cree, G. S. (2008). Evocation of functional and volumetric gestural knowledge by objects and words. *Cognition*, *106*(1), 27-58.

- Buxbaum, L. J., & Kalenine, S. (2010). Action knowledge, visuomotor activation, and embodiment, in the two action systems. *Annals of the New York Academy of Sciences, 1191*, 201-218.
- Buxbaum, L. J., Kyle, K. M., Tang, K., & Detre, J. A. (2006). Neural substrates of knowledge of hand postures for object grasping and functional object use: Evidence from fMRI. *Brain Research, 1117*, 175-185.
- Buxbaum, L. J., & Saffran, E. M. (2002). Knowledge of object manipulation and object function: Dissociations in apraxic and nonapraxic subjects. *Brain and Language, 82*(2), 179-199.
- Buxbaum, L. J., Veramonti, T., & Schwartz, M. F. (2000). Function and manipulation tool knowledge in apraxia: Knowing 'what for' but not 'how.'. *Neurocase, 6*(2), 83-97.
- Chao, L. L., & Martin, A. (2000). Representation of manipulable manmade objects in the dorsal stream. *NeuroImage, 12*, 478-484.
- Creem, S. H., & Proffitt, D. R. (2001). Grasping objects by their handles: A necessary interaction between cognition and action. *Journal of Experimental Psychology: Human Perception and Performance, 27*(1), 218-228.
- Cuetos, F., & Alija, M. (2003). Normative data and naming times for action pictures. *Behavior Research Methods, Instruments & Computers, 35*(1), 168-177.
- Filliter, J. H., McMullen, P. A., & Westwood, D. (2005). Manipulability and living/non-living category effects on object recognition. *Brain and Cognition, 57*, 61-65.

- Gauthier, I., Tarr, M. J., Moylan, J., Skudlarski, P., Gore, J. C., & Anderson, A. W. (2000). The fusiform 'face area' is part of a network that processes faces at the individual level. *Journal of Cognitive Neuroscience*, *12*(3), 495-504.
- Goodale, M. A. (2008). Action without perception in human vision. *Brain and Cognition*, *60*(2), 139-145.
- Goodale, M. A., & Milner, A. D. (1992). Separate visual pathways for perception and action. *Trends in Neurosciences*, *15*(1), 20-25.
- Goodale, M. A., & Milner, A. D. (1994). Separate visual pathways for perception and action. In H. Gutfreund & G. Toulouse (Eds.), *Biology and computation: A physicist's choice*. (pp. 606-611). River Edge, NJ US: World Scientific Publishing Co.
- Grèzes, J., Tucker, M., Armony, J., Ellis, R., & Passingham, R. E. (2003). Objects automatically potentiate action: An fMRI study of implicit processing. *European Journal of Neuroscience*, *17*(12), 2735-2740.
- Grill-Spector, K. (2003). The neural basis of object perception. *Current Opinion in Neurobiology*, *13*, 159-166.
- Grill-Spector, K., & Sayres, R. (2008). Object recognition: Insights from advances in fMRI methods. *Current Directions in Psychological Science*, *17*(2), 73-79.
- Haxby, J. V., Gobbini, M. I., Furey, M. L., Ishai, A., Schouten, J. L., & Pietrini, P. (2001). Distributed and overlapping representations of faces and objects in ventral temporal cortex. *Science*, *293*(5539), 2425-2430.
- Kalénine, S., & Bonthoux, F. (2008). Object manipulability affects children's and adult's conceptual processing. *Psychonomic Bulletin & Review*, *15*(3), 667-672.

- Kliegl, R., Masson, M. E. J., & Richter, E. M. (2010). A linear mixed model analysis of masked repetition priming. *Visual Cognition, 18*(5), 655-681.
- Lawrence, M. A., & Klein, R. M. (2012). Isolating exogenous and endogenous modes of temporal attention. *Journal of Experimental Psychology: General, 1-13*.
- Magnié, M. N., Besson, M., Poncet, M., & Dolisi, C. (2003). The Snodgrass and Vanderwart set revisited: Norms for object manipulability and for pictorial ambiguity of objects, chimeric objects, and nonobjects. *Journal of Clinical and Experimental Neuropsychology, 25*(4), 521-560.
- Malcolm, G. L., Lanyon, L. J., Fugard, A. J. B., & Barton, J. J. S. (2008). Scan patterns during the processing of facial expression versus identity: An exploration of task-driven and stimulus-driven effects. *Journal of Vision, 8*(8), 1-9.
- Matheson, H. E., & McMullen, P. A. (2010). Neuropsychological dissociations between motion and form perception suggest functional organization in extrastriate cortical regions in the human brain. *Brain and Cognition, 74*(2), 160-168.
- Pérez, M. A. (2007). Age of acquisition persists as the main factor in picture naming when cumulative word frequency and frequency trajectory are controlled. *The Quarterly Journal of Experimental Psychology, 60*(1), 32-42.
- Rosch, E. (1975). Cognitive representations of semantic categories. *Journal of Experimental Psychology: General, 104*(3), 192-233.
- Rossion, B., & Pourtois, G. (2004). Revisiting Snodgrass and Vanderwart's object pictorial set: The role of surface detail in basic-level object recognition. *Perception, 33*, 217-236.

- Salmon, J. P., McMullen, P. A., & Trappenberg, T. T. (2011). *Modeling mechanisms of reversed effects of manipulability on naming and categorizing objects*. Paper presented at the Cognitive Neuroscience Society (CNS), San Francisco, CA.
- Salmon, J. P., McMullen, P. A., & Filliter, J. H. (2010). Norms for two types of manipulability (graspability and functional usage), familiarity, and age of acquisition for 320 photographs of objects. *Behavior Research Methods*, *42*(1), 82-95.
- Salmon, J. P., McMullen, P. A., & Matheson, H. E. (submitted). The influence of object manipulability on categorization and naming of backward-masked photographs shown for brief durations: A reversal effect for object manipulability. *Cognition*.
- Snodgrass, J. G., & Vanderwart, M. (1980). A standardized set of 260 pictures: Norms for name agreement, image agreement, familiarity, and visual complexity. *Journal of Experimental Psychology: Human Learning and Memory*, *6*(2), 174-215.
- Tucker, M., & Ellis, R. (1998). On the relations between seen objects and components of potential actions. *Journal of Experimental Psychology: Human Perception and Performance*, *24*(3), 830-846.
- Tucker, M., & Ellis, R. (2004). Action priming by briefly presented objects. *Acta Psychologica*, *116*(2), 185-203.
- Witt, J. K. (2011). Action's effect on perception. *Current Directions in Psychological Science*, *20*(3), 201-206.
- Witt, J. K., Kemmerer, D., Linkenauger, S. A., & Culham, J. (2010). A functional role for motor simulation in identifying tools. *Psychological Science*, *21*(9), 1215-1219.

Witt, J. K., & Proffitt, D. R. (2005). See the ball, hit the ball: Apparent ball size is correlated with batting average. *Psychological Science, 16*(12), 937-938.

Wolk, D. A., Coslett, H. B., & Glosser, G. (2005). The role of sensory-motor information in object recognition: Evidence from the category-specific visual agnosia. *Brain and Language, 94*, 131-146.

5.14 SUPPLEMENTARY APPENDIX A. RT SCATTERPLOTS

Naming Experiment (Exp #1)

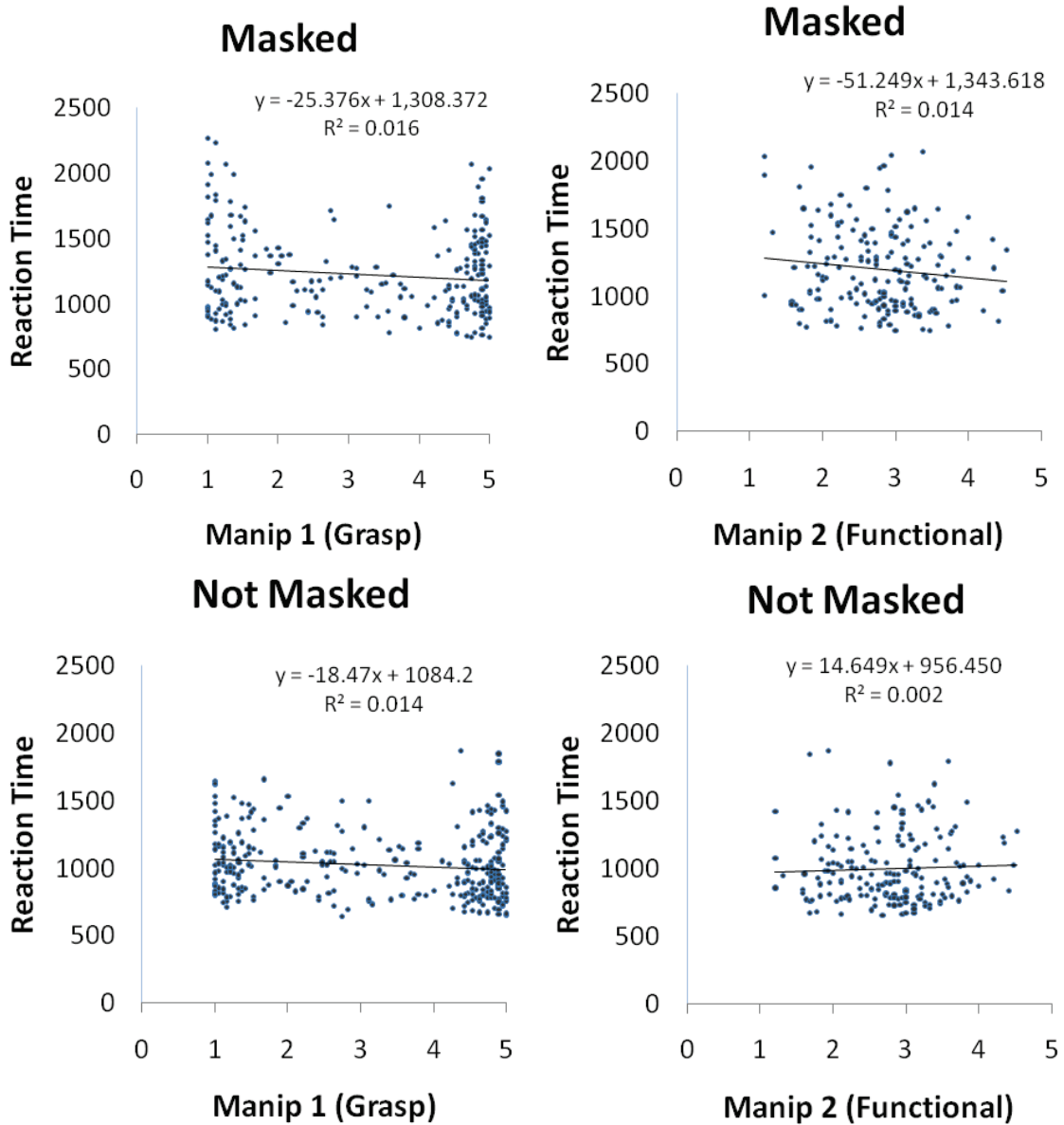


Figure 5.4. Reaction Time Data for Naming Experiment (each dot represents one of the items). Note: fewer dots for Manip2 data, as fewer items had ratings on this scale. R² values represent effect of the predictor in isolation (without the effects of familiarity and AoA).

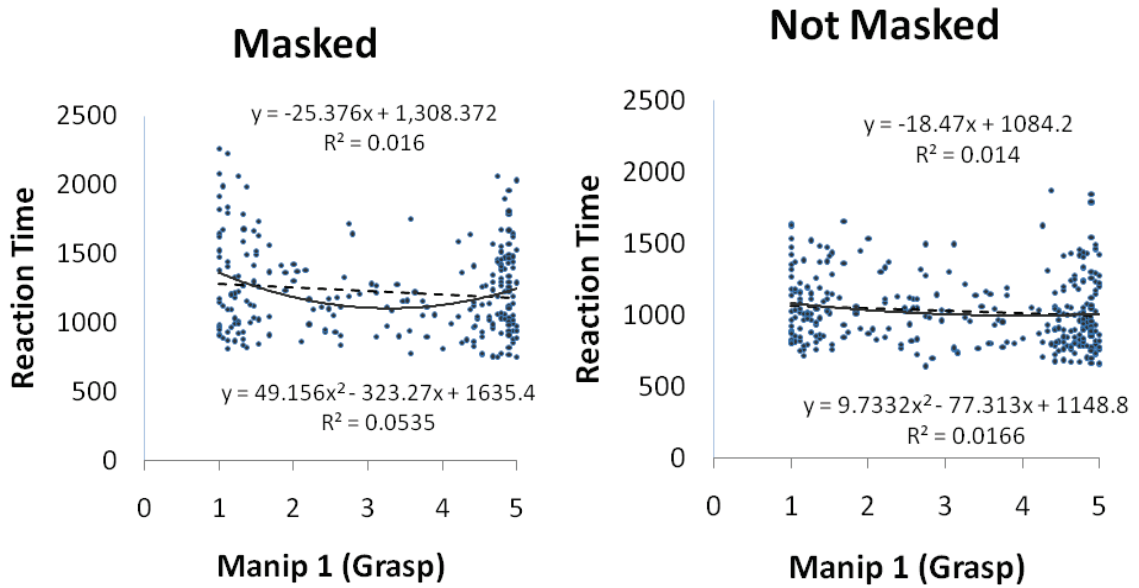


Figure 5.5. Data for Manip1 Masked & Not-Masked. In both cases, a polynomial fit explained more variance than a linear fit. (This fit was significantly better for the masked objects).

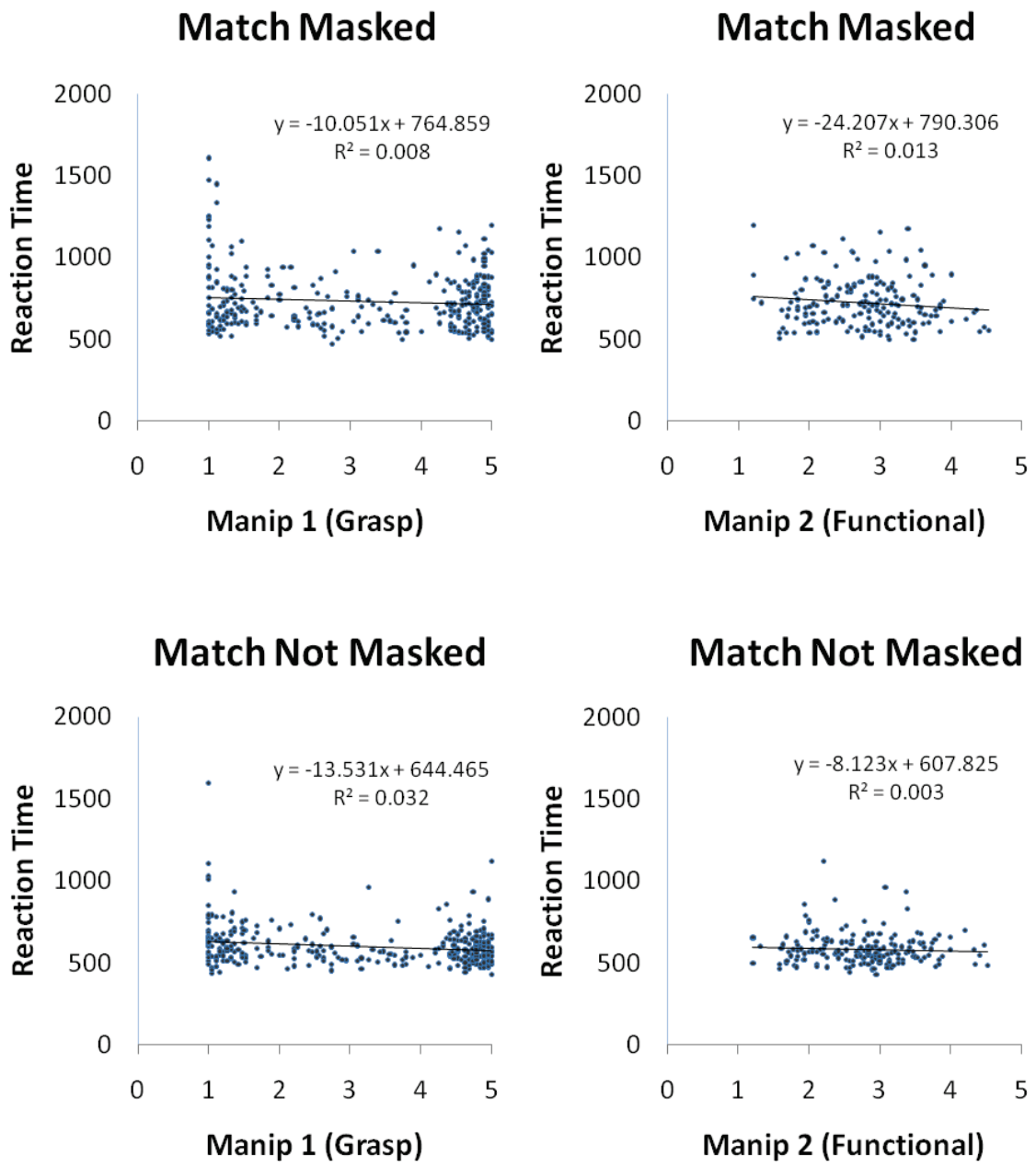


Figure 5.6. Reaction Time Data for the Matching Experiment (each dot represents one of the items). Note: fewer dots for Manip2 data, as fewer items had ratings on this scale.

**CHAPTER 6 PHOTOGRAPHS OF MANIPULABLE OBJECTS ARE
NAMED MORE QUICKLY THAN THE SAME OBJECTS DEPICTED AS
LINE-DRAWINGS: EVIDENCE THAT PHOTOGRAPHS ARE MORE
EMBODIED THAN LINE-DRAWINGS?**

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6.1 ABSTRACT

Previous research has shown that under controlled naming conditions, photographs of manipulable objects (i.e. those that can be grasped for use with one hand) are named more quickly than non-manipulable objects matched for object familiarity and age of acquisition (Salmon, Matheson & McMullen, in revision). This study tested the hypothesis that the amount of visual detail present in object depictions moderates such ‘manipulability’ effects on object naming. This was done by presenting the same objects as photographs and line-drawings for speeded naming. Forty-six participants named 222 objects in both format depictions. It was predicted that the same manipulable objects would be identified more quickly when presented as photographs as compared to line-drawings. Results were consistent with this prediction. However, there was no such photograph advantage observed for non-manipulable objects. These results indicate that factors such as surface detail moderate the role of action and “manipulability effects” during object identification tasks, and may provide evidence that photographs of manipulable objects are more ‘embodied’ than line-drawings of the same objects.

Keywords: manipulability, action, naming, photographs, line drawings, perception, identification

6.2 INTRODUCTION

The embodied and grounded cognition approach has been growing in popularity over the last decade or more (for a recent review from this journal see Borghi and Pecher, 2011). This approach has been interpreted to mean many different things, but the main tenant is that “cognitive activity is grounded in sensory-motor processes and situated in specific contexts and situations” (Borghi & Pecher, 2011, p. 1). Another way of saying this is that the same neural substrate activated when perceiving an object is also used to represent the object. For example, when I think about and talk about a “hammer”, I am activating the same neural pathways and brain areas that are active when I’m actually seeing and using a *hammer*. This raises interesting questions about the differences in representations between objects we regularly use and pick, hereafter referred to “manipulable” objects, versus those that we do not commonly engage with, hereafter referred to “non-manipulable” objects. Specifically, if manipulable objects are defined as those with learned motor-associations, then by definition, and according to grounded theories, these objects will activate motor-areas as a part of their object representation in a way that won’t be observed for non-manipulable objects. The question then becomes, to what extent is it necessary to activate action-areas in the brain to fully recognize a manipulable object if the task does not require action, such as during an object naming task or passive viewing task? Furthermore, and the topic of the current research, does the type of depiction of the object influence the extent to which such motor systems might be engaged. For example, line-drawings tend to depict a more simplified, basic-features version of the object, and are generally reduced in the intensity and quality of surface

details, texture, shading and 3D visual cues. Do line-drawings activate embodied actions to the same degree that a more realistic depiction like a photograph would?

The Snodgrass and Vanderwart's (1980) standardized set of line-drawings has been commonly used for many studies of object recognition. The implied assumption with use of these line drawings in the past is that processing objects on the basis of drawings is equivalent to processing more realistic depictions of the objects, such as photographs or 3-dimensional, real objects. However, this assumption may be invalid for certain kinds of behaviors (e.g. Nicolson & Humphrey, 2001; Price & Humphreys, 1989). In particular, "manipulable" objects, defined as those objects we can pick up and use with one hand, by definition, have certain visual properties that would indicate "manipulability". In the case of "tools" this could simply be the presence of a handle, in the case of "fruits and vegetables," some kind of roundness or elongation that 'affords' a place to grasp the object. If detecting these properties (i.e. smoothness & texture) is dependent on the amount of surface detail present, a photograph of an object should be more readily identified as "manipulable" than a less detailed line drawing of the same object.

Thus, it could be predicted that photographs of all objects should be identified more quickly than the same objects depicted as line drawings. Furthermore, if the object-action system and identification systems are integrated, one would expect faster identification of manipulable objects when more realistic depictions (i.e. surface detail) are available. For line-drawings, however, information indicating manipulability would be less readily available and hence manipulable objects would lose their processing advantage during identification. The current research sought to explore if inconsistencies

in previous object-identification studies could be explained by differences in object depiction (i.e. line-drawings versus photographs).

Evidence that object depiction matters comes in part from previous research that has shown that object naming is facilitated by both congruent surface color and photographic detail, although the effects of each combine under-additively (Price & Humphreys, 1989). For instance, Nicolson and Humphrey (2001) reported that added surface cues to depictions reduced the latency to name rotated objects, indicating the importance of surface cues during an object-naming task. As another example, Rossion and Pourtois (2004) found that the addition of texture and shading (without color) slightly improved naming agreement scores for the objects, but the effect of color was stronger, with the addition of color information unambiguously improving naming accuracy, and speeded correct responses times. Critically, however, Rossion and Pourtois (2004) tested line drawings with surface detail added by an artist which likely wasn't as realistic as an actual photograph with surface detail.

Most object-recognition research in the past has focused on the role of color as opposed to surface detail of objects (Brodie, Wallace, & Sharrat, 1991; Laws & Hunter, 2006; Tanaka & Presnell, 1999; Therriault, Yaxley, & Zwaan, 2009; Wurm, et al., 1993). However, recent evidence has suggested independent effects of form, color, and texture/surface detail during speeded-classification of objects (Cant, Large, McCall, & Goodale, 2008), as well as separate ventral-stream brain areas for form, color and texture (Cant & Goodale, 2007; Cavina-Pratesi, Kentridge, Heywood, & Milner, 2010).

The current research sought to test the relationship between surface detail and manipulability during object recognition in the absence of color with a large set of items

(over 200). Critically this analysis was done as a within-subjects design with each participant seeing the line-drawing and photograph versions of the same objects, and serving as their own control. We hypothesized that manipulable objects would be identified more quickly when presented as photographs than as line drawings, given that surface details are a particularly important part of visually parsing out a 3-dimensional manipulable object. This effect would appear as a two-way interaction between object depiction (line-drawing versus photograph) and object manipulability (manipulable versus non-manipulable objects).

Overall, this interaction was observed when the time to name objects was analyzed using both a linear mixed effects regression analysis, and a more standard repeated-measures (subjects) Analysis of Variance (ANOVA). The mixed-effects analysis was considered a more appropriate analysis for interpreting the data, but both statistics have been reported, including a derived F-statistic for the mixed-effects analysis, since many readers are more comfortable interpreting F-values. The significant interaction between type of depiction and manipulability supported our hypothesis in that reaction times to name manipulable objects shown as photographs were faster than the times to name the same objects shown as line drawings. For non-manipulable objects there was no difference in the time to name photographs versus line-drawings. Thus, identification of manipulable objects is sensitive to the type of representation (photograph or line drawing), presumably due to difference in the amount and quality of visual information available. In embodied cognition terms, these results could be interpreted to mean that photographs of manipulable objects do a better job activating the embodied action associated with the object than do line-drawings. However, this statement is not

true for non-manipulable objects, which have no associated-action to activate. The suggestion from these results is that photographs of manipulable objects activate more embodied representations of the objects than do line-drawings of the same objects.

6.3 MATERIALS AND METHODS

6.3.1 Participants

Forty-six participants (6 males, 17-25 years, $M_{\text{age}} = 19.67$ yrs) enrolled as students at Dalhousie University, Halifax, N. S. volunteered to participate in this experiment. Seven participants were left-handed, and all had English as a first-language, normal or corrected-to-normal vision, and no known history of neurological or visual disorders. This research was approved by the Dalhousie University Research Ethics Board.

6.3.2 Materials

Black and white photographs from the stimulus set normed by Salmon, McMullen, and Filliter (2010) were chosen to compare to line-drawing depictions were taken largely from the Snodgrass and Vanderwart (1980) set. To increase the overlap and power of the two object sets, a local artist (Andrea Rankin, <http://andrearankin.com/>) was hired to draw 27 additional line-drawings in a style similar to that of Snodgrass and Vanderwart (1980). The result was a total of 222 line-drawings and photographs of the same objects, to be compared. For a complete list of the items used, please refer to Appendix A, for examples of these new line drawings, please refer to Appendix B.

All stimuli were shown using the software DirectRT. Photographs were sized 4-11cm tall & wide for visual angles of 4.3-11.7 degrees. The line-drawings appeared slightly smaller on the screen (2-9 cm) subtending visual angles 2.2 –9.6 degrees in both directions. This may have given line-drawings a slight disadvantage (smaller object depictions) or a slight advantage (more of object presented at fixation). However, it was the interaction between object depiction and manipulability that was of key interest, not the main effect of object depiction.

6.3.3 Procedure

All participants named both the line-drawing and photographic versions of each object. Object depiction was blocked such that half of the participants named the photographs first and the half named the line drawings first (i.e. counter-balanced). Prior to each block of object depiction (line drawings or photographs), participants were provided with a practice block (12 objects) of objects depicted in the same way as the block (i.e. line drawing or photograph, respectively). For example, a participant would participate in practice with line-drawings, then complete the full line-drawing block, then practice for photographs, then the full photographs block. Participants were not told that the second block would contain the same items presented in the first.

Trials were preceded by a 1 second fixation point. Each stimulus remained on the screen until it was named. Also, the experimenter was in the room throughout stimulus presentation and coded errors using a keyboard with an extension cord that saved the data directly to the computer used for presentation. The entire experiment took less than 1 hour to complete.

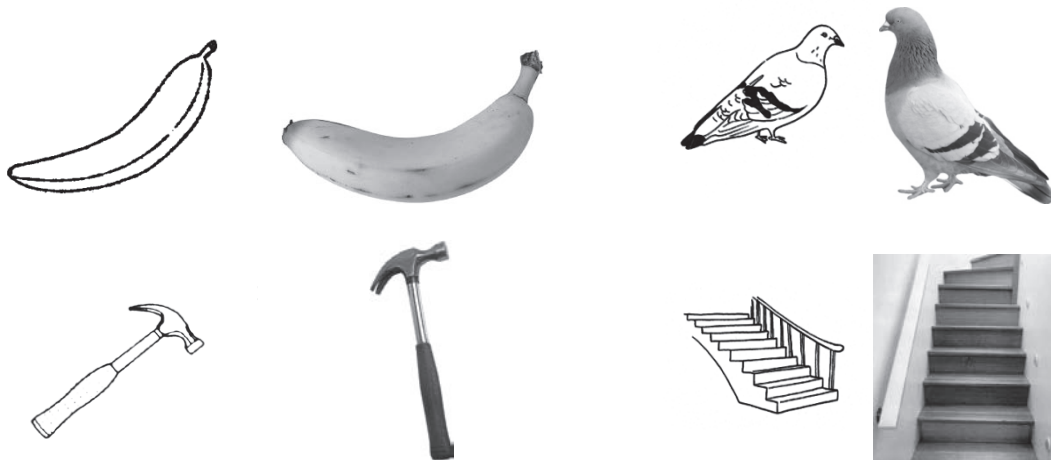


Figure 6.1. Examples of photographs and line drawings of the same objects, with “manipulable” objects in the left-most columns, and “non-manipulable” objects in the right-most columns.

6.4 DATA ANALYSIS

6.4.1 Analysis of variance (ANOVA) versus linear mixed-effects regressions

Traditionally, reaction time (RT) data from object recognition tasks have been analyzed with Analyses of Variance (ANOVA) (cf. Filliter, et al., 2005; Kalénine & Bonthoux, 2008; Wolk, et al., 2005). These analyses are often conducted with the statistical package SPSS ©, and require aggregating the data prior to conducting the analysis. This aggregation process requires collapsing RT data either across subjects/participants or items. With each analysis, significant findings can then presumably be generalized to other subjects and items. In cases where it is useful to generalize across both subjects and items, both analyses are conducted (i.e. a separate Subjects, and a separate Items analysis). Ideally, both analyses converge on the same results.

A growing trend in the analysis of reaction time (RT) data has been to favor a linear Mixed-Effects Regression Analysis (Agresti, 2002) over the traditional ANOVA analysis (cf. Kliegl, Masson, & Richter, 2010; Lawrence & Klein, 2012). This analysis is often conducted using the lme4 package (D. Bates, 2007) in R (www.r-project.org), and, unlike the ANOVA, does not require aggregating data. This new method for analysis of linguistic data has been advocated by other linguistic researchers (e.g. Baayen, 2008; Kliegl, et al., 2010) and researchers interested in stimulus-driven effects (e.g. Lawrence & Klein, 2012; Malcolm, et al., 2008). The mixed-effects regression model has a number of advantages over a standard repeated-measures ANOVA: (1) a mixed-effects model can account for the effects of subjects and items at the *same time*, and (2) the mixed-effects model can analyze the effect of manipulability as a continuous variable (instead of a categorical variable as is the case with the ANOVA).

6.4.2 Linear Mixed Effects Regression

Data analysis consisted of a mixed-effects regression analysis (conducted in R), followed by a more traditional 2 (Block-Order) x 2 (Depiction) x 2 (Manipulability) repeated measures ANOVA subjects analysis (in SPSS) to confirm that the more traditional analysis supported the findings from the mixed-effects analysis. Analyses were conducted on reaction times from accurate trials only (92% of the trials), with outlier rejection for RTs over 3 sec, and less than 300 ms (0.4 % of the remaining trials). Furthermore, a log transformation was applied to normalize the RT data for the regression, since RT is usually skewed. The mixed-effects model key variables of interest were Block (block 1 or block2), Manipulability (Manip), Depiction (photographs or line drawing), and the interaction between Manipulability and Depiction. Importantly,

Manipulability was based on the first type of Manipulability ratings collected by Salmon et al. (2010), defined as the “extent to which an object can be grasped and used with one hand”, and average ratings were used to treat Manipulability as a continuous variable in this analysis with scores from 1 (low manipulability) to 5 (high manipulability).

Covariate variables Age of Acquisition (Aoa) and Familiarity (Fam) were also entered into the model to ensure significant effects were not attributable to these covariates. Again, these were treated as continuous variables, with mean values taken from Salmon et al. (2010). Aoa was defined as “the age at which you likely learned the name of the object” and ranged from 1 (acquired early) to 7 (acquired late). Fam was defined as “familiarity with the object” or degree to which raters came into contact with or thought about the concept on a day-to-day basis, and ranged from 1 (low familiarity) to 5 (high familiarity) (Salmon et al., 2010, pp. 84-85).

Both the Subject error and Item error accounted for by each trial were entered into the model (Equation 1).

$$\Pr(\log(y_{RT})) = b_0 + b_1 \cdot \text{Block}_{si} + b_2 \cdot \text{Aoa}_{si} + b_3 \cdot \text{Fam}_{si} + b_4 \cdot \text{Depiction}_{si} + b_5 \cdot \text{manip}_{si} + b_6 \cdot (\text{Depiction} * \text{ManI}_{si}) + \text{subject}_s + \text{item}_i + \varepsilon_{si} \quad (1)$$

Where $\Pr(\log(y_{RT}))$ is the “probability of obtaining a given RT with the log-transformation applied”. The variables $b_0, b_1, b_2, b_3, b_4, b_5, b_6$ were the fixed effects coefficients, i.e. the group average effects induced by the variables $\text{block}_{si}, \text{aoa}_{si}, \text{fam}_{si}, \text{obType}_{si}, \text{manip}_{si}$, and the $\text{obType} * \text{manip}_{si}$ interaction term. The random effect term subject_s represented each subject’s deviation from the group RT average. Likewise, the random effect item_i represented each items deviation from the item group RT average. Finally, ε_{si} represented the residual term, representing remaining unexplained variance.

An analysis of the accuracy results was also conducted using a mixed-effects model to confirm the lack of speed-accuracy trade-off. For simplicity, only significant effects are reported except where comparison with previous studies is warranted.

6.4.3 Analysis of Variance (ANOVA)

For the standard ANOVA analysis, a Subjects analysis was conducted on the same mean RT data, aggregated for SPSS, considering the two critical variables in a 2 (Depiction) x 2 (Manipulability) design. Notice that Manipulability is, by necessity, treated as a categorical variable for this analysis. The goal of analyzing the data with both a mixed effect regression and ANOVA was to demonstrate that the results obtained by the Mixed-Effects analysis were also supported by more-traditional RT analyses. The Mixed-Effects method (or linear mixed-effects regression analysis) is growing in popularity in social science research (see Baayen, 2008; or Lawrence & Klein, 2012) but some reviewers are still more comfortable with a standard ANOVA analysis.

6.5 RESULTS

6.5.1 Linear mixed-effects regression: Analysis of reaction time (RT)

For the Mixed-Effects Regression analysis, F-values were derived for each of the effects of interest. The Mixed-Effects Regression analysis results showed a main effect of Block ($F(1) = 487.58$), Aoa ($F(1) = 30.14$), Familiarity ($F(1) = 22.61$), Depiction ($F(1) = 20.52$), but not Manipulability ($F(1) = 0.96$). The effects were in the direction of faster RTs in block 1 compared to block 2, faster RTs for more familiar objects, and those faster

RTs for objects acquired at a younger age (low Aoa). In addition, the results showed that RTs were generally faster for photographs of objects as compared to line drawings.

Importantly, however, the results also showed a significant interaction between Manipulability and Depiction ($F(1) = 9.40$), suggesting a bigger Manipulability effect for photographs of objects, as compared to line-drawings (see Figure 6.2 for a depiction of this interaction with Manipulability depicted as a categorical variable). Follow-up *post hoc* analyses did not support a significant main effect of Manipulability, when just photographs were considered ($F(1) = 2.31$). However, they did support a significant main effect of object depiction for manipulable objects ($F(1) = 25.47$), but not non-manipulable objects ($F(1) = 1.09$). These results indicated that manipulable objects were named more quickly as photographs than line drawings, but there was no difference in the time to name non-manipulable objects based on object depiction (line drawings versus photographs). That is, this result supported the notion that manipulable objects are more readily identified when portrayed with more realistic surface detail (such as that in a photograph). Importantly non-manipulable objects did not show this manipulable-object benefit.

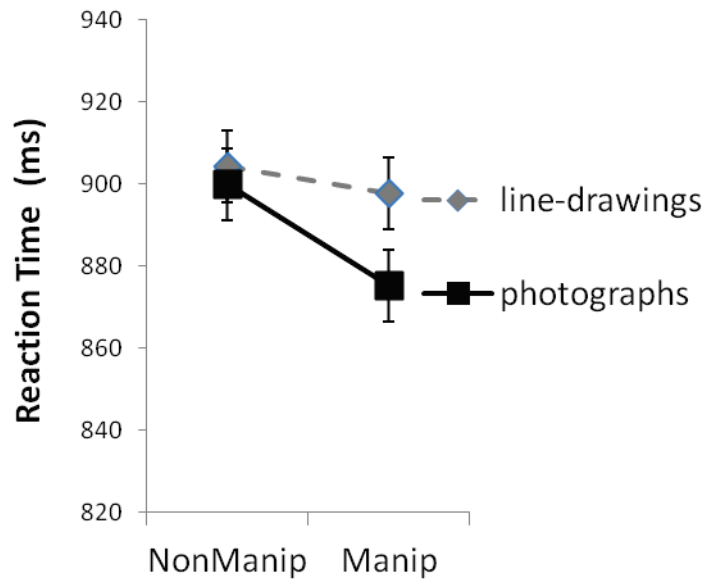


Figure 6.2. The RT means for the two-way interaction between Depiction and Manipulability, showing larger effects of object depiction (photographs versus line drawings) for manipulable than non-manipulable objects. Error bars show the 95% confidence intervals.

6.5.2 Linear mixed-effects regression: Analysis of Accuracy

A similar Mixed Effects regression analysis on accuracy (binomial/logit method) was conducted. Results yielded only significant main effects of Block ($z = 14.04, p < .001$) and AoA ($z = -3.54, p < .001$). With no effects of object depiction, manipulability nor interaction between the two, with $z = -0.11, p = .913, z = -1.68, p = .093$, and $z = 0.31, p = .756$, respectively. Thus, no evidence of a speed accuracy trade-off was apparent.

6.5.3 ANOVA: Subjects analysis with mean RTs

To confirm the results obtained with the Mixed-Effects regression analysis, more standard ANOVAs were conducted. A Subjects analysis was conducted, which required

aggregating the same mean RTs from the previous analysis over the 46 participants. The analysis, on the two critical variables, was a 2 (Depiction) x 2 (Manipulability) repeated measures ANOVA on subject's mean reaction times. Note, that for this analysis, Manipulability was now treated as a discrete two group variable. This was done by classifying all objects with an average Manipulability score of 3.0 or higher as "manipulable" objects, and all other objects as "non-manipulable". Also note, that because this was a subjects' analysis, there was no option to covariate out effects of "object familiarity" and "age of acquisition" in the way that is easily done with a mixed-effects analysis. Thus, this ANOVA analysis, by default, had less statistical power than a mixed-effects regression for the following reasons: (1) it could not measure subjects and items variance simultaneously, (2) it could not measure and account for effects of covariates such as object familiarity and age of acquisition, (3) it required treating manipulability as a categorical variable (and not a continuous one).

Despite these limitations, results from the ANOVA indicated a main effect of Manipulability, $F(1, 44) = 7.71, p < .01$, with faster RTs for manipulable as compared to non-manipulable objects (886 ms for manipulable objects and 902 ms for non-manipulable ones). But, for this analysis, there was no significant main effect of object Depiction, $F(1, 44) = 1.77, p = .189$.

Importantly, the critical interaction between Manipulability and Depiction was significant, $F(1, 44) = 4.65, p < .05$, with the same advantage that was observed in the Mixed-Effects analysis. Specifically, *post hoc* tests indicated a significant manipulability effect (faster RTs for manipulable objects) for photographs, $F(1, 44) = 19.38, p < .001, \eta^2 = .301$, but not for line-drawings, $F(1, 44) = 0.58, p = .451, \eta^2 = .013$. In addition, *post*

hoc tests revealed significant Object Depiction effects (faster RTs for photographs than line-drawings) for manipulable, $F(1, 44) = 4.21, p < .05, \eta^2 = .086$, but not for non-manipulable objects, $F(1, 44) = .28, p = .601, \eta^2 = .006$. Therefore, the results from this analysis were consistent with that of the mixed effects analysis – bigger effect of object depiction for manipulable objects.

6.6 RESULTS SUMMARY (ACROSS ANALYSES)

A common picture arose from the three analyses described above. First, although a large main effect of manipulability was not supported by these data (i.e. only the Subject-analysis supported a main effect), a significant interaction was found between object Depiction and Manipulability. Specifically, these results indicated that for manipulable objects the effect of object depiction was much larger than it was for non-manipulable objects. More specifically, manipulable objects presented as photographs were identified significantly more quickly than the same manipulable objects presented as line-drawings. This interaction was supported both by the Linear Mixed Effects regression analysis, and the more traditional ANOVA.

In addition, our results suggested some advantage for identifying photographs faster than line-drawings. Consistent with our findings, previous research (Price and Humphreys, 1989) has supported this advantage for naming black and white photographs over black and white line-drawings.

6.7 DISCUSSION

In this study, photographs and line-drawings of manipulable and non-manipulable objects were presented for speeded naming on a computer screen. The working hypothesis that was tested was that objects with motor associations (manipulable) would be named more quickly when presented as photographs. The hypothesis came from the notion the photographs contain more surface, texture, shading and 3D cues that should preferentially activate motor areas that would then use these cues to calculate action vectors, etc. In a sense, this hypothesis was based on the idea that more realistic depictions should lead to more motor facilitation which would then facilitate recognition of such manipulable objects. This is a little like suggesting that photographs of manipulable objects are more ‘embodied’ than line-drawings of the same objects.

Consistent with this hypothesis was the finding of a significant interaction between object manipulability and object depiction (photographs versus line-drawings). Manipulable objects, such as “pen” or “potato”, were named more quickly when shown as black & white photographs than when shown as line drawings. In contrast, non-manipulable objects, such as “table” or “bear”, showed no difference in time to name when shown as black & white photographs or line-drawings. This interaction was supported both with a more traditional repeated-measures ANOVA analysis, and a linear mixed-effects regression analysis. The results were also consistent with our hypothesis that manipulable objects are identified more quickly relative to non-manipulable objects when shown as photographs due to the extra texture and surface detail afforded during identification. Although these results cannot prove that this additional surface detail and

texture in the photographs is the definitive mechanism driving this observed interaction, the pattern of results is consistent with that theory.

Support for a main effect of manipulability was less robust but still present in the ANOVA. In particular, these results suggest that strong manipulability effects (i.e. faster responses to manipulable objects) are less frequent for experiments in which objects are depicted as line-drawings, such as those that use the Snodgrass and Vanderwart (1980) set. Our results suggest that the extra surface detail in a photograph aids recognition of manipulable objects but not non-manipulable objects (for which identification must depend more on object features, i.e. presence or absence, and less on surface details). Without the rich detail present in photographs, the effects of manipulability are much weaker. Under these circumstances, other variables such as the age of acquisition of the object, or object familiarity could overshadow effects of manipulability.

The present results are important in confirming that the property of manipulability confers an advantage on object naming (cf. Salmon, Matheson, & McMullen, in revision). Furthermore, this advantage is optimized with increasing visual detail such as that present in a photograph relative to a line-drawing.

A caveat of these findings is that the effect sizes were not very large, i.e. $F(1, 44) = 4.65, p < .05$, for the interaction in the ANOVA, and $F(1) = 9.40$ for the interaction in the mixed effects regression. This small effect size may explain why other researchers have found weaker effects of surface detail compared to, say, those of color (e.g. Brodie, et al., 1991; Laws & Hunter, 2006; Rossion & Pourtois, 2004; Tanaka & Presnell, 1999; Therriault, et al., 2009; Wurm, et al., 1993). Certainly, these results suggest that although the link between object depiction (line drawing versus photographs) and manipulability is

real, the effect size is small and may depend on both a large sample of items (i.e. 222 objects in the current case), and participants (i.e. $N = 46$ participants). That is, future research, without a large sample of objects and participants, may have difficulty replicating these findings.

6.8 CONCLUSIONS

In conclusion, the results of the current research suggest that manipulable objects are sensitive to surface detail and/or object depiction (photographs versus line-drawings), in a way that is not true for non-manipulable objects. That is, these results indicate that an advantage for identifying manipulable objects is more likely to appear when these objects are presented as photographs than when presented as line-drawings. This result has implications for our understanding of effects of manipulability during object identification tasks, and the factors that moderate such effects. Specifically they suggest that manipulability effects are influenced by early perceived surface details of the objects, and further suggest an ‘embodiment’ difference that may exist between manipulable and non-manipulable objects.

6.9 REFERENCES

- Agresti, A. (2002). *Categorical data analysis*. Hoboken, NJ: A John Wiley & Sons, Inc.
- Baayen, R. H. (2008). *Analyzing Linguistic Data: A practical introduction to statistics*: Cambridge University Press.
- Bates, D. (2007). lme4: Linear mixed-effects models using S4 classes (Version R package version 0.99875-9).
- Borghi, A. M., & Pecher, D. (2011). Introduction to the special topic embodied and grounded cognition. *Frontiers in Psychology*, 2(187), 1-3.
- Brodie, E. E., Wallace, A. M., & Sharrat, B. (1991). Effect of surface characteristics and style of production on naming and verification of pictorial stimuli. *American Journal of Psychology*, 104(4), 517-545. doi: 10.2307/1422939
- Cant, J. S., & Goodale, M. A. (2007). Attention to form or surface properties modulates different regions of human occipitotemporal cortex. *Cerebral Cortex*, 17(3), 713-731. doi: 10.1093/cercor/bhk022
- Cant, J. S., Large, M.-E., McCall, L., & Goodale, M. A. (2008). Independent processing of form, colour, and texture in object perception. *Perception*, 37(1), 57-78. doi: 10.1068/p5727
- Cavina-Pratesi, C., Kentridge, R. W., Heywood, C. A., & Milner, A. D. (2010). Separate processing of texture and form in the ventral stream: Evidence from fMRI and visual agnosia. *Cerebral Cortex*, 20(2), 433-446. doi: 10.1093/cercor/bhp111
- Filliter, J. H., McMullen, P. A., & Westwood, D. (2005). Manipulability and living/non-living category effects on object recognition. *Brain and Cognition*, 57, 61-65. doi:

- Kalénine, S., & Bonthoux, F. (2008). Object manipulability affects children's and adult's conceptual processing. *Psychonomic Bulletin & Review*, *15*(3), 667-672. doi:
- Kalénine, S., Bonthoux, F., & Borghi, A. M. (2009). How action and context priming influence categorization: A developmental study. *British Journal of Developmental Psychology*, *27*(3), 717-730. doi: 10.1348/026151008x369928
- Kliegl, R., Masson, M. E. J., & Richter, E. M. (2010). A linear mixed model analysis of masked repetition priming. *Visual Cognition*, *18*(5), 655-681.
- Lawrence, M. A., & Klein, R. M. (2012). Isolating exogenous and endogenous modes of temporal attention. *Journal of Experimental Psychology: General*, 1-13.
- Laws, K. R., & Hunter, M. Z. (2006). The impact of colour, spatial resolution, and presentation speed on category naming. *Brain and Cognition*, *62*(2), 89-97. doi: 10.1016/j.bandc.2006.03.002
- Malcolm, G. L., Lanyon, L. J., Fugard, A. J. B., & Barton, J. J. S. (2008). Scan patterns during the processing of facial expression versus identity: An exploration of task-driven and stimulus-driven effects. *Journal of Vision*, *8*(8), 1-9. doi:
- Nicholson, K. G., & Humphrey, G. K. (2001). Surface cues reduce the latency to name rotated images of objects. *Perception*, *30*(9), 1057-1081.
- Price, C. J., & Humphreys, G. W. (1989). The effects of surface detail on object categorization and naming. *The Quarterly Journal of Experimental Psychology A: Human Experimental Psychology*, *41*(4), 797-827. doi:
- Rossion, B., & Pourtois, G. (2004). Revisiting Snodgrass and Vanderwart's object pictorial set: The role of surface detail in basic-level object recognition. *Perception*, *33*, 217-236. doi: 10.1068/p5117

- Salmon, J. P., McMullen, P. A., & Filliter, J. H. (2010). Norms for two types of manipulability (graspability and functional usage), familiarity, and age of acquisition for 320 photographs of objects. *Behavior Research Methods*, *42*(1), 82-95. doi: 10.3758/BRM.42.1.82
- Salmon, J. P., Matheson, H. E., & McMullen, P. A. (in revision). The influence of object manipulability on categorization and naming of backward-masked photographs shown for brief durations: A reversal effect for object manipulability. *Visual Cognition*.
- Snodgrass, J. G., & Vanderwart, M. (1980). A standardized set of 260 pictures: Norms for name agreement, image agreement, familiarity, and visual complexity. *Journal of Experimental Psychology: Human Learning and Memory*, *6*(2), 174-215. doi: 10.1037/0278-7393.6.2.174
- Tanaka, J. W., & Presnell, L. M. (1999). Color diagnosticity in object recognition. *Perception & Psychophysics*, *61*(6), 1140-1153. doi:
- Therriault, D. J., Yaxley, R. H., & Zwaan, R. A. (2009). The role of color diagnosticity in object recognition and representation. *Cognitive Processing*, *10*(4), 335-342. doi: 10.1007/s10339-009-0260-4
- Wurm, L. H., Legge, G. E., Isenberg, L. M., & Luebker, A. (1993). Color improves object recognition in normal and low vision. *Journal of Experimental Psychology: Human Perception and Performance*, *19*(4), 899-911. doi: 10.1037/0096-1523.19.4.899

6.10 APPENDIX A. (A LIST OF THE 222 OBJECTS/ITEMS USED)

accordion	drum	pepper (bell)
airplane ³	dryer ^{3*}	piano
anchor	duck ⁴	pigeon ^{4*}
ant ²	eagle ⁴	pineapple ²
ashtray	egg ^{2*}	pipe
axe	elephant	pitcher
baby bib ^{1*}	envelope	pliers
baby bottle ¹	fence	plug
baby carriage	fire hydrant ^{3*}	pool table ^{3*}
balloon ¹	fish ²	pot
banana ²	flower ²	potato ²
barn ³	fly ⁴	present ^{1*}
barrel	football	rabbit ²
basket	forest ^{4*}	raccoon
bath tub ^{3*}	fork ¹	raspberry ^{2*}
bear ⁴	fox	refrigerator ³
bee ⁴	frog ²	ring
beetle ⁴	frying pan	road ^{3*}
bell (church) ³	garbage can ¹	roof ^{3*}
belt	giraffe ⁴	rooster ⁴
bicycle ³	glasses ¹	ruler ¹
bird (chickadee) ⁴	glove	sailboat ³
book	goat	salt shaker ¹
boot	gorilla	sandwich
bottle	grapes ²	saw
bow ¹	grass ^{4*}	scissors ¹
bowl	guitar	screw
box	gun	screwdriver
bread	hammer	seahorse
broom	harp	seal
brush ¹	hat	sheep ⁴
bus	helicopter ³	shell ^{2*}
butterfly ⁴	horse	sink ^{3*}
cake ¹	house ³	sippy cup ^{1*}
camel	iron	skirt
candle	ironing board ¹	sled ¹
candy canes ^{1*}	jacket	snail ²
cannon	kangaroo	snake ⁴
cap	kettle	sock
car ³	key	spider ²
carrot ²	kite	stairs ^{3*}

cat ²	knife ¹	stool ¹
celery ²	ladder	stove ³
chain	lamp ¹	strawberry ²
chair ¹	leaf ²	suitcase
chalkboard ^{3*}	lemon ²	sweatshirt
cherry ²	leopard	table ³
chicken ⁴	lettuce ²	telephone
chisel	light bulb	television ³
church ³	lion ⁴	thread (spool)
cigar	lobster ²	tie
cigarette	lock ¹	tiger
clock	mitten ¹	toaster ¹
closet ^{3*}	mixer ^{1*}	toilet ^{3*}
clothespin	monkey ⁴	tomato ²
clouds ⁴	moon ⁴	toothbrush
clown	motorcycle	train
comb	mountain ⁴	tree ⁴
computer ^{3*}	mouse ²	truck ³
couch ³	mushroom ²	turtle
cow ⁴	nail	umbrella
crab ^{4*}	necklace	vase
crocodile	onion ²	vest
crown	orange	violin
cup	ostrich	wagon
deer ⁴	owl ⁴	washing machine ^{3*}
desk ³	pacifier ^{1*}	watch
dog ⁴	paintbrush ¹	well
doll	pants	wheels ¹
donkey	peach ²	whistle
door	peacock ⁴	windmill
dragonfly ^{4*}	pear ²	window
dress	pen ¹	wrench
dresser ³	penguin	zebra

1. comes from set of “Manipulable (Manmade)” used by Salmon, McMullen & Trappenberg (2011)
 2. comes from set of “Manipulable (Natural)” used by Salmon, McMullen & Trappenberg (2011)
 3. comes from set of “Non-Manipulable (Manmade)” used by Salmon, McMullen & Trappenberg (2011)
 4. comes from set of “Non-Manipulable (Natural)” used by Salmon, McMullen & Trappenberg (2011)
- * New line drawings created for this comparison (all other line drawings came from Snodgrass and Vanderwart, 1980). For a depiction of the new line drawing artwork created for this experiment, please refer to Appendix B.

6.11 APPENDIX B – NEW LINE DRAWINGS (BY ANDREA RANKIN)

CHAPTER 7 GENERAL DISCUSSION

In this research, across multiple experiments, we have shown an influence of object manipulability on object identification. That is, this research has supported the idea that action systems in the brain interact with the object identification system. Importantly, this research has shown these effects to be significant in neurologically normal individuals when both familiarity and age of acquisition of the objects are controlled, and for two separate types of manipulability: (1) *graspability*, the extent to which an object can be grasped and used with one hand, and (2) *functional use*, the extent to which the actions made when using an object differs from those made when grasping it. In Chapter 2, I collected new ratings for these two types of manipulability and was able to show that (for manipulable items) they were not correlated, suggesting that these two variables were capturing independent dimensions.

In Chapter 3, I used a brief exposure paradigm on a subset of items adapted from Chapter 2 to show that manipulable (graspable) items are categorized more slowly despite being named more quickly than non-manipulable items. In Chapter 4, I extended Yoon et al.'s (2002) computational Naming Action model (NAM) to show that the two mechanisms likely explaining this reversal categorizing-naming effect were semantic branching and/or similarity; specifically, with manipulable objects belonging to smaller (more sparse) and less similar semantic categories than non-manipulable objects.

In Chapter 5, I more fully explored the differences between the two types of manipulability showing that the strengths of their effects depended on the presence or absence of a concurrent mask. Specifically, the results showed that effects of graspability were larger for unmasked items, and effects of functional use were larger for masked

items: this indicates that these two types of manipulability had different effects on object identification. Finally, in Chapter 6, I demonstrated that visual depiction (line drawing versus photograph) can modulate manipulability effects, suggesting that some manipulability effects depend on surface detail and texture information. Thus, across multiple chapters this dissertation has both (1) shown a role for action and object manipulability on object identification and (2) begun to characterize the nature of these effects.

The next sections will revisit in more depth the key findings and subsequent contributions of the preceding chapters. It will lead into a discussion of where these effects may fit into the “hardware” or neuro-architecture of the brain.

7.1 CHAPTER 2: THE VALUE OF A GOOD STIMULUS SET (AND RATINGS)

In order to study the influence of object manipulability on object recognition, one first needs a stimulus set. As described in chapter 2, we decided to develop our own stimulus set (see example photos of the set we developed in Figure 7.1). The other option would have been to choose a well-normed and commonly used stimulus set, like the set of 260 line-drawings that were developed and normed by Snodgrass and Vanderwart (1980). I believe the set we developed has several advantages over other sets, such as those developed by Snodgrass and Vanderwart (1980). First, our set used photographs which depict more realistic representations of the real-world objects than you get in a line-drawing. In particular, we had reason to suspect that manipulable objects might be sensitive to surface texture and detail that are more evident in a photograph (this was explored in detail in chapter 6). Second, our set was normed recently, and based on a set

of local participants who were more demographically-matched to the participants we tested in subsequent experiments. Third, and perhaps most importantly, our set contained ratings for two types of manipulability, using definitions designed to match distinctions outlined by Buxbaum and colleagues (e.g. Boronat, et al., 2005; Buxbaum & Kalenine, 2010; Buxbaum, et al., 2006; Buxbaum & Saffran, 2002; Buxbaum, et al., 2000). Specifically, we had participants rate “graspability” according to the “extent to which they could grasp and use the object with one hand” and “functional use” according to the extent to which actions when using the object differed from those involved in just grasping (see also Bub & Masson, 2012; Bub, et al., 2003; Bub, et al., 2008 for examples of other researchers exploring the effects of the different action systems).

APPENDIX A
Examples of Items/Pictures Used in the Present Design









		Low AoA (Acquired Early)	High AoA (Acquired Late)
High familiarity	Manipulable		
	Nonmanipulable		
Low familiarity	Manipulable		
	Nonmanipulable		

Figure 7.1. Example photos from the 320 object photograph set we normed on two types of manipulability, familiarity and age of acquisition (AoA). Reprinted from Salmon, McMullen and Filliter (2010).

A common problem in research grouping objects into “manipulable” versus “non-manipulable” sets, is that “graspability” and “functional use” are naturally confounded. That is, if you use “graspable” to define your manipulable objects, you can only LOGICALLY have *functional use* ratings for manipulable objects. This fact seemed so logical to us, that we didn’t even ask participants to provide “functional use” ratings for objects they gave a low “graspability” rating to. Therefore any direct comparison between graspability and functional use (like the ratings correlations in chapter 2) can only be done within the set of manipulable objects, i.e. a subset of the objects. Our correlation showed that within this subset the ratings were not correlated, that is, they were orthogonal. On the other hand, if we had assigned all non-manipulable objects a functional use rating score = 0, and then completed the correlation across the entire set of objects, we would have instead found that *graspability* and *functional use* are highly correlated & confounded with one another. This led us naturally to the question: can the effects of these two types of manipulability be teased out, and if so, how are they different? This question was explored in great detail in chapter 5. But first, we explored the more traditional experiment comparing manipulable versus non-manipulable objects based on these first *graspability* ratings (chapters 3 & 4)²⁹.

In summary, the ratings and object set we developed in chapter 2, filled a void in this research area, and allowed us to ask questions we could not address with other stimulus sets, in particular, questions about *graspability* versus *functional use*. Do either

²⁹ It could be noted here that no definition is perfect, and it’s possible that our manipulability definitions introduced some confounds that made them behave in a way unlike the intent behind definitions discussed by Buxbaum and colleagues, as well as Bub, Masson and colleagues. One example, is that our current definitions emphasize “grasp and use with *one* hand” which automatically imposes a physical size restriction on which objects get labeled “graspable” because now they have to small enough to be “graspable” and perhaps even used with one hand.

of these types of manipulability play a role in object identification in healthy participants, and under what circumstances? These were questions explored in subsequent chapters.

7.2 CHAPTER 3: SHOWING EFFECTS OF MANIPULABILITY ON IDENTIFICATION TASKS

The results from chapter 3 (naming and categorizing manipulable versus non-manipulable objects) were, I felt, particularly compelling for a number of reasons. First, although it is not discussed elsewhere in my dissertation, this was my first successful study, out of multiple (unpublished) studies, to find effects of manipulability during object identification. For more details on this unpublished work, refer to Appendix A, but suffice to say effects of manipulability (the action systems) are not always clearly observed during identification tasks, which speaks to the necessity of using large object sets, degraded viewing conditions (chapters 3 & 5), and photographs of objects instead of line-drawings (cf. chapter 6).

The second strength from the results from chapter 3 was that two known predictors/covariates of object identification were carefully controlled. In particular, chapter 3 controlled for both the effects of object familiarity and age of acquisition, both of which are well-known predictors of identification efficiency (E. Bates, et al., 2003; Bonin, et al., 2003; Cuetos & Alija, 2003; Pérez, 2007; Uttl, et al., 2007). However, despite their known importance, they often go uncontrolled in studies of the effects of manipulability on object identification (cf. Kalénine & Bonthoux, 2008; Wolk, et al., 2005). Thus, I felt it was a great strength of this paper that we able to show effects of manipulability, even with these two other predictors controlled.

A third strength from chapter 3 was that I was able to show these results using a traditional balanced analysis of variance (ANOVA) design. As I articulate in chapters 5 and 6, I really think linear mixed effects regression analysis is the best analysis method for analyzing these kinds of data because it can control for effects of subjects and items in the same analysis, leading to better power and sensitivity to observe effects of the variables you are interested in. However, this kind of analysis is still new to many researchers in the field. So I think it was a real strength of chapter 3 to show that we could get our effects with the more familiar, albeit less powerful analysis tool of the ANOVA.

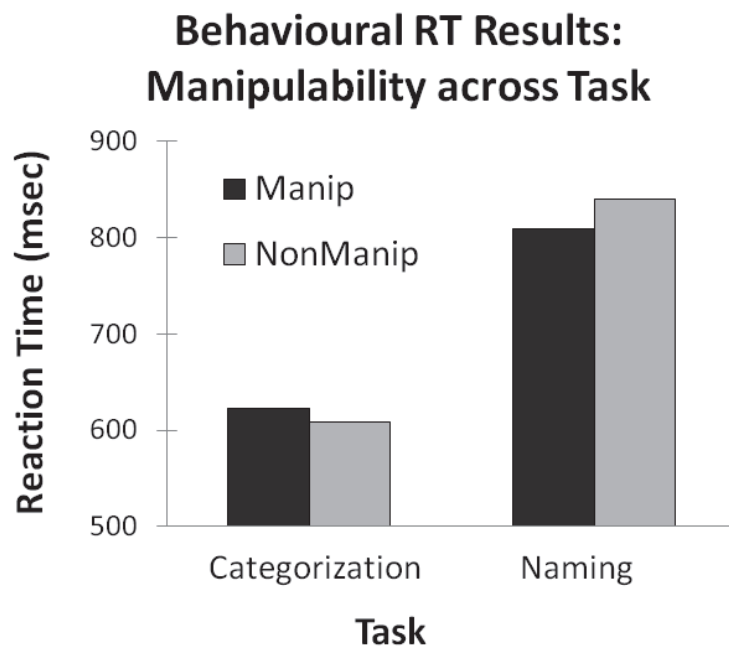


Figure 7.2. A depiction of the manipulability by task reversal observed in chapter 3. Manipulable objects were named more quickly, but categorized more slowly.

Finally, one of the most interesting results from chapter 3 was the “manipulability by task reversal,” shown again in figure 7.2. In particular, manipulable objects were

shown to be named more quickly but categorized more slowly. Why should the same objects be identified quickly in one task (naming) but identified slowly in another (categorization)? I felt this result was particularly meaningful for two results, (1) it created an interesting puzzle that we could explore with computational models (i.e. chapter 4), and (2) it suggested that there really was an effect here based on manipulability, and not just some unmeasured confound that would manifest or not manifest based on the luck of the stimulus set chosen. This latter point can be explained best with an example:

Imagine three experiments each using three different object stimulus sets trying to measure a difference between manipulable and non-manipulable objects, for simplicity let's call them A, B, C, and you might get null effects for *object set A*, where *object set B* shows effects in one direction and *object set C* shows effects in the reverse direction. However, given these results it would be hard to conclude anything about manipulability. That is some confound or combination of confounds (that you didn't think to measure, and is uncorrelated to what you're trying to measure), are really what's causing one effect on set A and the opposite on set C. More specifically, the problem is, if the effects of the "variable" change every time you change your stimulus set, what does that really say about the generalizability of the "effects" you are reportedly observing? How interesting, really, are effects that go away when you change the stimulus set, and don't they suggest that there's likely some uncorrelated other variable that is really causing the effect that you are attributing to your variable of interest (in this case manipulability)?

On the other hand, if you have two effects (in opposite directions) with the SAME stimulus set it shifts the blame away from the chosen stimulus set, and towards the tasks. More specifically, our categorization and naming experiment in chapter 3 used the

stimuli to show participants were faster to name manipulable objects but slower to categorize the same objects relative to non-manipulable objects. If, instead, our results had been faster identification of manipulable objects in both tasks, a reviewer could criticize that we did not control for some (any) confound, such as ‘visual complexity’ (the complexity of the lines & shapes comprising the images) of the objects, and that higher (or lower) visual complexity of the manipulable objects facilitates their identification. However, with the current pattern of results, the same critic that thought ‘visual complexity’ should be controlled for would now have the additional onus of explaining why the variable visual complexity should facilitate identification for one task (naming) but inhibit it for another task (categorization). That is, the current result shifts the conversation away from discussions about whether some (unmeasured) property of the current stimulus set is really causing the observed effects (that would disappear if a different stimulus set was chosen); and shifts the discussion to issues around the task, and what about naming versus categorization could cause a reversal in the identification tasks?

Of course, the current result does not eliminate the possibility that some variable highly correlated with manipulability is really causing this effect. But the result at least suggests that whatever caused this reversing effect is correlated (perhaps even inextricably correlated) with manipulability. That is, this result reduces the chance that these effects were based on the “luck” of the stimulus set that I chose, and that there was some uncorrelated variable to manipulability that just ‘happened’ to be causing the effect. In summary, after failed attempts to observe manipulability effects (see unpublished work described in Appendix A), I was beginning to hypothesize that (1) previously reported

effects of manipulability on identification (cf. Filliter, et al., 2005; Kalénine & Bonthoux, 2008) were a “fluke” based on the stimulus set chosen, and wouldn’t have been observed if the stimulus set had been controlled on variables like object familiarity, and age of acquisition, and (2) even though research supports the idea action activation during even passive viewing of manipulable (cf. Chao & Martin, 2000) the presence or absence of this “motor resonance” does not have any impact on pure identification tasks the same as it does during grasping tasks (cf. Bub & Masson, 2012; Bub, et al., 2003; Bub, et al., 2008).

However, the results of the current research (chapter 3) began to convince me that (1) effects of object manipulability could be observed during identification tasks with the right experimental design, and even with familiarity and age of acquisition controlled, and (2) these effects really were related to something to do with manipulability (and not just luck of the particular stimulus set chosen for that experiment). Despite the convincing results of chapter 3, two questions remained unanswered. Question 1, what possible mechanism could drive such a manipulability reversal depending on naming or categorization? This question was explored in the next chapter (chapter 4). Question 2, were these reversal effects related to effects of “graspability” or “functional use”? That is, *which* type of manipulability was likely driving these effects? This was the subject of chapter 5.

7.3 CHAPTER 4: MODELING SEMANTIC IMBALANCE/ORGANIZATION OF THE SYSTEM

The computational model in chapter 4 was developed in collaboration with Dr. Thomas Trappenberg from the department of computer science. This chapter attempted to consider computational models that might explain the naming and categorization reversal

observed in the previous chapter. Yoon, Heinke and Humphreys (2002), had developed a computational “Naming Action Model” that was defined, in particular, by a dedicated action output module to which objects had direct access (see Figure 7.3). Thus, the first test of their model was to modify it so that it could accommodate both manipulable and non-manipulable objects, and see if any mechanism inherent in their architecture could explain a reversal whereby manipulable objects were named more quickly than non-manipulable objects, but those same manipulable objects were categorized more slowly.

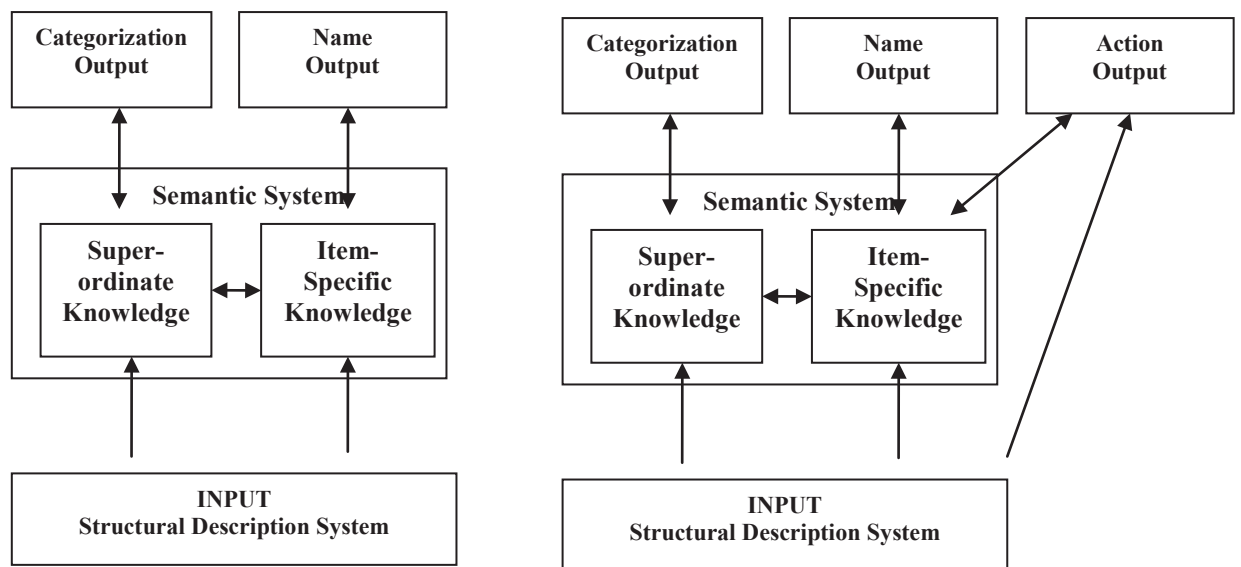


Figure 7.3. Our model architectures for an extended version Naming Action Model by Yoon, Heinke & Humphreys (2002). Architectures shown with and without a dedicated action output module.

After testing the role of this ‘action output module’ in various ways it was evident that within their model architecture, any change to the action output module affected naming and categorization equally (by speeding them both up). Thus, it seemed evident that this action module alone was not sufficient to explain a categorization versus naming reversal effect. Thus two new mechanisms were considered: (1) semantic organization,

and (2) object similarity. The case for a role of similarity is fairly easy to understand – categories with high within-category similarity are categorized quickly (because shared features within exemplars of objects allows evidence to accumulate faster), but named more slowly (because it is hard to extract the specific features among similar things that are required to give a specific label). Semantic organization is about how categories of objects are encoded and organized, i.e. in crowded or sparse domains. Some categories of objects are very ‘crowded,’ meaning the category is comprised of many different, but similar, objects. Some categories are ‘sparse’, meaning the category is comprised of fewer objects because they are more distinct / less similar from one another. The predictions for the semantic organization mechanism are parallel to those of similarity: ‘crowded’ categories are categorized more quickly (because all the activity within in the category agree quickly to form an answer), but ‘crowded’ categories are named less quickly (because of the competition within the category of all the other possible ‘names’ for the object). For a depiction of the difference between crowded and sparse categories and how they can lead to differences in Categorization and Naming, refer to Figure 7.4.

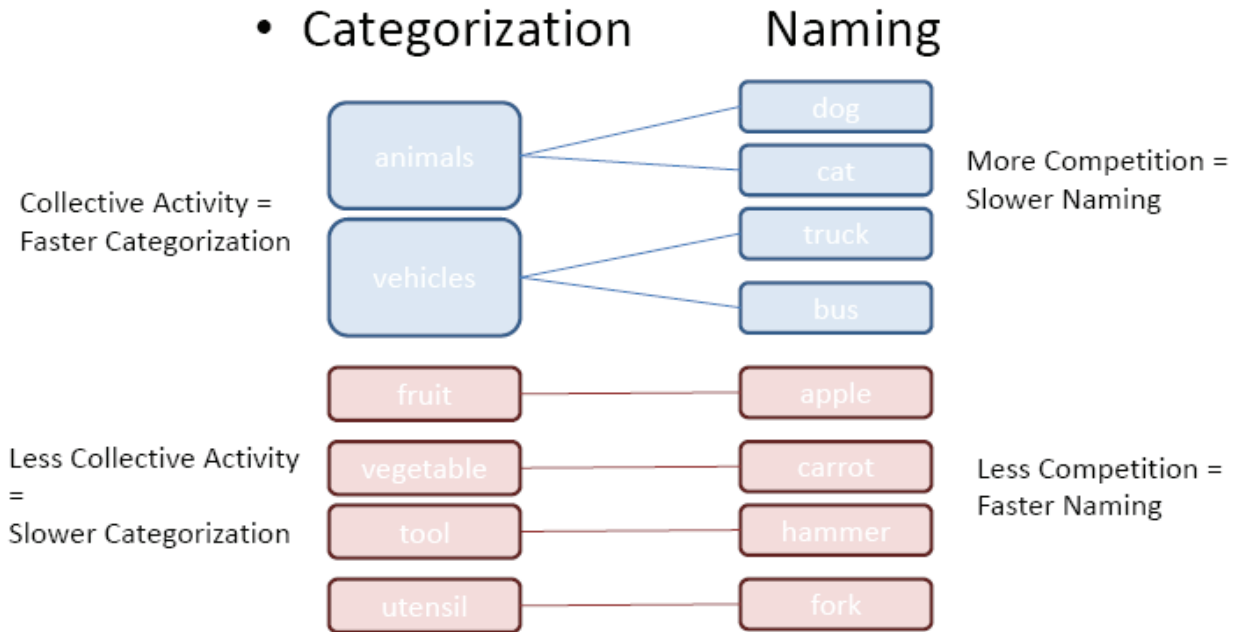


Figure 7.4. A depiction of semantic branching/imbalance can lead to super-ordinate category-based reversals. Relative to sparse categories (red) the crowded (blue) categories are faster to categorize because of collective activity in the category building up evidence faster. However, these same categorizes are slower to name because there's more competition within the category.

Our modeling of similarity and semantic organization were both able to show the pattern of faster categorization of non-manipulable objects and faster naming of manipulable if (1) manipulable objects were considered to represent more sparse categories than non-manipulable objects, or if (2) non-manipulable objects were treated as more 'similar' than manipulable objects. That is, both mechanisms were able to replicate in an extended computational model NAM the behavioural reversal effect found in chapter 3. However, when comparing the two mechanisms directly to each other, and relating them back to the actual stimulus set used in the behavioural data, the evidence for the role of visual similarity was not strong. Specifically, analyses on the visual similarity of the actual objects did not overwhelmingly support the idea of higher visual similarity

within non-manipulable objects. In contrast, our visual similarity analysis (presented in chapter 3) suggested the opposite – that manipulable objects were more similar to one another.

Action similarity, of the type described by Desmarais and colleagues, (Desmarais & Dixon, 2005; Desmarais, Dixon, et al., 2007), was another candidate for driving similarity-based effects. Arguments of action similarity suggest that manipulable objects represent a more diverse set of objects by virtue of the range and variation in the different actions associated with each of them. Note however, this explanation is not too far from that expounded by semantic organization. That is, the semantic organization account would explain things in terms of more varied or ‘sparse’ categories versus more uniform or ‘crowded’ ones. In this case, perhaps “action similarity” denotes the *why* and “semantic organization” the *what* for the explanation of why manipulable and non-manipulable objects come to be represented differently in semantics. That is, the semantic imbalance along the lines of manipulability is a description of *what* the semantic system is organized as; where action similarity is the *why* in why the semantic system is organized that way. Or more specifically, action similarity differences inherent in objects leads to the semantic system being developed / organized in a particular way (with a more sparse representation of manipulable objects). This is akin to the basic embodied cognition tenant that the perception and substrate are one-in-the same. We’ll revisit this in the context of embodied cognition later.

In summary, our simulations in chapter 4 were able to demonstrate that semantic imbalance/organization in the representation of manipulable and non-manipulable objects was a plausible mechanism for driving a naming versus categorization reversal effect.

One limitation, however, of this research was that action similarity mechanisms were equally plausible, and the model was insufficient to rule out one explanation versus the other. However, it was possible to speculate that these two interpretations of these mechanisms may be two different explanations for the same phenomenon.

A further limitation of the computational models in chapter 4 was that within the traditional NAM, we were unable to specify which type of manipulability the model was describing. However, our modeling appeared to be flagging the ‘functional use’ type of manipulability more than graspability. This appeared to be the case because the mechanisms involved in the model were in relation to semantics, and ‘*functional use*’, by definition, is more semantic-based. In fact, some researchers think ‘graspability’ is capturing a dimension of manipulability that is completely semantics free (for example, see Westwood & Goodale, 2011 for a recent review). Thus, the models in this chapter were able to indicate that the behavioural effects observed in chapter 3 were more likely driven by effects of ‘functional use’ manipulability than by ‘graspability’ effects. However, we felt it was necessary to develop an experimental design where we could more unambiguously parse out the role of the two types of manipulability (‘graspability’ and ‘functional use’) we identified in chapter 2. Thus, we designed the research in chapter 5, where we carefully measured the effects of both types of manipulability across the entire stimulus set we developed in chapter 2.

7.4 CHAPTER 5: GRASPABILITY VERSUS FUNCTIONAL USE, IS THERE REALLY A DIFFERENCE?

The focus of chapter 5 was to determine if we could parse out the roles of the two types of manipulability during object identification. The methods included using the full set of 320 objects developed in chapter 2, and having them identified either with or without a mask (Figure 7.5 shows examples of what the stimuli looked like masked). Furthermore, identification was done in two ways: standard naming, and picture-word matching. The latter was done for comparing to data from Filliter et al. (2005).

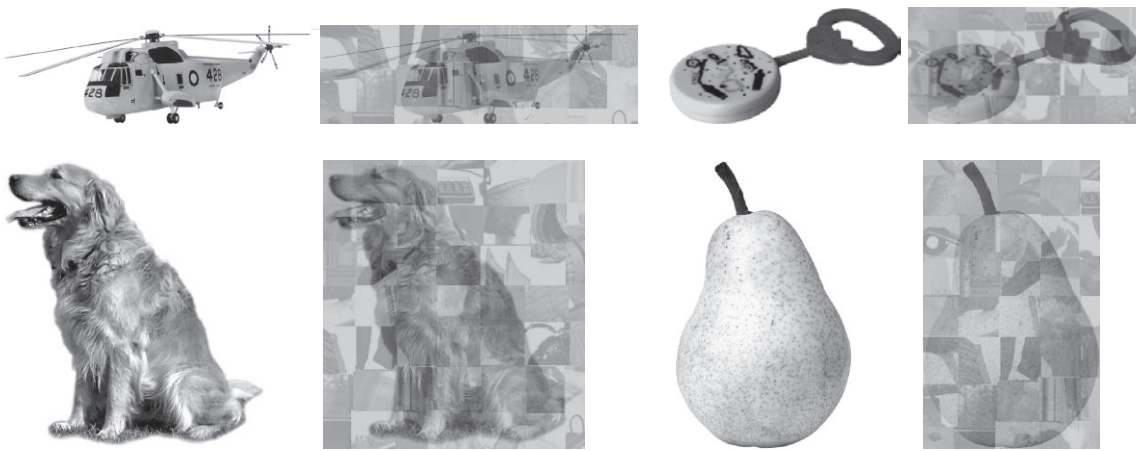


Figure 7.5. Masked and un-masked versions of the stimuli used in chapter 5. Note, the right panel shows examples of manipulable objects, the left non-manipulable objects. Furthermore, the top panel shows manmade objects, and the bottom panel natural objects.

One strength of the design and analysis of data from chapter 5 is that it employed the use of mixed effects regression analysis instead of a standard ANOVA to analyze the results. Mixed effects regression analysis has a number of advantages over the standard ANOVA. These were discussed in chapter 5, but to summarize, the advantages include: (1) the ability to treat the predictors (the two types of manipulability in particular) as

continuous predictors – which allows the ability to capture more nuance in the data, and (2) the ability to control for both subjects and items variability simultaneously – which increases the overall power of the analysis and the ability to detect real effects.

As it turned out, the most interesting effects were across the masked versus not-masked condition, and not across type of identification task (i.e. not between naming versus picture-word matching). That is, the pattern of results of the two types of manipulability was different according to whether or not the stimuli were masked (degraded). Specifically, the results indicated that both types of manipulability predicted faster identification of manipulable objects, but effects of high *functional use* ratings were larger for masked items. On the other hand, effects of high *graspability* were largest for objects that were not masked (i.e. objects in full view). The key results figures from this chapter are reiterated in Figure 7.6. This difference, in particular, indicated that the manipulability ratings we had collected (in chapter 2) really did represent two different systems at work: (1) the slower functional system which is tied to semantics and gets involved more for degraded/masked stimuli, and (2) the faster graspability system that is strongest during fast full-view identification of objects. As stated earlier, some researchers believe this latter fast system may act quickly and independently of semantics (e.g. Westwood & Goodale, 2011). These results, of course, further beg the question of where these abstract modular-level descriptions fit into the actual neuro-architecture of the brain. That is, did our *graspability* ratings capture a “dorsal” function, and the *functional use* ratings a “ventral” function? We’ll revisit the question later, but first, I’ll consider the question about how the results from this chapter could be used to further interpret the behavioural pattern observed in chapter 3.

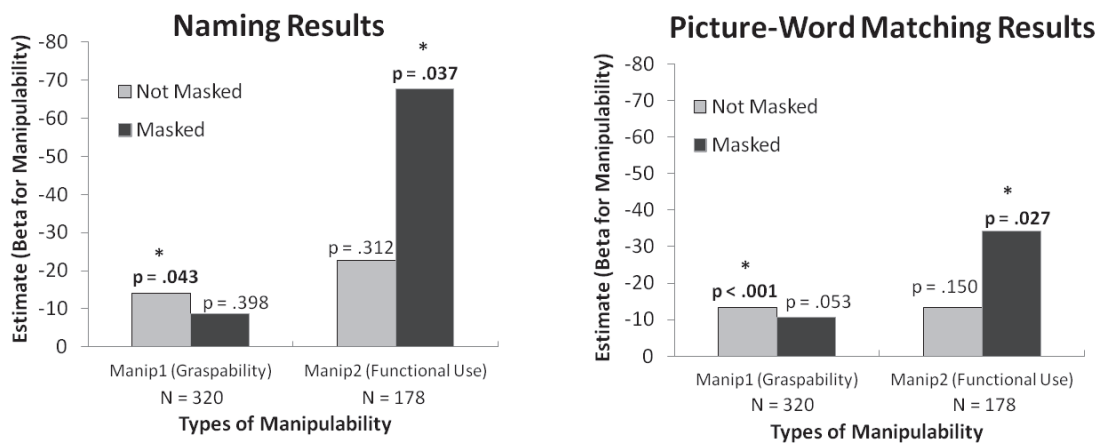


Figure 7.6. Manipulability effect sizes (betas) during object Naming (left-side) and Picture-Word Matching (right-side) for Masked and non-Masked conditions (simple effects analyses) in chapter 5. Note that negative betas are plotted up, and indicate a relationship between higher scores on manipulability and faster RTs, with each beta coming from a different analysis. Also note that masking interrupts these effects in different ways for the two types of manipulability. For Manip1 (graspability), effects were larger for non-masked items, but for Manip2 (functional use), effects are larger for masked items.

What does this difference in the two types of manipulability tell us about the results we observed in previous chapters, specifically the behavioral result of chapter 3? It tells us that the effects from chapter 3 (faster naming of manipulable objects, and slower categorization) were likely driven by the more semantic type of manipulability (specifically by our *functional use* ratings). We can infer this from the fact that in chapter 3, we used brief exposure durations, so all the stimuli (regardless of whether the task was categorization or naming) were presented in a degraded form which is most like the masked condition in Chapter 5. Thus, both chapter 3 and chapter 5 contained degraded stimuli (objects presented in a way that was hard to see). In chapter 5, the half of the

stimuli that were degraded had larger *functional use* effects, so it seems logical to infer that *functional use* effects would have also been larger in chapter 3. We therefore conclude that the effects we observed in chapter 3 were largely driven by that type of “functional use” manipulability.

In summary, chapter 5 left us with (1) further evidence that BOTH types of manipulability affect object identification in healthy participants, and (2) further evidence of the value of measuring the role of these types of manipulability (graspability versus functional use) independently. Specifically, this chapter demonstrated that, within the same experiment, the strength of the predictive power of the two types of manipulability can be different depending on the viewing conditions of the stimuli (i.e. degraded or intact).

One concern about chapter 5 was that the results were based on photographs, where results from previous research have been based on line-drawings (e.g. Kalénine & Bonthoux, 2008; Wolk et al., 2005). If the effects observed in chapter 5 were really based on object manipulability then shouldn't they be bigger for objects depicted as photographs, as compared to those depicted as line-drawings? There are lots of reasons to expect that the action-system / action-semantics would be more primed and sensitive to stimuli that were close to the real-world presentations. Thus, I hypothesized that any study that directly compared representations of the same objects depicted as line-drawings versus photographs (i.e. more realistic) would show bigger manipulability effects for the more realistic depictions (i.e. bigger effects for photographs compared to line-drawings). This hypothesis I explored in chapter 6.

7.5 CHAPTER 6: PHOTOGRAPHS VERSUS LINE DRAWINGS – TYING UP LOOSE ENDS

Isn't a line-drawing of 'hammer' more abstract than a photograph of a 'hammer'? Shouldn't we expect that a photograph would be more 'embodied' than the line-drawing? And by that I mean, shouldn't we expect more action system involvement when we show a photograph of a manipulable object than when we show a line-drawing? These were the kind of questions I explored in the final content chapter – chapter 6. Specifically, I addressed this question by finding photographs and line-drawing representations of 222 objects. All of the photographs came from our set (described in chapter 2), and most of the line-drawings came from Snodgrass and Vanderwart (1980): the rest were commissioned by a local artist to be drawn in a matching style. Refer to Figure 7.7 for examples of what the stimuli looked like in chapter 6.

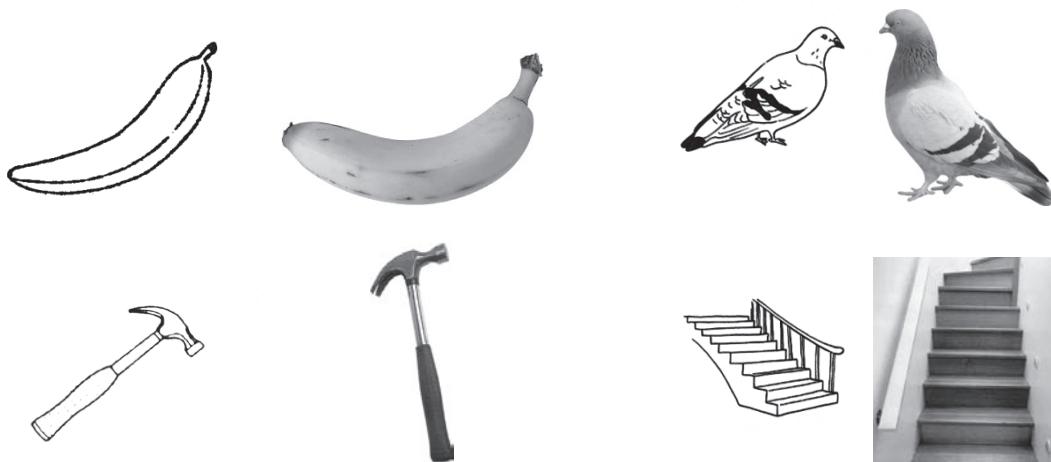


Figure 7.7. Examples of photographs and line drawings used in chapter 6. Note, this experiment involved the same objects depicted as photographs or line-drawings, as well manipulable (left panel) and non-manipulable (right-panel) objects.

Based on the results from Filliter et al.'s (2005) research, and chapter 5, we might have predicted a clean “cross-over” interaction result, with faster identification of non-manipulable objects for line-drawings, but faster identification of manipulable objects. Instead, we got an interaction, but differences were all within the set of manipulable objects (see Figure 7.8). Specifically, manipulable objects were identified more quickly when they were identified as photographs, but non-manipulable objects were identified equally quickly as line-drawings and photographs (see figure 7.8 for a summary of the results).

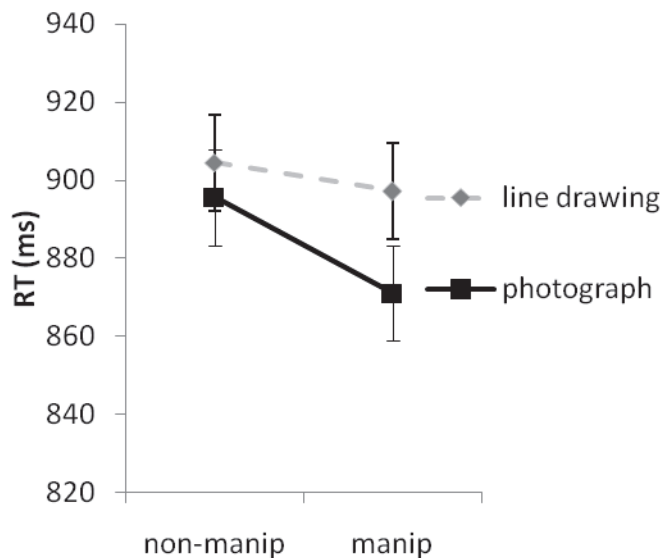


Figure 7.8. The RT means for the two-way interaction between Depiction (photograph versus line-drawing) and Manipulability (manipulable versus non-manipulable), showing larger effects of object depiction (photographs versus line drawings) for manipulable than non-manipulable objects.

Although these results appeared at odds with Filliter et al.'s (2005) finding for a non-manipulable advantage (during picture-word matching on a familiarity-controlled object set), they *did* support the main theme of a difference in manipulable objects

depending on whether they are presented as photographs or line-drawings. In particular, this research showed that manipulability effects are more likely to be observed when more realistic depictions of objects (i.e. photographs) are used. Specifically, within the set of line-drawings, we saw no difference between manipulable and non-manipulable objects. These differences were only seen when photographs were used (although see Kalénine & Bonthoux, 2008 for examples of research that found effects with line-drawings; Wolk, et al., 2005). This result could explain why I had difficulty getting significant manipulability effects in the (unpublished) research I mentioned earlier that also used line-drawings for its stimulus set. Regardless, this result reinforced the importance of using a set of photographed objects (i.e. the set from chapter 2) when looking for effects of action and manipulability during object identification research. Of course, it suggests further that real-world objects would be even better than photographs of objects. However, using real-world objects is unpractical in many research studies when the difference of interest is between manipulable and non-manipulable objects – particularly when the desired non-manipulable object set contains animals.

In summary, the research in this chapter (6) demonstrated the importance of using photographs over line-drawings during object identification tasks when the researcher is interested in the role of the action system. In particular, it illustrated that with even the same set of objects, researchers could increase their chances of observing manipulability effects if they use a photograph-based set of objects (like the set we developed in chapter 2). That is, this research further underscored the value of the stimulus set we developed and discussed in chapter 2.

7.6 RELATING OUR GRASPABILITY AND FUNCTIONAL USE RATINGS TO THE BIGGER PICTURE

At the beginning of this dissertation we considered a number of possible architectures for incorporating ‘action’ into an object recognition system. At first we discussed these architectures as if there were one singular action system that would play a role. But as we explored the evidence, and in particular, results articulated by Buxbaum and colleagues (2006; 2002; 2000), it was obvious that more than one action system was involved. Thus, in the current dissertation, I focused on two types of action systems or object ‘manipulability’.

Other research has also considered the role of object manipulability during identification. For example, Wolk, Coslett, and Glosser (2005) considered manipulable objects based on a definition derived by Magnié, Besson, Poncet, and Dolisi (2003) which defined manipulable objects as those that could be unambiguously pantomimed. Wolk et al.’s (2005) second definition, called ‘form-manipulation’ ratings, was defined as the extent to which object *form* predicted how it was used. These ratings, particularly those by Magnié et al. (2003), appeared strange to us, because, according to their definitions, objects like “celery” and “strawberry” got rated as “unmanipulable” whereas “car” and “cow” were rated as manipulable. Thus, we felt it necessary to develop our own set of objects, with their own, more intuitive definition of manipulability.

For our ratings, we focused on two types of action systems or ‘manipulability’. Specifically, *graspability*: the extent to which an object can be grasped (with one hand) for use, and *functional use*: the extent to which the action involved when using the object

differed from that involved when grasping the object. Not only did my results suggest that these two types of manipulability play a role during object identification, in healthy participants, but they further suggested that the role of these two types were different.

Thus, we could represent the parallel box-plots from the Introduction in a framework with two different types of action. One dedicated, and independent of semantics, and one tied bound to semantics, or *graspability* and *functional use*, specifically (see Figure 7.9). Moreover, it appeared the time-course of these two types of manipulability differed depending on the type of identification task. This will be detailed in the next section.

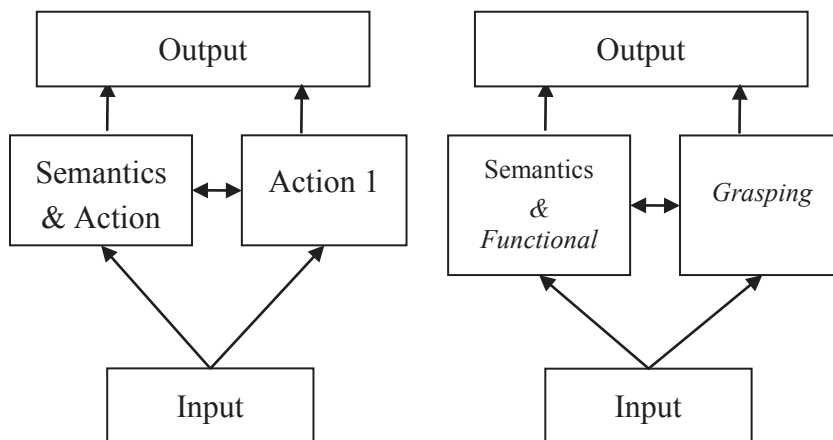


Figure 7.9. Model for multiple action systems presented in the Introduction (left panel). The right panel shows that same model including the two types of manipulability with *graspability* with its own dedicated module, and *functional use* as part of semantics.

7.6.1 Early and Late influence of action/manipulability

This research supported an early role of manipulability in object identification. Specifically, this research demonstrated that manipulable, i.e. graspable, objects were named and matched faster than non-manipulable objects (e.g. chapter 3 & 5). Importantly however, this effect was much larger when objects were not masked, suggesting that the role of this type of manipulability is fast-acting and disappears quickly. Likewise, these effects were also larger for photographs (where surface-detail, texture and 3-D information is present) compared to line-drawings of the same objects (e.g. chapter 6); further suggesting that these effects were based on early visual structural encoding of objects.

In addition to supporting an early role of manipulability, this research also supported a late role of manipulability in object identification. Specifically, this research demonstrated that manipulability, and in particular, objects for which there was a *functional use* were named and matched faster than non-manipulable objects (e.g. chapter 3 & 5). Importantly, however, unlike graspability, *functional use* had larger effects when the objects were harder to see, such as when they were presented with a concurrent mask (chapter 5) or made difficult to see due to a brief exposure duration (chapter 3) (see also Bub & Masson, 2012; Kiefer, et al., 2011 for recent research exploring the timing dynamics between the identification and action systems).

In particular, these action systems appeared to have two different loci, one earlier and one later. The earlier system, measured by *graspability* ratings, was affected by early disruption to the visual system such as masking, and reduced quality of the visual image, as in the case of line drawings which contain reduced texture and surface detail

information. The later system, measured by *functional use* ratings, was more semantic in nature, was influenced by category membership. Further, this later system did not appear to be reduced by visual masking, and in fact, effects were larger for this type of manipulability when objects were visually masked, possibly due to the system working harder and processing more deeply (i.e. semantically) when visual information was minimal.

7.6.2 Neuro-architecture and fitting things in Newer Models: 3 Action Systems?

As stated, this dissertation focused on two types of manipulability, and it is well accepted that there are two primary visual pathways after visual information is processed in the primary visual cortex (V1). To recap, these pathways include (1) the dorsal pathway which is typically thought of as the “where” or “how” pathway, which controls sensorimotor transformations for actions directed at objects, and (2) the ventral, “what” or semantic pathway, which is involved during object identification tasks (Goodale & Milner, 1992, 1994). It is tempting to try and map the two manipulability types discussed in this dissertation onto these two pathways. In particular, it is tempting to suggest that our basic *graspability* ratings capture the differences between objects that activate **dorsal** regions (i.e. manipulable objects) and objects that do not activate this pathway (i.e. non-manipulable objects). For example, this kind of selective activation has been observed in the dorsal pathway, e.g. Chao and Martin (2000), showing, in an fMRI design, that manipulable objects preferentially activate regions of the dorsal pathway, while presentations of non-manipulable objects do not. Furthermore, since our *functional use*

ratings have such a semantic component, it is tempting to conclude that these ratings capture a dimension of action-semantics represented in the **ventral** pathway.

In fact, however, matters might be complicated by additional sub-divisions within these action systems. In particular, a recent review paper by Buxbaum and Kalenine (2010), described their ‘two action systems’ model which contained a sub-division within the dorsal pathway. Thus, although they called it a “two action systems” model, it really functionally had three sub pathways or “streams”: (1) the **dorso-dorsal** pathway, (2) the **ventro-dorsal** pathway, and (3) the **ventral** pathway. According to their model, which was based on a review of recent neuroimaging and neuropsychological research, each of these pathways serves a different role during object identification. Starting from the top, the dorso-dorsal pathway or **structure** is involved in “planning and execution of structure based movements, body posture and movement knowledge *vis a vis* space”. The ventro-dorsal pathway or **function** pathway is involved in “knowledge of body position and movement *vis a vis* objects (use gestures, recognition of object related action)”. Lastly, the ventral pathway is involved in “knowledge of object[s]’ functional purpose” (p. 208). See Figure 7.10, reprinted from Buxbaum and Kalenine (2010) for a symbolic representation of function overlaid schematically on the neuroanatomical substrate.

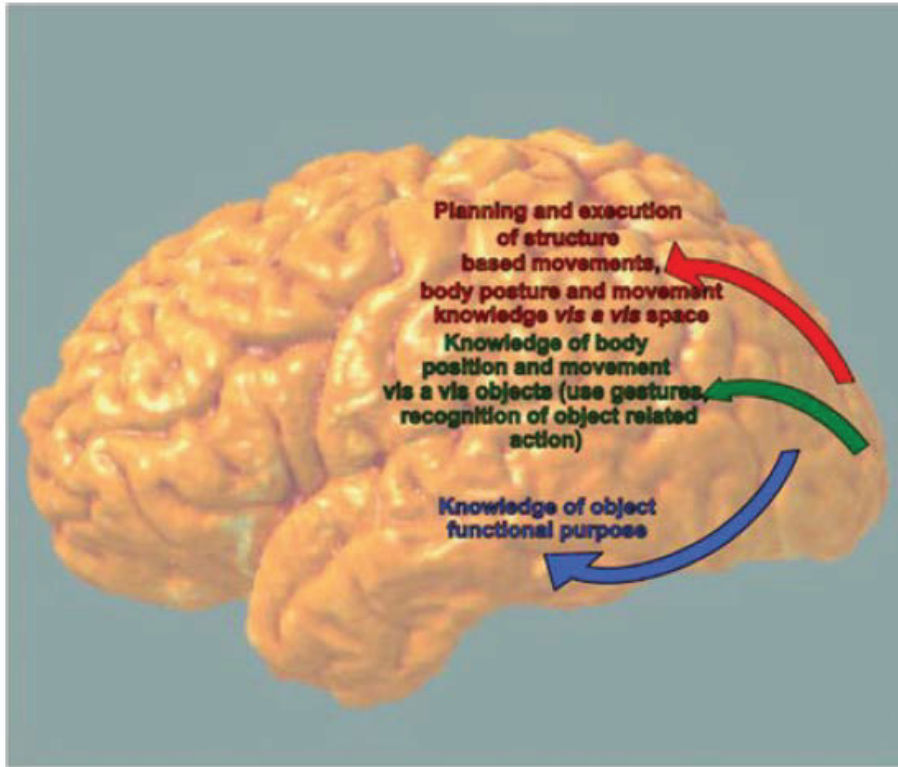


Figure 7.10. Diagram from Buxbaum and Kalenine (2010) mapping function onto neuroanatomic substrate (reprinted with permission from the publisher). Schematic includes the sub-division between the dorsal pathway (red and green arrows), as well as the ventral stream (blue arrow).

Buxbaum and Kalenine (2010) further described the dorso-dorsal (structure) stream as having a weak relationship to conceptual knowledge (i.e. semantics), and being activated without motor intention. That is, motor responses generated by the dorso-dorsal stream could be activated outside of conscious awareness, and involve nonarbitrary “affordances” (such as those described by Humphreys, 2001) related to current visual information. Further, the dorso-dorsal system was described as representing structure-based actions that were rapidly elicited by objects but quickly degrading; in contrast, the function-based actions were “slower but maintained over an interval of at least several minutes” (Buxbaum & Kalenine, 2010, p. 213). This description of this dorso-dorsal system was consistent with the results we observed throughout my dissertation as

predicted by the “graspability” ratings. In particular, my results showed that “graspable” objects were identified more quickly when identification could be done quickly, such as when stimuli were not masked (chapter 5) and were shown as photographs instead of line-drawings (chapter 6). By comparison, these effects on graspability were not strong for objects shown with a concurrent mask (chapter 5), suggesting the quick (msec) influence of this processing stream had dissipated and ceased to have an effect on the system – for slower identification tasks.

By comparison, the ventro-dorsal (function) stream was described as having a strong relationship to conceptual knowledge (i.e. semantics), and requiring relevant motor intention to be activated (Buxbaum & Kalenine, 2010). More specifically this system was described to involve canonical actions, which might be distantly related to structure. Furthermore, representation (and thus recognition) of skilled functional action was described as a distributed cognitive function supported by the ventro-dorsal stream acting in concert with the ventral stream. Thus, our ratings of *functional use*, based on the definition to “what extent is the action required to use the object different from that required to pick it up” was really a question about the movements involved for function use of the object - a combination of the activity in both the standard semantic ventral stream, and the ventro-dorsal “function” stream described by Buxbaum and Kalenine (2010). Not only did our definition align with the description of these two streams, but our results did as well. In particular, we found larger effects of *functional use* during slower identification tasks, such as when the object was degraded either by a brief exposure duration (chapter 3) or a visual mask (chapter 5). Presumably this occurred in these conditions, because the effects of these two streams are maintained over a longer

interval – seconds and minutes. In the case of degraded stimuli, larger effects on these systems makes sense for two reasons. First, the basic task of identification is slowed down, and these streams have a longer time to have an effect. Second, part of the reason the task slows down is likely due to the fact that semantics has to be engaged more deeply to reconstruct and retrieve representation of the degraded stimulus. The action represented by these *functional use* ratings is therefore either (1) part of a separate module that is active around the same time as semantics or (2) active as a part of semantics-representation itself. This latter possibility will be discussed in a bit in the section on embodied cognition.

In summary, we can amend the schematic presented in Figure 7.10, by showing which streams we believe were captured by the ratings in chapter 2, and therefore, which aspects of the whole integrated system our effects in chapters 3 through 6 reflected. More specifically, our graspability or grasping ratings captured a description of the dorso-dorsal stream, and our functional use ratings captured the combined activity and representation between the ventral and ventral-dorsal stream (see boxes in Figure 7.11). Moreover, we can highlight the kinds of objects for which effects are biggest in these streams - In the dorso-dorsal stream effects are biggest for full-view, non-degraded stimuli (photo of cell-phone in top-right of Figure 7.11); for the combined ventro-dorsal and ventral stream, effects are biggest for visually degraded, e.g. masked stimuli (photo of masked cell-phone in bottom-right of Figure 7.11).

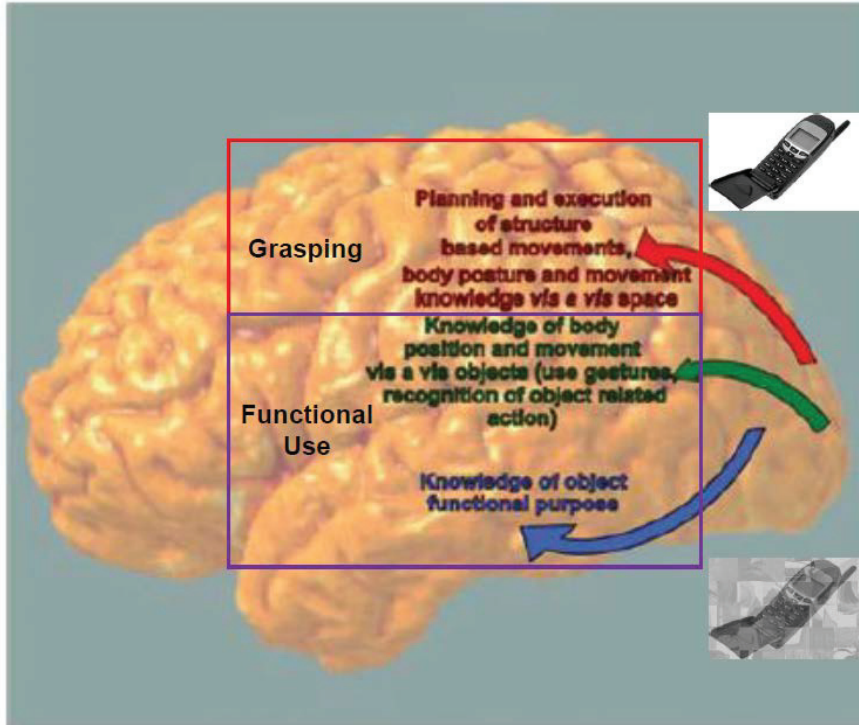


Figure 7.11. Diagram from Buxbaum and Kalenine (2010) with plausible over-lap from current dissertation added. Specifically, our first manipulability ratings (graspability) likely capture aspects of the dorso-dorsal stream, and are maximally active during fast identification tasks where the complete object is visible (e.g. the non-masked photo of the cell-phone in the top-right corner). Our second type of manipulability ratings (functional use) likely captured aspects involved in both the ventro-dorsal and ventral streams, and are maximally active during slower identification tasks where the object is presented for a brief exposure duration and/or is degraded with a mask (e.g. the masked photo of the cell-phone in the bottom-right corner).

7.7 HOW DO THESE RESULTS RELATE TO EMBODIMENT?

A rising theme in recent psychology is the idea of ‘embodied cognition’.

Embodied cognition can be thought of as the idea that sensori-motor representation in the brain *is* cognition/semantics, and no separate external abstract construct is needed. That is, the same neural substrate used in perceiving an object is used in representing that object. Embodied cognition is in contrast to the more traditional viewpoint that higher

more abstract levels above the perceptual brain areas are used in cognition, or that mind arises as something outside of the brain and body. Allport (1985) described the basic ideas of embodied cognition as the following:

“The essential idea is that the *same* neural elements that are involved in coding the sensory attributes of a (possibly unknown) object presented to eye or hand or ear also make up the elements of the auto-associated activity-patterns that represent familiar object-concepts in 'semantic memory'. This model is, of course, in radical opposition to the view, apparently held by many psychologists, that 'semantic memory' is represented in some abstract, modality-independent, 'conceptual' domain remote from the mechanisms of perception and of motor organization” (Allport, 1985).

Allport (1985) also emphasized the importance of the motor attributes on perception of objects with motor properties, and how object representations were likely distributed based on their properties, and relevance to the different modalities. Thus, it might be fair to assume that Allport would say that visualizing or seeing and identifying manipulable objects would necessarily activate motor regions of cortex (since such areas contain part of the complete representation of that object).

Other researchers, such as Wilson (2002), pointed out that modern concepts of ‘embodied cognition’ actually seem to include many separate theoretical claims including: (1) cognition is situated, (2) cognition is time-pressured, (3) we off-load cognitive work onto the environment, (4) the environment is part of the cognitive system, (5) cognition is for action, (6) offline cognition is body based. By “cognition is for action” Wilson (2002) meant that cognition’s primary role is to serve action, or as put by Churchland, Ramachandran, and Sejnowski, “vision has its evolutionary rationale rooted in improved motor control” (1994, p. 25). Similarly, memory has also been argued to have “evolved in the service of perception and action in a three-dimensional

environment” (Glenberg, 1997, p. 1) Thus, within ‘embodied cognition’, as a theoretical framework, *action* has a pivotal role (see also Zwann, 1999).

The question about embodied cognition is: to what extent are the areas that encode object action *necessary* to the representation (and thus identification) of that object? In other words, to what extent is it necessary to activate these motor areas for manipulable objects in order to successfully complete identification of the object. This idea is related to literature on “motor resonance” (cf. Bub & Masson, 2012; Vainio, Symes, Ellis, Tucker, & Ottoboni, 2008), a term related to the observation that identifying graspable objects includes the processing of its action-related attributes (e.g. Chao & Martin, 2000; Grèzes, et al., 2003). Similarly, “visuomotor priming” or “motor priming” research has observed that viewing manipulable objects can prime or interfere with planned or elicited actions (e.g. Bub, et al., 2003; Ellis & Tucker, 2000; Tucker & Ellis, 2001, 2004).

Although results from this dissertation cannot directly answer the question about whether or not seeing manipulable objects necessarily activates dedicated action areas, the results using our ratings *do* suggest that anticipated activity in these areas predict faster identification times in objects. That is, objects for which you would expect more “motor resonance” (those for which there are high graspability and functional use ratings from Salmon, McMullen, & Filliter, 2010) are generally identified more quickly, presumably because activity in these action areas are helping semantics converge on the correct identity more quickly.

In regards to a strictly “embodied cognition” explanation, Buxbaum and Kalenine (2010), were careful to note that the two action streams may not be treated equally.

Specifically, they suggested that neurons in fast acting dorso-dorsal “structure” stream are not critical for a full action understanding, and thus not part of traditional semantics or “embodied object concepts” (see also Westwood & Goodale, 2011). That is, Buxbaum and Kalenine (2010) proposed that only the function-based action streams were a component of embodied object concepts.

In the next section we’ll explore the related and seemingly contrasting view, of a localist representation.

7.7.1 Distributed versus Localist Representation: Grandmother Cell’s & Sparseness

A related debate is whether or not object and concept representation is purely distributed or if one can find highly specialist localist regions; such as the so-called ‘grandmother-cell’³⁰? Simply put, is there one cell (or collection of cells) that always fires when I think of my grandmother? Or, is representation of my grandmother purely distributed with separate cell-assemblies firing when I imagine her face and others for when I am imagining her voice.

Connor (2005) explained that this argument is related to the issue of ‘sparseness’ and representation in a hierarchy. Early in representation, the “neural code for an object is a broad activity pattern distributed across a population of neurons, each responsive to some discrete visual feature” (p. 1036). At later representational stages, neurons become “increasingly selective for combinations of features, and the code becomes increasingly sparse – that is, fewer neurons are activated by a given stimulus, although the code is still

³⁰ As pointed out by Bowers (2009) , grandmother-cells are similar to what is meant by gnostic cells (Konorsky, 1967) or cardinal cells (Barlow, 1972).

population-based” (p. 1036). As Connor (2005) explains further, “sparseness has its advantages, especially for memory, because compact coding maximizes total storage capacity” and grandmother cells “are the theoretical limit of sparseness, where the representation of an object is reduced to a single neuron” (p. 1036-1037).

Until recently, a growing assumption in the field was that all neural representation is distributed, and not sparse enough to ever reveal cells behaving like a grandmother-cell. However, research by Quiroga, Reddy, Kreiman, Koch, & Fried (2005) identified cells in the medial temporal lobe of the human brain that fire selectively and invariantly to pictures of celebrities, places, and objects. For example, one cell was found that responded invariantly to different pictures of Jennifer Aniston, but not to pictures of other celebrities, objects, or pictures with Jennifer and Brad Pitt. Another cell fired selectively to pictures of Halle Barry, including pictures of her dressed as catwoman, and her name in print. Therefore this research suggests that it is possible that cells high enough in the hierarchy can be selective for an individual identity.

Bowers (2009, 2010, 2011) has argued that the idea of ‘grandmother-cells’ or localist representation in the brain is not inconsistent with recent neuropsychological evidence nor computational (neural network models). Bowers makes the case that current parallel distributed processing (PDP) theories, prematurely rule-out the possibility of ‘grandmother-cells’ due a number of confusions they make. First, “critics fail to distinguish between the selectivity and sparseness of neural firing and, as a result, predict (incorrectly) that one and only one neuron should fire in response to a given input. Second, critics often fail to distinguish between what a neuron responds to and what it represents and as a result, predict (incorrectly) that a grandmother cell should fire in

response to one and only one thing” (Bowers, 2011, p. 91). That is, Bowers is saying that within a strictly localist representation theory there can be more than one localist cell (‘grandmother cell’) for a specific identity, and further, that selectively for a certain identity (e.g. Jennifer Aniston) does not mean that that cell represents or encapsulates all aspects of that identity. For more on this debate, see also Plaut and McClelland (2010) and Quiroga and Kreima (2010).

Although my dissertation does not speak directly to the presence or absence of grandmother cells, the model I presented in chapter 4 had aspects in common with a localist representation. In particular the model was designed hierarchically and cumulated in a single “node” that fired maximally in response to each semantic object (item) or category in my simulated stimulus set. In this way, this model was acting like a localist semantic representation. However, even more relevant to my dissertation was this conversation of sparse versus crowded domains. In particular, my research was able to show that a crowded domain representation (in this model) is categorized more quickly but named more slowly relative to more sparse domains. Thus, any evidence that would show manipulable objects to belong to more sparse domains than non-manipulable objects would help build a case for this being the mechanism underlying the behavioural reversal observed in chapter 3. This topic will be explored in more detail in the next section.

7.7.2 Representation in Semantics: Sparse versus Crowded domains

One of the more interesting results from this research was a reversal effect of manipulability based on whether or not participants were asked to categorize (manmade

or natural) or name objects (chapter 3). Further, my computational modeling (chapter 4) suggested that a dedicated ‘action’ module, such as the one suggested by Yoon, Heinke and Humphreys (2002), failed to explain this reversal. Instead a hypothesis relating to semantic organization differences between manipulable and non-manipulable objects appeared to offer a better explanation for this reversal. The semantic theory demonstrated (with computational support) that super-ordinate semantic categories with more members (i.e. crowded) were categorized more quickly despite being named more slowly compared to categories with fewer items (i.e. sparse). In particular, if manipulable objects belonged to more sparse categories than non-manipulable objects, then this could explain why manipulable objects were named more quickly despite being categorized more slowly.

This result is comparable to the semantic proximity effects observed by Dixon, Bub, and Arguin (1997; see also Dixon, Bub, Chertkow, & Arguin, 1999). Specifically, Dixon et al. (1997) observed that in an experiment in which participants were trained to identify novel objects (the objects were essentially blob shapes with different thicknesses and contours). These novel objects were paired with semantic content, such as sounds made by different objects, that were either similar (e.g. sound of robin, crow, owl) or not very similar (e.g. sound of helicopter, saw, photocopier). Their results indicated that during testing, healthy participants were more likely to confuse items that had been paired with semantically similar sounds. This pattern of results was even more pronounced for a temporal lobe stroke patient they tested who suffered from visual agnosia for biological objects and musical instruments (but not artifacts like tools and furniture). Thus, the results from Dixon et al. (1997) suggested that semantic similarity

(or proximity) can affect accuracy (and likely speed) at which learned objects are identified.

Desmarais, Dixon, and Roy (2007) conducted a similar study in which different actions were assigned to these same blob-like shapes with known degrees of visual similarity. Equivalently, their results showed that objects that were assigned similar actions were identified less quickly than when the same objects were assigned dissimilar actions. Thus, this result was able to show that *action similarity* can influence object identification of learned objects. We'll revisit the topic of action similarity at the end of this section.

The studies mentioned above demonstrate that mechanisms of semantic “distance” (or sparseness) or action similarity can work for abstract blob shapes. Therefore, it's easy to imagine that these same mechanisms could work in the real world. As I explained in chapter 3, if non-manipulable objects are considered to have similar actions (i.e. they all have no action) then it's easy to agree about action similarity differences between manipulable and non-manipulable objects, but why should we expect semantic differences? Presumably, this has something to do with how categories (super-ordinate categories) are formed through development from infancy to adulthood. One of the most difficult & primary early goals of all mobile animals is successful navigation of the environment. For human babies, this challenge is particularly difficult as they live in particular complex indoor environments with many manmade, novel, and often recently invented technologies. Thus, it seems logical, that through the development of language, and progression through childhood, many meaningful semantic categories of manipulable things will have to be learned: dolls, balls, blocks, books, food, candy, cups,

utensils, writing implements, etc. In contrast, non-manipulable things can fit into fewer categories: animals, plants, people, buildings, furniture, cars. The exact semantic categories that children first form are debatable, and likely vary from child to child. However, the key prediction here is that manipulable objects, because of their *functional* significance to the child are likely to emerge with fewer specific items/exemplars within each category. This is akin to what Gale, Laws, and Foley (2006) would call a more ‘sparse’ domain for manipulable objects. Visual similarity or *functional* similarity may further drive this effect.

The idea of more ‘sparse’ domains or fewer items per category for manipulable objects is partly supported by the research on object ‘potency’, or the average number of objects generated by participants to a certain category during time constraints (i.e. “how many articles of clothing can you name in 30 seconds?”). In particular, I re-analyzed potency ratings collected by Battig and Montague (1969) as well as Overschelde, Rawson, & Dunlosky (2004), and found they showed higher average potency ratings for non-manipulable objects. That is, participants, in general, generated more items (in a set amount of time) when provided with non-manipulable category labels such as “animals”, “birds”, “furniture” than they did when provided with manipulable category labels like “tools”, “kitchen utensils”, “toys”, “non-alcoholic beverages”, and “vegetables”. Thus, this research offered data consistent with my hypothesis that super-ordinate level manipulable categories contain fewer items relative to non-manipulable objects (i.e. categories of manipulable contain fewer items, on average).

While the potency research offers partial support for the idea of less branching/sparse domains for manipulable objects, better support comes from a pilot

study data I collected and presented in chapter 4. Participants (N=20) were asked to generate higher-level category names for each of the 120 photographs of objects used during the categorization & naming experiment (chapter 3). Their instructions were to “choose categories that would include more than one item, but to generate more than 4 meaningful categories”. Example categories of “musical instruments” and “body parts” were provided to bias the level of categories that were generated (i.e. not too broad, but not too specific). As predicted, participants generated significantly more super-ordinate categories for manipulable objects as compared to non-manipulable objects. This meant that each category consisting of manipulable objects had fewer items within it. The number of categories generated for manipulable *manmade* objects was the highest, and the number of categories for non-manipulable *natural* object was the lowest (see Table 7.1 reproduced from chapter 4). These results offer further independent support for the idea that semantic sparseness (related to the functional use of objects) played a role in the reversal effect on manipulability observed during categorization and naming.

	Manmade	Natural
Manipulable	14.4	11.9
Non-Manipulable	7.5	7.4

Table 7.1. Average number of (super-ordinate level) categories generated for 30 objects of the following types.

However, as discussed in chapter 4 as earlier in this chapter, our modeling results did allow for the possibility of similarity causing these effects. Our analysis of *visual* similarity, suggested no visual similarity differences between manipulable and non-

manipulable objects that could explain the reversal observed in chapter 3. Thus, these effects must either be driving by the semantic effects described above, or by differences based on *action* similarity. In fact, it may be very difficult to differentiate the roles played by action similarity versus semantic differences, in the real world, as I expect they are highly correlated. The best approach might be to take a design like Desmarais et al.'s (2007) where each novel object gets assigned an action on manipulandum (to measure action similarity) and combine it with the approach used by Dixon et al. (1997) where each object is paired with semantic content (to measure semantic similarity). Such a design could determine the relative contribution of semantic similarity versus action similarity during object identification tasks on novel objects. Although I expect the results of such an experiment would be very similar to those reported in the original research. Specifically, I expect such research would show objects assigned similar semantic content are confused more often, and likewise objects assigned similar actions are confused more often. Thus, such a finding, much like my computational modeling result, would demonstrate that both mechanisms are valid in the abstract, but would fail to definitely inform which mechanism (over the other) was causing the effects (such as the reversal effect observed in chapter 3) in the real world. As stated previously, I expect in the real world these two variables are highly correlated, and that differences in action similarity constrains the way the semantic system develops and organizes itself. That is, differences in action similarity lead to differences in semantic similarity because action representation is a critical component to semantics.

7.8 CONCLUDING REMARKS

Not only was the research in this dissertation able to show significant effects of object manipulability above and beyond effects of object familiarity and age of acquisition on object identification, but it was able to more fully characterize the effects of two types of manipulability: (1) graspability: ‘whether or not an object can be grasped with one hand’ and (2) functional usage, defined by the ‘extent to which hand movements made when using an object differ from those made to pick it up’. Specifically, *graspability* effects were largest for photographs of objects presented without a Mask, while *functional usage* effects were largest for degraded or Masked photographs.

In addition, this research identified an interesting reversal effect in that manipulable objects were named more quickly despite being categorized more slowly than non-manipulable objects. The results from my computational modeling suggested different organization of manipulable objects at the semantic level was a prime candidate for explaining this effect. Support for this comes from research on potency ratings, and recent pilot data collected to suggest support for this ‘branching’ hypothesis. I believe this branching asymmetry arises in part based on similarity (primarily action similarity), and in part based on evolutionary constraints – that require manipulable objects to be organized into smaller more meaningful semantic units based on function (during learning and development).

7.9 FUTURE DIRECTIONS

All good research leads to future questions, and I would love to put my theory of differential semantic organization based on manipulability to the test of additional research methodologies. For example, there is a computational learning model (COVIS) developed by Ashby and colleagues (F. G. Ashby, Alfonso-Reese, Turken, & Waldron, 1998; F. G. Ashby & Ell, 2002; F. G. Ashby & Valentin, in press) that I think could be used to explore differences between how manipulable and non-manipulable object categories are learned. Also, it would be interesting to use these same objects (naming & categorization) in a neuroimaging (fMRI) experiment. Specifically, I would predict more variation in representation of manipulable objects than non-manipulable objects (supporting the idea of more meaningful super-ordinate categories for manipulable objects compared to non-manipulable).

In addition, the methodology of transcranial magnetic stimulation (TMS, see Walsh & Cowey, 2000) could be used to observe the extent to which “motor resonance” for manipulable objects in dorsal stream is a necessary component for object recognition of manipulable objects. That is, TMS could be used to interfere with brain areas in premotor / fronto-parietal cortex while participants are asked to identify both manipulable and non-manipulable objects. The results could be used to determine to what extent activation in the dorsal visual areas is necessary for accurate identification of manipulable objects as compared to non-manipulable objects. If these motor areas are necessary during object identification than TMS interference should slow the time to identify manipulable objects as compared to non-manipulable objects. On the other hand, if these

differences or more based in the ventral (semantic) system, no differences should be observed.

7.10 REFERENCES

- Allport, D. A. (1985). Distributed memory, modular subsystems and dysphasia. In S. K. Newman & R. Epstein (Eds.), *Current Perspectives in Dysphasia* (pp. 32-60). Edinburgh: Churchill Livingstone.
- Ashby, F. G., Alfonso-Reese, L. A., Turken, A. U., & Waldron, E. M. (1998). A neuropsychological theory of multiple systems in category learning. *Psychological Review*, *105*, 442-481.
- Ashby, F. G., & Ell, S. W. (2002). Single versus multiple systems of category learning: Reply to Nosofsky and Kruschke (2002). *Psychonomic Bulletin & Review*, *9*(1), 175-180.
- Ashby, F. G., & Valentin, V. V. (in press). Multiple systems of perceptual category learning: Theory and cognitive tests. In H. C. C. Lefebvre (Ed.), *Categorization in cognitive science*. New York: Elsevier.
- Barlow, H. B. (1972). Single units and sensation: A neuron doctrine for perceptual psychology? *Perception*, *1*(4), 371-394.
- Bates, E., D'Amico, S., Jacobsen, T., Székely, A., Andonova, E., Devescovi, A., et al. (2003). Timed picture naming in seven languages. *Psychonomic Bulletin & Review*, *10*(2), 344-380.
- Battig, W. F., & Montague, W. E. (1969). Category norms for verbal items in 56 categories: A replication and extension of the Connecticut category norms. *Journal of Experimental Psychology Monograph*, *80*(3), 1-46.
- Bonin, P., Peereman, R., Malardier, N., Méot, A., & Chalard, M. (2003). A new set of 299 pictures for psycholinguistic studies: French norms for name agreement,

- image agreement, conceptual familiarity, visual complexity, image variability, age of acquisition, and naming latencies. *Behavior Research Methods, Instruments & Computers*, 35(1), 158-167.
- Boronat, C. B., Buxbaum, L. J., Coslett, H. B., Tang, K., Saffran, E. M., Kimberg, D. Y., et al. (2005). Distinctions between manipulation and function knowledge of objects: Evidence from functional magnetic resonance imaging. *Cognitive Brain Research*, 23(2-3), 361-373.
- Bowers, J. S. (2009). On the Biological Plausibility of Grandmother Cells: Implications for Neural Network Theories in Psychology and Neuroscience. [Article]. *Psychological Review*, 116(1), 220-251.
- Bowers, J. S. (2010). More on Grandmother Cells and the Biological Implausibility of PDP Models of Cognition: A Reply to Plaut and McClelland (2010) and Quiñero and Kreiman (2010). [Article]. *Psychological Review*, 117(1), 300-308.
- Bowers, J. S. (2011). What is a grandmother cell? And how would you know if you found one? *Connection Science*, 23(2), 91-95.
- Bub, D. N., & Masson, M. E. J. (2010). Grasping beer mugs: On the dynamics of alignment effects induced by handled objects. *Journal of Experimental Psychology: Human Perception and Performance*, 36, 341-358.
- Bub, D. N., & Masson, M. E. J. (2012). On the dynamics of action representations evoked by names of manipulable objects. *Journal of Experimental Psychology: General*, 141, 502-517.

- Bub, D. N., Masson, M. E. J., & Bukach, C. M. (2003). Gesturing and naming: The use of functional knowledge in object identification. *Psychological Science, 14*(5), 467-472.
- Bub, D. N., Masson, M. E. J., & Cree, G. S. (2008). Evocation of functional and volumetric gestural knowledge by objects and words. *Cognition, 106*(1), 27-58.
- Buxbaum, L. J., & Kalenine, S. (2010). Action knowledge, visuomotor activation, and embodiment, in the two action systems. *Annals of the New York Academy of Sciences, 1191*, 201-218.
- Buxbaum, L. J., Kyle, K. M., Tang, K., & Detre, J. A. (2006). Neural substrates of knowledge of hand postures for object grasping and functional object use: Evidence from fMRI. *Brain Research, 1117*, 175-185.
- Buxbaum, L. J., & Saffran, E. M. (2002). Knowledge of object manipulation and object function: Dissociations in apraxic and nonapraxic subjects. *Brain and Language, 82*(2), 179-199.
- Buxbaum, L. J., Veramonti, T., & Schwartz, M. F. (2000). Function and manipulation tool knowledge in apraxia: Knowing 'what for' but not 'how.'. *Neurocase, 6*(2), 83-97.
- Chao, L. L., & Martin, A. (2000). Representation of manipulable manmade objects in the dorsal stream. *NeuroImage, 12*, 478-484.
- Churchland, P. S., Ramachandran, V. S., & Sejnowski, T. J. (1994). A critique of pure vision. In C. Koch & J. L. Davis (Eds.), *Large-scale neuronal theories of the brain*. (pp. 23-60). Cambridge, MA US: The MIT Press.

- Connor, C. E. (2005). Neuroscience: Friends and grandmothers. [Article]. *Nature*, 435(7045), 1036-1037.
- Cuetos, F., & Alija, M. (2003). Normative data and naming times for action pictures. *Behavior Research Methods, Instruments & Computers*, 35(1), 168-177.
- Desmarais, G., & Dixon, M. J. (2005). Understanding the structural determinants of object confusion in memory: An assessment of psychophysical approaches to estimating visual similarity. *Perception & Psychophysics*, 67(6), 980-996.
- Desmarais, G., Dixon, M. J., & Roy, E. A. (2007). A role for action knowledge in visual object identification. *Memory & Cognition*, 35(7), 1712-1723.
- Dixon, M. J., Bub, D. N., & Arguin, M. (1997). The interaction of object form and object meaning in the identification performance of a patient with category-specific visual agnosia. *Cognitive Neuropsychology*, 14(8), 1085-1130.
- Dixon, M. J., Bub, D. N., Chertkow, H., & Arguin, M. (1999). Object identification deficits in dementia of the Alzheimer type: Combined effects of semantic and visual proximity. *Journal of the International Neuropsychological Society*, 5(4), 330-345.
- Ellis, R., & Tucker, M. (2000). Micro-affordance: The potentiation of components of action by seen objects. *British Journal of Psychology*, 91(4), 451-471.
- Filliter, J. H., McMullen, P. A., & Westwood, D. (2005). Manipulability and living/non-living category effects on object recognition. *Brain and Cognition*, 57, 61-65.
- Gale, T. M., Laws, K. R., & Foley, K. (2006). Crowded and sparse domains in object recognition: Consequences for categorization and naming. *Brain and Cognition*, 60(2), 139-145.

- Glenberg, A. M. (1997). What memory is for. *Behavioral and Brain Sciences*, 20(1), 1-55.
- Goodale, M. A., & Milner, A. D. (1992). Separate visual pathways for perception and action. *Trends in Neurosciences*, 15(1), 20-25.
- Goodale, M. A., & Milner, A. D. (1994). Separate visual pathways for perception and action. In H. Gutfreund & G. Toulouse (Eds.), *Biology and computation: A physicist's choice*. (pp. 606-611). River Edge, NJ US: World Scientific Publishing Co.
- Grèzes, J., Tucker, M., Armony, J., Ellis, R., & Passingham, R. E. (2003). Objects automatically potentiate action: An fMRI study of implicit processing. *European Journal of Neuroscience*, 17(12), 2735-2740.
- Humphreys, G. W. (2001). Objects, affordances...action! *The Psychologist*, 14(8), 408-412.
- Kalénine, S., & Bonthoux, F. (2008). Object manipulability affects children's and adult's conceptual processing. *Psychonomic Bulletin & Review*, 15(3), 667-672.
- Kiefer, M., Sim, E.-J., Helbig, H., & Graf, M. (2011). Tracking the time course of action priming on object recognition: Evidence for fast and slow influences of action on perception. *Journal of Cognitive Neuroscience*, 23(8), 1864-1874.
- Konorsky, J. (1967). *Integrative activity of the brain: An interdisciplinary approach*. Chicago: University of Chicago Press.
- Magnié, M. N., Besson, M., Poncet, M., & Dolisi, C. (2003). The Snodgrass and Vanderwart set revisited: Norms for object manipulability and for pictorial

- ambiguity of objects, chimeric objects, and nonobjects. *Journal of Clinical and Experimental Neuropsychology*, 25(4), 521-560.
- Masson, M. E. J., Bub, D. N., & Breuer, A. T. (2011). Priming of reach and grasp actions by handled objects. *Journal of Experimental Psychology: Human Perception and Performance*, 37(5), 1470-1484.
- Overschelde, J. P. V., Rawson, K. A., & Dunlosky, J. (2004). Category norms: An updated and expanded version of the Battig and Montague (1969) norms. *Journal of Memory and Language*, 50, 289-335.
- Pérez, M. A. (2007). Age of acquisition persists as the main factor in picture naming when cumulative word frequency and frequency trajectory are controlled. *The Quarterly Journal of Experimental Psychology*, 60(1), 32-42.
- Plaut, D. C., & McClelland, J. L. (2010). Locating Object Knowledge in the Brain: Comment on Bowers's (2009) Attempt to Revive the Grandmother Cell Hypothesis. [Article]. *Psychological Review*, 117(1), 284-290.
- Quiroga, R. Q., & Kreiman, G. (2010). Measuring Sparseness in the Brain: Comment on Bowers (2009). [Article]. *Psychological Review*, 117(1), 291-299.
- Quiroga, R. Q., Reddy, L., Kreiman, G., Koch, C., & Fried, I. (2005). Invariant visual representation by single neurons in the human brain. *Nature*, 435(7045), 1102-1107.
- Salmon, J. P., McMullen, P. A., & Filliter, J. H. (2010). Norms for two types of manipulability (graspability and functional usage), familiarity, and age of acquisition for 320 photographs of objects. *Behavior Research Methods*, 42(1), 82-95.

- Snodgrass, J. G., & Vanderwart, M. (1980). A standardized set of 260 pictures: Norms for name agreement, image agreement, familiarity, and visual complexity. *Journal of Experimental Psychology: Human Learning and Memory*, 6(2), 174-215.
- Tucker, M., & Ellis, R. (2001). The potentiation of grasp types during visual object categorization. *Visual Cognition*, 8(6), 769-800.
- Tucker, M., & Ellis, R. (2004). Action priming by briefly presented objects. *Acta Psychologica*, 116(2), 185-203.
- Uttl, B., Graf, P., & Siegenthaler, A. L. (2007). Influence of object size on baseline identification, priming, and explicit memory. *Scandinavian Journal of Psychology*, 48, 281-288.
- Vainio, L., Symes, E., Ellis, R., Tucker, M., & Ottoboni, G. (2008). On the relations between action planning, object identification, and motor representations of observed actions and objects. *Cognition*, 108(2), 444-465.
- Walsh, V., & Cowey, A. (2000). Transcranial magnetic stimulation and cognitive neuroscience. *Nature Reviews Neuroscience*, 1(1), 73-79.
- Westwood, D. A., & Goodale, M. A. (2011). Converging evidence for diverging pathways: Neuropsychology and psychophysics tell the same story. *Vision Research*, 51(8), 804-811.
- Wilson, M. (2002). Six views of embodied cognition. *Psychonomic Bulletin & Review*, 9(4), 625-636.

- Wolk, D. A., Coslett, H. B., & Glosser, G. (2005). The role of sensory-motor information in object recognition: Evidence from the category-specific visual agnosia. *Brain and Language, 94*, 131-146.
- Yoon, E. Y., Heinke, D., & Humphreys, G. W. (2002). Modelling direct perceptual constraints on action selection: The Naming and Action Model (NAM). *Visual Cognition, 9*(4-5), 615-661.
- Zwann, R. A. (1999). Embodied cognition, perceptual symbols, and situation models. *Discourse Processes, 28*(1), 81-88.

7.11 APPENDIX A – UNREPORTED / UNPUBLISHED RESEARCH

Before the necessity of developing our own stimulus set (i.e. chapter 2) was realized, I conducted two experiments (& one re-analysis of old data) in Dr. McMullen's lab considering effects of object manipulability using line drawings derived from the Snodgrass and Vanderwart (1980) set. None of these results were published, because the results were neither significant nor compelling, therefore they were never placed in a manuscript. Upon reconsideration of these results, which I haven't thought about for many years, the lack of significant results was probably related to (1) the design which lacked a method of stimulus degradation (cf. chapter 3 and 5), (2) these earlier studies used line-drawings and not photographs, and photographs appear to show larger manipulability effects (cf. chapter 6), (3) smaller stimulus sets, and (4) analysis methods used ANOVA, and not more powerful linear mixed effects regressions (cf. chapter 5 and 6).

7.11.1 Unpublished Experiments (x2)

Prior to the research reported in chapters 2 through 6, I conducted two object orientation studies, where the task was to identify the object (i.e. object naming). The goal of this research of this research was to explore previous results in the Dr. McMullen lab suggesting a difference between the time to identify manipulable and non-manipulable objects oriented away from the canonical orientation in one direction (60 degrees) or by the same amount in the other direction (300 degrees). A significant effect would have suggested that manipulable (unlike non-manipulable) objects afford grasping better in some orientations than in others leading to differences in manipulable objects

rotated in one direction but not others. This kind of effect is not unlike the orientation effects recently reported by Bub, Masson and colleagues (Bub & Masson, 2010; Masson, et al., 2011) except for the following critical differences: (1) Bub and Masson studied effects on manipulable objects with handles, whereas our research included “manipulable” objects without handles, (2) Bub and Masson did not look at the difference between manipulable and non-manipulable objects, they focused only on differences within orientations, (3) the Bub and Masson outcome task was a grasping action, where our outcome task was object naming, and (4) Bub and Masson used photographs of objects (i.e. beer mugs and frying pans) where our objects for these (unpublished) experiments used line-drawings.

In the first experiment (circa Apr 2007) we collected data from healthy participants naming objects in only 3 orientations. As suggested in the figure below (figure 7.12) there was no observed difference between manipulable and non-manipulable objects at 60 and 300 degrees of rotation. At the time we thought this lack of significant result might be related to the fact that only 3 orientations were used, where in the original result (figure 7.13) six different orientation were used. In other words, we thought the uncertainty of a six orientation design might be a necessary ingredient to create this effect. We therefore conducted a second experiment that was a complete replication of the data presented in figure 7.13.

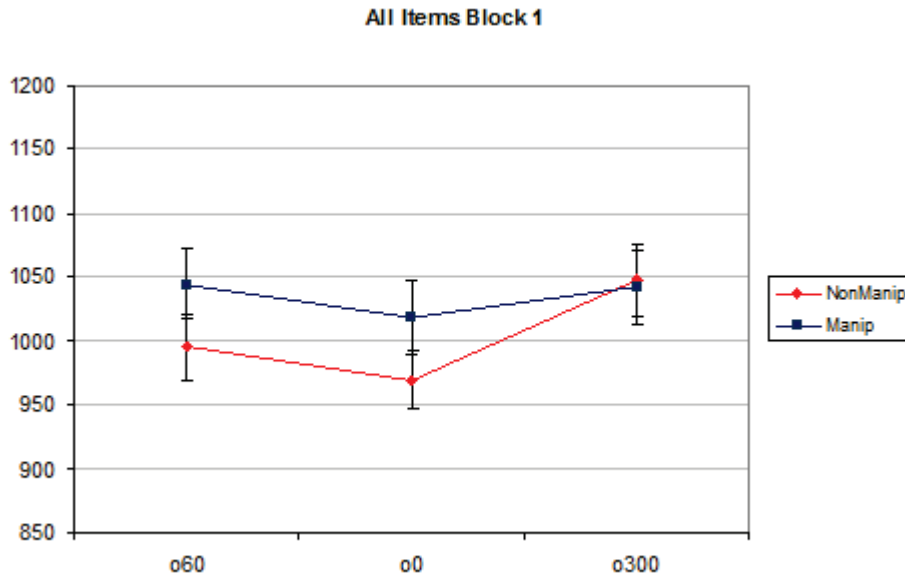


Figure 7.12. Results from the 3 orientation study (circa Apr 2007) using line-drawings. Of note, no significant differences between manipulable and non-manipulable objects at any object rotation. Error bars represent standard error.

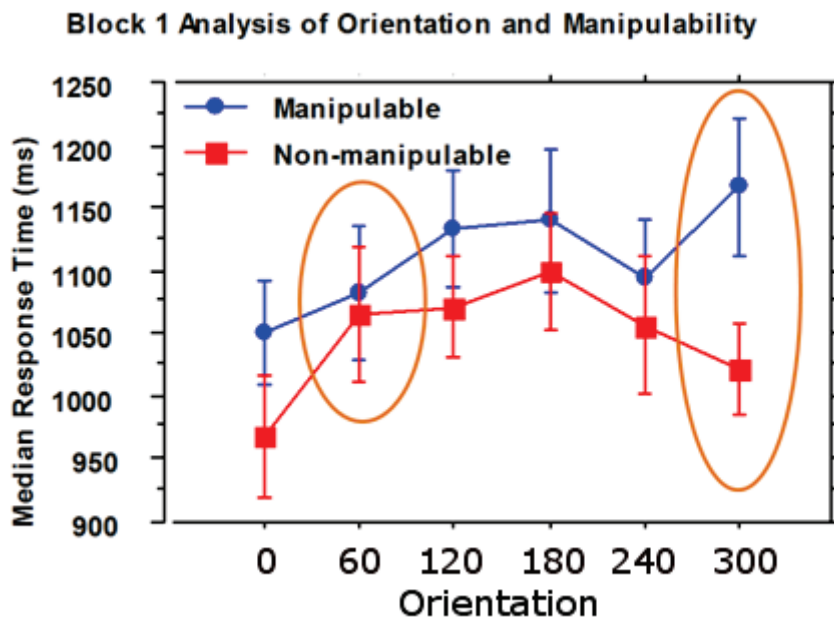


Figure 7.13. Results collected by Dr. McMullen and one of her students prior to my arrival in the lab. Highlighted is the suggested difference between manipulable and non-manipulable objects rotated either 60 degrees or 300 degrees away from the canonical orientation, that we were attempting to replicate. Error bars indicate standard error.

However, during this replication with all 6 orientations (circa July 2007) and the exact same object set used in the original, we failed to replicate this difference at 60 and 300 degrees (see results below, figure 7.14). We thus concluded that the original finding was a chance outcome and pursued these findings no further.

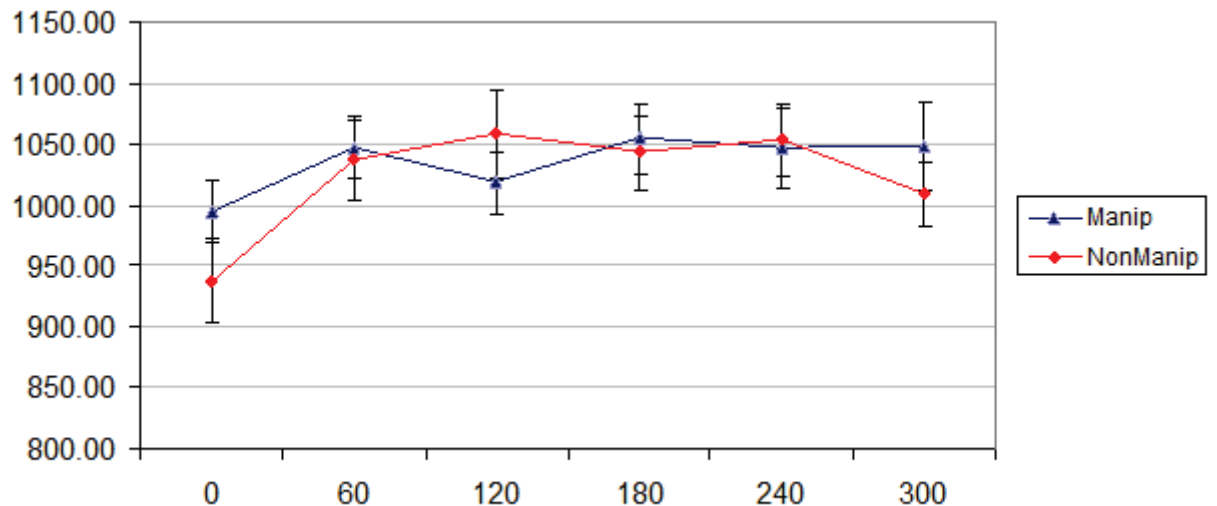


Figure 7.14. Results from my attempted replication (circa July 2007) of the study from Figure 7.13. As before, y-axis indicates reaction time, and x-axis indicates object orientation. Of note, no replication of the difference between objects at 60 and 300 degrees. Error bars indicate standard error.

7.11.2 Unpublished Re-analysis

My (circa 2009, unpublished) re-analysis was on a dataset collected by a former student from our lab on naming speed and accuracy data from a visual agnosic patient they had tested. The goal of the re-analysis was to determine if the patient showed a difference in their ability (in either reaction time or accuracy) to identify manipulable versus non-manipulable objects when the role of familiarity and age of acquisition had been controlled. Finding a significant result would have been equivalent to the result

observed by Wolk et al. (2005), who reported that their patients were more accurate at identifying manipulable objects. However, the re-analysis from my re-analysis of the patient data collected in the McMullen lab (using an ANOVA) showed no significant difference in reaction time or accuracy results between manipulable and non-manipulable objects.

7.11.3 Unpublished Research Summary

No good drafts of the experiments and results above were ever prepared or submitted (as the peer-review process is known to be unreceptive to studies exhibiting null effects). However, I felt it was worth mentioning in this discussion section that these three other studies *did* exist as a part of my research program. And, although they are not officially part of this dissertation, they underscore that I really do mean it when I say “the effects of manipulability can be elusive.” (and may be observable with only certain research designs). I have three studies sitting in my ‘file drawer’ that attest to this fact³¹. But reported this results, briefly, in this Appendix I hope to give a more full picture of my research program, as well trying to avoid perpetuating the “file drawer” problem by at least discussing the nature of the research that yielded this null effects, albeit briefly.

³¹ Note, when I say “file drawer”, I am of course alluding to the “file drawer” problem in science. Specifically, the problem that science can over-estimate effect sizes for certain phenemonon, because significant effects get reported and null results go unreported, or sit unpublished in researcher’s file drawer.

BIBLIOGRAPHY

- Adamo, M., & Ferber, S. (2009). A picture says more than a thousand words: Behavioural and ERP evidence for attentional enhancements due to action affordances. *Neuropsychologia*, 47(6), 1600-1608.
- Agresti, A. (2002). *Categorical data analysis*. Hoboken, NJ: A John Wiley & Sons, Inc.
- Allport, D. A. (1985). Distributed memory, modular subsystems and dysphasia. In S. K. Newman & R. Epstein (Eds.), *Current Perspectives in Dysphasia* (pp. 32-60). Edinburgh: Churchill Livingstone.
- Ashby, F. G., Alfonso-Reese, L. A., Turken, A. U., & Waldron, E. M. (1998). A neuropsychological theory of multiple systems in category learning. *Psychological Review*, 105, 442-481.
- Ashby, F. G., & Ell, S. W. (2002). Single versus multiple systems of category learning: Reply to Nosofsky and Kruschke (2002). *Psychonomic Bulletin & Review*, 9(1), 175-180.
- Ashby, F. G., & Valentin, V. V. (in press). Multiple systems of perceptual category learning: Theory and cognitive tests. In H. C. C. Lefebvre (Ed.), *Categorization in cognitive science*. New York: Elsevier.
- Baayen, R. H. (2008). *Analyzing Linguistic Data: A practical introduction to statistics*: Cambridge University Press.
- Bacon-Macé, N., Kirchner, H., Fabre-Thorpe, M., & Thorpe, S. J. (2007). Effects of task requirements on rapid natural scene processing: From common sensory encoding to distinct decisional mechanisms. *Journal of Experimental Psychology: Human Perception and Performance*, 33(5), 1013-1026.

- Bacon-Macé, N., Macé, M. J. M., Fabre-Thorpe, M., & Thorpe, S. J. (2005). The time course of visual processing: Backward masking and natural scene categorisation. *Vision Research*, 45(11), 1459-1469.
- Bar, M., & Aminoff, E. (2003). Cortical analysis of visual context. [Article]. *Neuron*, 38(2), 347-358.
- Barlow, H. B. (1972). Single units and sensation: A neuron doctrine for perceptual psychology? *Perception*, 1(4), 371-394.
- Barsalou, L. W. (2008). Grounded cognition. *Annual Review of Psychology*, 59, 617-645.
- Bates, D. (2007). lme4: Linear mixed-effects models using S4 classes (Version R package version 0.99875-9).
- Bates, E., D'Amico, S., Jacobsen, T., Székely, A., Andonova, E., Devescovi, A., et al. (2003). Timed picture naming in seven languages. *Psychonomic Bulletin & Review*, 10(2), 344-380.
- Battig, W. F., & Montague, W. E. (1969). Category norms for verbal items in 56 categories: A replication and extension of the Connecticut category norms. *Journal of Experimental Psychology Monograph*, 80(3), 1-46.
- Biederman, I. (1985). Human image understanding: Recent research and a theory. *Computer Vision, Graphics, and Image Processing*, 32(1), 29-73.
- Biederman, I. (1987). Recognition-by-components: A theory of human image understanding. *Psychological Review*, 94(2), 115-147.
- Bonin, P., Peereman, R., Malardier, N., Méot, A., & Chalard, M. (2003). A new set of 299 pictures for psycholinguistic studies: French norms for name agreement, image agreement, conceptual familiarity, visual complexity, image variability, age

- of acquisition, and naming latencies. *Behavior Research Methods, Instruments & Computers*, 35(1), 158-167.
- Boronat, C. B., Buxbaum, L. J., Coslett, H. B., Tang, K., Saffran, E. M., Kimberg, D. Y., et al. (2005). Distinctions between manipulation and function knowledge of objects: Evidence from functional magnetic resonance imaging. *Cognitive Brain Research*, 23(2-3), 361-373.
- Bowers, J. S. (2009). On the Biological Plausibility of Grandmother Cells: Implications for Neural Network Theories in Psychology and Neuroscience. [Article]. *Psychological Review*, 116(1), 220-251.
- Bowers, J. S. (2010). More on Grandmother Cells and the Biological Implausibility of PDP Models of Cognition: A Reply to Plaut and McClelland (2010) and Quian Quiroga and Kreiman (2010). [Article]. *Psychological Review*, 117(1), 300-308.
- Bowers, J. S. (2011). What is a grandmother cell? And how would you know if you found one? *Connection Science*, 23(2), 91-95.
- Brodie, E. E., Wallace, A. M., & Sharrat, B. (1991). Effect of surface characteristics and style of production on naming and verification of pictorial stimuli. *American Journal of Psychology*, 104(4), 517-545.
- Bub, D. N., & Masson, M. E. J. (2010). Grasping beer mugs: On the dynamics of alignment effects induced by handled objects. *Journal of Experimental Psychology: Human Perception and Performance*, 36, 341-358.
- Bub, D. N., & Masson, M. E. J. (2012). On the dynamics of action representations evoked by names of manipulable objects. *Journal of Experimental Psychology: General*, 141, 502-517.

- Bub, D. N., Masson, M. E. J., & Bukach, C. M. (2003). Gesturing and naming: The use of functional knowledge in object identification. *Psychological Science, 14*(5), 467-472.
- Bub, D. N., Masson, M. E. J., & Cree, G. S. (2008). Evocation of functional and volumetric gestural knowledge by objects and words. *Cognition, 106*(1), 27-58.
- Buxbaum, L. J., & Kalenine, S. (2010). Action knowledge, visuomotor activation, and embodiment, in the two action systems. *Annals of the New York Academy of Sciences, 1191*, 201-218.
- Buxbaum, L. J., Kyle, K. M., Tang, K., & Detre, J. A. (2006). Neural substrates of knowledge of hand postures for object grasping and functional object use: Evidence from fMRI. *Brain Research, 1117*, 175-185.
- Buxbaum, L. J., & Saffran, E. M. (2002). Knowledge of object manipulation and object function: Dissociations in apraxic and nonapraxic subjects. *Brain and Language, 82*(2), 179-199.
- Buxbaum, L. J., Veramonti, T., & Schwartz, M. F. (2000). Function and manipulation tool knowledge in apraxia: Knowing 'what for' but not 'how.'. *Neurocase, 6*(2), 83-97.
- Cant, J. S., & Goodale, M. A. (2007). Attention to form or surface properties modulates different regions of human occipitotemporal cortex. *Cerebral Cortex, 17*(3), 713-731.
- Cant, J. S., Large, M.-E., McCall, L., & Goodale, M. A. (2008). Independent processing of form, colour, and texture in object perception. *Perception, 37*(1), 57-78.

- Carpenter, G. A., & Grossberg, S. (2002). A self-organizing neural network for supervised learning, recognition, and prediction. In T. A. Polk & C. M. Seifert (Eds.), *Cognitive modeling*. (pp. 289-314). Cambridge, MA US: MIT Press.
- Catling, J. C., Dent, K., & Williamson, S. (2008). Age of acquisition, not word frequency affects object recognition: Evidence from the effects of visual degradation. *Acta Psychologica*, *129*(1), 130-137.
- Cavina-Pratesi, C., Kentridge, R. W., Heywood, C. A., & Milner, A. D. (2010). Separate processing of texture and form in the ventral stream: Evidence from fMRI and visual agnosia. *Cerebral Cortex*, *20*(2), 433-446.
- Chainay, H., & Humphreys, G. W. (2002). Privileged access to action for objects relative to words. *Psychonomic Bulletin & Review*, *9*(2), 348-355.
- Chao, L. L., Haxby, J. V., & Martin, A. (1999). Attribute-based neural substrates in temporal cortex for perceiving and knowing about objects. *Nature Neuroscience*, *2*(10), 913-919.
- Chao, L. L., & Martin, A. (2000). Representation of manipulable manmade objects in the dorsal stream. *NeuroImage*, *12*, 478-484.
- Chao, L. L., Martin, A., & Haxby, J. V. (1999). Are face-responsive regions selective only for faces? *NeuroReport: For Rapid Communication of Neuroscience Research*, *10*(14), 2945-2950.
- Cheng, Y., Meltzoff, A. N., & Decety, J. (2007). Motivation modulates the activity of the human mirror-neuron system. *Cerebral Cortex*, *17*(8), 1979-1986.

- Chouinard, P. A., & Goodale, M. A. (2010). Category-specific neural processing for naming pictures of animals and naming pictures of tools: An ALE meta-analysis. *Neuropsychologia*, *48*(2), 409-418.
- Churchland, P. S., Ramachandran, V. S., & Sejnowski, T. J. (1994). A critique of pure vision. In C. Koch & J. L. Davis (Eds.), *Large-scale neuronal theories of the brain*. (pp. 23-60). Cambridge, MA US: The MIT Press.
- Connor, C. E. (2005). Neuroscience: Friends and grandmothers. [Article]. *Nature*, *435*(7045), 1036-1037.
- Coppens, P., & Frisinger, D. (2005). Category-specific naming effect in non-brain-damaged individuals. *Brain and Language*, *94*(1), 61-71.
- Coslett, H. B., & Saffran, E. M. (1992). Optic aphasia and the right hemisphere: A replication and extension. *Brain and Language*, *43*(1), 148-161.
- Craighero, L., Fadiga, L., Rizzolatti, G., & Umiltà, C. (1998). Visuomotor priming. *Visual Cognition*, *5*(1-2), 109-125.
- Craighero, L., Fadiga, L., Rizzolatti, G., & Umiltà, C. (1999). Action for perception: A motor-visual attentional effect. *Journal of Experimental Psychology: Human Perception and Performance*, *25*(6), 1673-1692.
- Creem, S. H., & Proffitt, D. R. (2001). Grasping objects by their handles: A necessary interaction between cognition and action. *Journal of Experimental Psychology: Human Perception and Performance*, *27*(1), 218-228.
- Cuetos, F., & Alija, M. (2003). Normative data and naming times for action pictures. *Behavior Research Methods, Instruments & Computers*, *35*(1), 168-177.

- Dent, K., Catling, J. C., & Johnston, R. A. (2007). Age of acquisition affects object recognition: Evidence from visual duration thresholds. *Acta Psychologica, 125*(3), 301-318.
- Dent, K., Johnston, R. A., & Humphreys, G. W. (2008). Age of acquisition and word frequency effects in picture naming: A dual-task investigation. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 34*(2), 282-301.
- DeRenzi, E., Faglioni, P., & Sorgato, P. (1982). Modality-specific and supramodal mechanisms of apraxia. *Brain, 105*, 301-312.
- Desmarais, G., & Dixon, M. J. (2005). Understanding the structural determinants of object confusion in memory: An assessment of psychophysical approaches to estimating visual similarity. *Perception & Psychophysics, 67*(6), 980-996.
- Desmarais, G., Dixon, M. J., & Roy, E. A. (2007). A role for action knowledge in visual object identification. *Memory & Cognition, 35*(7), 1712-1723.
- Desmarais, G., Pensa, M. C., Dixon, M. J., & Roy, E. A. (2007). The importance of object similarity in the production and identification of actions associated with objects. *Journal of the International Neuropsychological Society, 13*(6), 1021-1034.
- Dixon, M. J., Bub, D. N., & Arguin, M. (1997). The interaction of object form and object meaning in the identification performance of a patient with category-specific visual agnosia. *Cognitive Neuropsychology, 14*(8), 1085-1130.
- Dixon, M. J., Bub, D. N., Chertkow, H., & Arguin, M. (1999). Object identification deficits in dementia of the Alzheimer type: Combined effects of semantic and

- visual proximity. *Journal of the International Neuropsychological Society*, 5(4), 330-345.
- Downing, P. E., Chan, A. W. Y., Peelen, M. V., Dodds, C. M., & Kanwisher, N. (2006). Domain specificity in visual cortex. [Article]. *Cerebral Cortex*, 16(10), 1453-1461.
- Ellis, R., & Tucker, M. (2000). Micro-affordance: The potentiation of components of action by seen objects. *British Journal of Psychology*, 91(4), 451-471.
- Epstein, R., Harris, A., Stanley, D., & Kanwisher, N. (1999). The parahippocampal place area: Recognition, navigation, or encoding? *Neuron*, 23, 115-125.
- Fabre-Thorpe, M., Delorme, A., Marlot, C., & Thorpe, S. (2001). A limit to the speed of processing in ultra-rapid visual categorization of novel natural scenes. *Journal of Cognitive Neuroscience*, 13(2), 171-180.
- Fang, F., & He, S. (2005). Cortical responses to invisible objects in the human dorsal and ventral pathways. *Nature Neuroscience*, 8(10), 1380-1385.
- Ferrari, P. F., Gallese, V., Rizzolatti, G., & Fogassi, L. (2003). Mirror neurons responding to the observation of ingestive and communicative mouth actions in the monkey ventral premotor cortex. *European Journal of Neuroscience*, 17(8), 1703-1714.
- Filliter, J. H., McMullen, P. A., & Westwood, D. (2005). Manipulability and living/non-living category effects on object recognition. *Brain and Cognition*, 57, 61-65.
- Gaffan, D., & Heywood, C. A. (1993). A spurious category-specific visual agnosia for living things in normal human and nonhuman primates. *Journal of Cognitive Neuroscience*, 5(1), 118-128.

- Gale, T. M., Done, D. J., & Frank, R. J. (2001). Visual crowding and category specific deficits for pictorial stimuli: A neural network model. *Cognitive Neuropsychology*, *18*(6), 509-550.
- Gale, T. M., Laws, K. R., & Foley, K. (2006). Crowded and sparse domains in object recognition: Consequences for categorization and naming. *Brain and Cognition*, *60*(2), 139-145.
- Garbarini, F., & Adenzato, M. (2004). At the root of embodied cognition: Cognitive science meets neurophysiology. *Brain and Cognition*, *56*(1), 100-106.
- Garofeanu, C., Króliczak, G., Goodale, M. A., & Humphrey, G. K. (2004). Naming and grasping common objects: A priming study. *Experimental Brain Research*, *159*(1), 55-64.
- Gauthier, I., & Tarr, M. J. (1997). Becoming a 'greeble' expert: Exploring mechanisms for face recognition. *Vision Research*, *37*(12), 1673-1682.
- Gauthier, I., Tarr, M. J., Moylan, J., Skudlarski, P., Gore, J. C., & Anderson, A. W. (2000). The fusiform 'face area' is part of a network that processes faces at the individual level. *Journal of Cognitive Neuroscience*, *12*(3), 495-504.
- Gauthier, I., Williams, P., Tarr, M. J., & Tanaka, J. (1998). Training 'greeble' experts: A framework for studying expert object recognition processes. *Vision Research*, *38*(15-16), 2401-2428.
- Gerlach, C. (2001). Structural similarity causes different category-effects depending on task characteristics. *Neuropsychologia*, *39*(9), 895-900.
- Gerlach, C. (2009). Category-specificity in visual object recognition. *Cognition*, *111*(3), 281-301.

- Gerlach, C., Law, I., Gade, A., & Paulson, O. B. (1999). Perceptual differentiation and category effects in normal object recognition: A PET study. *Brain: A Journal of Neurology*, *122*(11), 2159-2170.
- Gerlach, C., Law, I., Gade, A., & Paulson, O. B. (2002). The role of action knowledge in the comprehension of artefacts - A PET study. *NeuroImage*, *15*, 143-152.
- Gerlach, C., Law, I., & Paulson, O. B. (2004). Structural similarity and category-specificity: A refined account. *Neuropsychologia*, *42*(11), 1543-1553.
- Gerlach, C., Law, I., & Paulson, O. B. (2006). Shape configuration and category-specificity. *Neuropsychologia*, *44*(7), 1247-1260.
- Gibson, J. J. (1979). *The ecological approach to visual perception*. Boston: Houghton-Mifflin.
- Glenberg, A. M. (1997). What memory is for. *Behavioral and Brain Sciences*, *20*(1), 1-55.
- Goodale, M. A. (2008). Action without perception in human vision. *Brain and Cognition*, *60*(2), 139-145.
- Goodale, M. A., & Ganel, T. (2009). Two visual systems: Separate pathways for perception and action in the human cerebral cortex. In M. R. M. Jenkin & L. R. Harris (Eds.), *Cortical mechanisms of vision*. (pp. 375-397). New York, NY US: Cambridge University Press.
- Goodale, M. A., & Milner, A. D. (1992). Separate visual pathways for perception and action. *Trends in Neurosciences*, *15*(1), 20-25.
- Goodale, M. A., & Milner, A. D. (1994). Separate visual pathways for perception and action. In H. Gutfreund & G. Toulouse (Eds.), *Biology and computation: A*

- physicist's choice*. (pp. 606-611). River Edge, NJ US: World Scientific Publishing Co.
- Goodale, M. A., Milner, A. D., Jakobson, L. S., & Carey, D. P. (1991). A neurological dissociation between perceiving objects and grasping them. *Nature*, *349*(6305), 154-156.
- Grezes, J., & Decety, J. (2002). Does visual perception of object afford action? Evidence from a neuroimaging study. *Neuropsychologia*, *40*, 212-222.
- Grèzes, J., Tucker, M., Armony, J., Ellis, R., & Passingham, R. E. (2003). Objects automatically potentiate action: An fMRI study of implicit processing. *European Journal of Neuroscience*, *17*(12), 2735-2740.
- Grill-Spector, K. (2003). The neural basis of object percpetion. *Current Opinion in Neurobiology*, *13*, 159-166.
- Grill-Spector, K., & Sayres, R. (2008). Object recognition: Insights from advances in fMRI methods. *Current Directions in Psychological Science*, *17*(2), 73-79.
- Hamm, J. P., & McMullen, P. A. (1998). Effects of orientation on the identification of rotated objects depend on the level of identity. *Journal of Experimental Psychology: Human Perception and Performance*, *24*(2), 413-426.
- Hauk, O., Johnsrude, I., & Pulvermüller, F. (2000). Somatotopic representation of action words in human motor and premotor cortex. *Neuron*, *41*(2), 301-307.
- Haxby, J. V., Gobbini, M. I., Furey, M. L., Ishai, A., Schouten, J. L., & Pietrini, P. (2001). Distributed and overlapping representations of faces and objects in ventral temporal cortex. *Science*, *293*(5539), 2425-2430.

- Helbig, H. B., Graf, M., & Kiefer, M. (2006). The role of action representations in visual object recognition. *Experimental Brain Research*, *174*, 221-228.
- Hillis, A. E., & Caramazza, A. (1995). Cognitive and neural mechanisms underlying visual and semantic processing: Implications from 'optic aphasia.'. *Journal of Cognitive Neuroscience*, *7*(4), 457-478.
- Hinton, G. E. (2007). Learning multiple layers of representation. *Trends in Cognitive Sciences*, *11*(10), 428-434.
- Hummel, J. E., & Biederman, I. (2002). Dynamic binding in a neural network for shape recognition. In T. A. Polk & C. M. Seifert (Eds.), *Cognitive modeling*. (pp. 337-374). Cambridge, MA US: MIT Press.
- Humphreys, G. W. (2001). Objects, affordances...action! *The Psychologist*, *14*(8), 408-412.
- Humphreys, G. W., & Forde, E. M. E. (2001). Hierarchies, similarity, and interactivity in object recognition: 'Category-specific' neuropsychological deficits. *Behavioral and Brain Sciences*, *24*(3), 453-509.
- Humphreys, G. W., & Riddoch, M. J. (2001). Detection by action: neuropsychological evidence for action-defined templates in search. . *Nature Neuroscience*, *4*, 84-88.
- Humphreys, G. W., & Riddoch, M. J. (2002). Do pixel-level analyses describe psychological perceptual similarity? A comment on 'Category-specific naming and the 'visual' characteristics of line drawn stimuli' by Laws and Gale. *Cortex: A Journal Devoted to the Study of the Nervous System and Behavior*, *38*(1), 1-3.
- Humphreys, G. W., Riddoch, M. J., & Quinlan, P. T. (1988). Cascade processes in picture identification. *Cognitive Neuropsychology*, *5*(1), 67-104.

- Ishibashi, R., Lambon Ralph, M. A., Saito, S., & Pobric, G. (2011). Different roles of lateral anterior temporal lobe and inferior parietal lobule in coding function and manipulation tool knowledge: Evidence from an rtms study. *Neuropsychologia*.
- Jarvis, B. G. (2008). DirectRT (Version 2008.1.0.11) [Computer Software]. New York, NY: Empirisoft Corporation.
- Jeannerod, M. (1997). *The cognitive neuroscience of action*. Malden: Blackwell Publishing.
- Johnson-Frey, S. H. (2004). The neural bases of complex tool use in humans. *Trends in Cognitive Sciences*, 8(2), 71-78.
- Jolicoeur, P. (1985). The time to name disoriented natural objects. *Memory & Cognition*, 13(4), 289-303.
- Jolicoeur, P., Gluck, M. A., & Kosslyn, S. M. (1984). Pictures and names: Making the connection. *Cognitive Psychology*, 16(2), 243-275.
- Kalénine, S., & Bonthoux, F. (2008). Object manipulability affects children's and adult's conceptual processing. *Psychonomic Bulletin & Review*, 15(3), 667-672.
- Kanwisher, N. (2000). Domain specificity in face perception. *Nature Neuroscience*, 3(8), 759-763.
- Kanwisher, N., McDermott, J., & Chun, M. M. (1997). The fusiform face area: A module in human extrastriate cortex specialized for face perception. *The Journal of Neuroscience*, 17(11), 4302-4311.
- Kanwisher, N., Stanley, D., & Harris, A. (1999). The fusiform face area is selective for faces not animals. *NeuroReport: For Rapid Communication of Neuroscience Research*, 10(1), 183-187.

- Kiefer, M., Sim, E.-J., Helbig, H., & Graf, M. (2011). Tracking the time course of action priming on object recognition: Evidence for fast and slow influences of action on perception. *Journal of Cognitive Neuroscience*, 23(8), 1864-1874.
- Kirchner, H., Barbeau, E. J., Thorpe, S. J., Régis, J., & Liegeois-Chauvel, C. (2009). Ultra-rapid sensory responses in the human frontal eye field region. *The Journal of Neuroscience*, 29(23), 7599-7606.
- Kirchner, H., & Thorpe, S. J. (2006). Ultra-rapid object detection with saccadic eye movements: Visual processing speed revisited. *Vision Research*, 46(11), 1762-1776.
- Kliegl, R., Masson, M. E. J., & Richter, E. M. (2010). A linear mixed model analysis of masked repetition priming. *Visual Cognition*, 18(5), 655-681.
- Konorsky, J. (1967). *Integrative activity of the brain: An interdisciplinary approach*. Chicago: University of Chicago Press.
- Kraut, M. A., Moo, L. R., Segal, J. B., & Hart, J., Jr. (2002). Neural activation during an explicit categorization task: Category- or feature-specific effects? *Cognitive Brain Research*, 13(2), 213-220.
- Kung, C.-C. (2007). *Expanding the FFA debate: A reevaluation of recent studies and evidence for the multimodal and dynamic fusiform gyrus*. ProQuest Information & Learning, US.
- Lakoff, G., & Johnson, M. (1999). *Philosophy in the flesh: The embodied mind and its challenge to Western philosophy*. New York: Basic Books.
- Lawrence, M. A., & Klein, R. M. (2012). Isolating exogenous and endogenous modes of temporal attention. *Journal of Experimental Psychology: General*, 1-13.

- Laws, K. R., & Gale, T. M. (2002a). Category-specific naming and the 'visual' characteristics of line drawn stimuli. *Cortex: A Journal Devoted to the Study of the Nervous System and Behavior*, 38(1), 7-21.
- Laws, K. R., & Gale, T. M. (2002b). Why are our similarities so different? A reply to Humphreys and Riddoch. *Cortex: A Journal Devoted to the Study of the Nervous System and Behavior*, 38(4), 643-650.
- Laws, K. R., Gale, T. M., Frank, R., & Davey, N. (2002). Visual similarity is greater for line drawings of nonliving than living things: The importance of musical instruments and body parts. *Brain and Cognition*, 48(2-3), 421-424.
- Laws, K. R., & Hunter, M. Z. (2006). The impact of colour, spatial resolution, and presentation speed on category naming. *Brain and Cognition*, 62(2), 89-97.
- Laws, K. R., & Neve, C. (1999). A 'normal' category-specific advantage for naming living things. *Neuropsychologia*, 37(11), 1263-1269.
- Lee, C.-l., Middleton, E., Mirman, D., Kalénine, S., & Buxbaum, L. J. (2013). Incidental and context-responsive activation of structure- and function-based action features during object identification. *Journal of Experimental Psychology: Human Perception and Performance*, 39(1), 257-270.
- Lewis, J. W. (2006). Cortical networks related to human use of tools. *Neuroscientist*, 12(3), 211-231.
- Lhermitte, F. (1983). 'Utilization behaviour' and its relation to lesions of the frontal lobes. *Brain*, 106, 237-255.

- Lindemann, O., Stenneken, P., van Schie, H. T., & Bekkering, H. (2006). Semantic activation in action planning. *Journal of Experimental Psychology: Human Perception and Performance*, 32(3), 633-643.
- Magnié, M. N., Besson, M., Poncet, M., & Dolisi, C. (2003). The Snodgrass and Vanderwart set revisited: Norms for object manipulability and for pictorial ambiguity of objects, chimeric objects, and nonobjects. *Journal of Clinical and Experimental Neuropsychology*, 25(4), 521-560.
- Malcolm, G. L., Lanyon, L. J., Fugard, A. J. B., & Barton, J. J. S. (2008). Scan patterns during the processing of facial expression versus identity: An exploration of task-driven and stimulus-driven effects. *Journal of Vision*, 8(8), 1-9.
- Marr, D., & Nishihara, H. K. (1978). Representation and recognition of the spatial organization of three-dimensional shapes. *Proc. R. Soc. Lond. B Biol. Sci.*, 200, 269–294.
- Martin, A., Haxby, J. V., Lalonde, F. M., & Wiggs, C. L. (1995). Discrete cortical regions associated with knowledge of color and knowledge of action. *Science*, 270(5233), 102-105.
- Masson, M. E. J., Bub, D. N., & Breuer, A. T. (2011). Priming of reach and grasp actions by handled objects. *Journal of Experimental Psychology: Human Perception and Performance*, 37(5), 1470-1484.
- Matheson, H. E., & McMullen, P. A. (2010). Neuropsychological dissociations between motion and form perception suggest functional organization in extrastriate cortical regions in the human brain. *Brain and Cognition*, 74(2), 160-168.

- McNair, N. A., & Harris, I. M. (2012). Disentangling the contributions of grasp and action representations in the recognition of manipulable objects. *Experimental Brain Research*, 220(1), 71-77.
- Miceli, G., Fouch, E., Capasso, R., Shelton, J. R., Tamaiuolo, F., & Caramazza, A. (2001). The dissociation of color from form and function knowledge. *Nature Neuroscience*, 4(6), 662-667.
- Milner, A. D., & Goodale, M. A. (1995). *The visual brain in action*. New York, NY US: Oxford University Press.
- Noppeney, U., Price, C. J., Penny, W. D., & Friston, K. J. (2006). Two Distinct Neural Mechanisms for Category-selective Responses. *Cerebral Cortex*, 16(3), 437-445.
- Ostergaard, A. L., & Davidoff, J. B. (1985). Some effects of color on naming and recognition of objects. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 11(3), 579-587.
- Overschelde, J. P. V., Rawson, K. A., & Dunlosky, J. (2004). Category norms: An updated and expanded version of the Battig and Montague (1969) norms. *Journal of Memory and Language*, 50, 289-335.
- Peissig, J. J., & Tarr, M. J. (2007). Visual Object Recognition: Do We Know More Now Than We Did 20 Years Ago? *Annual Review of Psychology*, 58, 75-96.
- Pérez, M. A. (2007). Age of acquisition persists as the main factor in picture naming when cumulative word frequency and frequency trajectory are controlled. *The Quarterly Journal of Experimental Psychology*, 60(1), 32-42.

- Pezzulo, G., Barca, L., Bocconi, A. L., & Borghi, A. M. (2010). When affordances climb into your mind: Advantages of motor simulation in a memory task performed by novice and expert rock climbers. *Brain and Cognition*, 73(1), 68-73.
- Pilgrim, E., & Humphreys, G. W. (1991). Impairment of action to visual objects in a case of ideomotor apraxia. *Cognitive Neuropsychology*, 8(6), 459-473.
- Plaut, D. C., & Farah, M. J. (1990). Visual object representation: Interpreting neurophysiological data within a computational framework. *Journal of Cognitive Neuroscience*, 2(4), 320-343.
- Plaut, D. C., & McClelland, J. L. (2010). Locating Object Knowledge in the Brain: Comment on Bowers's (2009) Attempt to Revive the Grandmother Cell Hypothesis. [Article]. *Psychological Review*, 117(1), 284-290.
- Poggio, T., & Edelman, S. (1990). A network that learns to recognize three-dimensional objects. *Nature*, 343, 263-266.
- Price, C. J., & Humphreys, G. W. (1989). The effects of surface detail on object categorization and naming. *The Quarterly Journal of Experimental Psychology A: Human Experimental Psychology*, 41(4), 797-827.
- Proffitt, D. R. (2006). Embodied perception and the economy of action. *Perspectives on Psychological Science*, 1(2), 110-122.
- Quiroga, R. Q., & Kreiman, G. (2010). Measuring Sparseness in the Brain: Comment on Bowers (2009). [Article]. *Psychological Review*, 117(1), 291-299.
- Quiroga, R. Q., Reddy, L., Kreiman, G., Koch, C., & Fried, I. (2005). Invariant visual representation by single neurons in the human brain. *Nature*, 435(7045), 1102-1107.

- Riddoch, M. J., Edwards, M. G., Humphreys, G. W., West, R., & Heafield, T. (1998). Visual affordances direct action: Neuropsychological evidence from manual interference. *Cognitive Neuropsychology*, *15*(6/7/8), 645-683.
- Riddoch, M. J., & Humphreys, G. W. (1987). Visual object processing in optic aphasia: A case of semantic access agnosia. *Cognitive Neuropsychology*, *4*(2), 131-185.
- Riddoch, M. J., & Humphreys, G. W. (2004). Object identification in simultanagnosia: When wholes are not the sum of their parts. *Cognitive Neuropsychology*, *21*(2-4), 423-441.
- Riddoch, M. J., Humphreys, G. W., & Price, C. J. (1989). Routes to action: Evidence from apraxia. *Cognitive Neuropsychology*, *6*(5), 437-454.
- Riesenhuber, M., & Poggio, T. (2000). Models of object recognition. *Nature Neuroscience*, *3*(Suppl), 1199-1204.
- Rizzolatti, G., & Craighero, L. (2004). The Mirror-Neuron System. *Annual Review of Neuroscience*, *27*, 169-192.
- Rosch, E. (1975). Cognitive representations of semantic categories. *Journal of Experimental Psychology: General*, *104*(3), 192-233.
- Rossion, B., & Pourtois, G. (2004). Revisiting Snodgrass and Vanderwart's object pictorial set: The role of surface detail in basic-level object recognition. *Perception*, *33*, 217-236.
- Rousselet, G. A., Macé, M. J. M., & Fabre-Thorpe, M. (2003). Is it an animal? Is it a human face? Fast processing in upright and inverted natural scenes. *Journal of Vision*, *3*(6), 440-455.

- Rumiati, R. I., & Humphreys, G. W. (1998). Recognition by action: Dissociating visual and semantic routes to action in normal observers. *Journal of Experimental Psychology: Human Perception and Performance*, 24(2), 631-647.
- Salmon, J. P., Matheson, H. E., & McMullen, P. A. (in revision). The influence of object manipulability on categorization and naming of backward-masked photographs shown for brief durations: A reversal effect for object manipulability. *Visual Cognition*.
- Salmon, J. P., McMullen, P. A., & Trappenberg, T. T. (2011). *Modeling mechanisms of reversed effects of manipulability on naming and categorizing objects*. Paper presented at the Cognitive Neuroscience Society (CNS), San Francisco, CA.
- Salmon, J. P., McMullen, P. A., & Filliter, J. H. (2010). Norms for two types of manipulability (graspability and functional usage), familiarity, and age of acquisition for 320 photographs of objects. *Behavior Research Methods*, 42(1), 82-95.
- Salmon, J. P., McMullen, P. A., & Matheson, H. E. (submitted). The influence of object manipulability on categorization and naming of backward-masked photographs shown for brief durations: A reversal effect for object manipulability. *Cognition*.
- Sanocki, T., Bowyer, K. W., Heath, M. D., & Sarkar, S. (1998). Are edges sufficient for object recognition? *Journal of Experimental Psychology: Human Perception and Performance*, 24(1), 340-349.
- Sergent, J., Ohta, S., & MacDonald, B. (1992). Functional neuroanatomy of face and object processing: a positron emission tomography study. *Brain*, 115, 15-36.

- Sirigu, A., Duhamel, J., & Poncet, M. (1991). The role of sensorimotor experience in object recognition. A case of multimodal agnosia. . *Brain*, *114*, 2555-2573.
- Smith, M. C., & Magee, L. E. (1980). Tracing the time course of picture–word processing. *Journal of Experimental Psychology: General*, *109*(4), 373-392.
- Snodgrass, J. G., & Vanderwart, M. (1980). A standardized set of 260 pictures: Norms for name agreement, image agreement, familiarity, and visual complexity. *Journal of Experimental Psychology: Human Learning and Memory*, *6*(2), 174-215.
- Spitzer, M., Kwong, K. K., Kennedy, W., & Rosen, B. R. (1995). Category-specific brain activation in fMRI during picture naming. *Neuroreport: An International Journal for the Rapid Communication of Research in Neuroscience*, *6*(16), 2109-2112.
- Spunt, R. P., Falk, E. B., & Lieberman, M. D. (2010). Dissociable neural systems support retrieval of how and why action knowledge. *Psychological Science*, *21*(11), 1593-1598.
- Tanaka, J. W., & Presnell, L. M. (1999). Color diagnosticity in object recognition. *Perception & Psychophysics*, *61*(6), 1140-1153.
- Tanaka, J. W., & Taylor, M. (1991). Object categories and expertise: Is the basic level in the eye of the beholder? *Cognitive Psychology*, *23*(3), 457-482.
- Tarr, M. J. (1995). Rotating objects to recognize them: A case study on the role of viewpoint dependency in the recognition of three-dimensional objects. *Psychonomic Bulletin & Review*, *2*(1), 55-82.
- Tarr, M. J., & Pinker, S. (1989). Mental rotation and orientation-dependence in shape recognition. *Cognitive Psychology*, *21*(2), 233-282.

- Therriault, D. J., Yaxley, R. H., & Zwaan, R. A. (2009). The role of color diagnosticity in object recognition and representation. *Cognitive Processing, 10*(4), 335-342.
- Thorpe, S. J. (2009). The speed of categorization in the human visual system. *Neuron (Previews), 62*, 168-170.
- Tranel, D., Logan, C. G., Frank, R. J., & Damasio, A. R. (1997). Explaining category-related effects in the retrieval of conceptual and lexical knowledge for concrete entities: Operationalization and analysis of factors. *Neuropsychologia, 35*(10), 1329-1339.
- Tucker, M., & Ellis, R. (1998). On the relations between seen objects and components of potential actions. *Journal of Experimental Psychology: Human Perception and Performance, 24*(3), 830-846.
- Tucker, M., & Ellis, R. (2001). The potentiation of grasp types during visual object categorization. *Visual Cognition, 8*(6), 769-800.
- Tucker, M., & Ellis, R. (2004). Action priming by briefly presented objects. *Acta Psychologica, 116*(2), 185-203.
- Turnbull, O. H., & Laws, K. R. (2000). Loss of stored knowledge of object structure: Implications for 'category-specific' deficits. *Cognitive Neuropsychology, 17*(4), 365-389.
- Uttl, B., Graf, P., & Siegenthaler, A. L. (2007). Influence of object size on baseline identification, priming, and explicit memory. *Scandinavian Journal of Psychology, 48*, 281-288.

- Vainio, L., Symes, E., Ellis, R., Tucker, M., & Ottoboni, G. (2008). On the relations between action planning, object identification, and motor representations of observed actions and objects. *Cognition*, *108*(2), 444-465.
- VanRullen, R., & Thorpe, S. J. (2001). Is it a bird? Is it a plane? Ultra-rapid visual categorisation of natural and artifactual objects. *Perception*, *30*(6), 655-668.
- Walsh, V., & Cowey, A. (2000). Transcranial magnetic stimulation and cognitive neuroscience. *Nature Reviews Neuroscience*, *1*(1), 73-79.
- Warrington, E. K., & McCarthy, R. (1983). Category specific access dysphasia. *Brain*, *106*(4), 859-878.
- Warrington, E. K., & McCarthy, R. (1987). Categories of knowledge: Further fractionations and an attempted integration. *Brain*, *110*(5), 1273-1296.
- Warrington, E. K., & Shallice, T. (1984). Category specific semantic impairments. *Brain*, *107*, 829-854.
- Westwood, D. A., & Goodale, M. A. (2011). Converging evidence for diverging pathways: Neuropsychology and psychophysics tell the same story. *Vision Research*, *51*(8), 804-811.
- Wilson, M. (2002). Six views of embodied cognition. *Psychonomic Bulletin & Review*, *9*(4), 625-636.
- Witt, J. K. (2011). Action's effect on perception. *Current Directions in Psychological Science*, *20*(3), 201-206.
- Witt, J. K., Kemmerer, D., Linkenauger, S. A., & Culham, J. (2010). A functional role for motor simulation in identifying tools. *Psychological Science*, *21*(9), 1215-1219.

- Witt, J. K., & Proffitt, D. R. (2005). See the ball, hit the ball: Apparent ball size is correlated with batting average. *Psychological Science, 16*(12), 937-938.
- Wolk, D. A., Coslett, H. B., & Glosser, G. (2005). The role of sensory-motor information in object recognition: Evidence from the category-specific visual agnosia. *Brain and Language, 94*, 131-146.
- Wühr, P., & Elsner, B. (2007). Effects of irrelevant stimulus orientation on visually guided grasping movements. *Behavioral Neuroscience, 121*(2), 301-309.
- Wurm, L. H., Legge, G. E., Isenberg, L. M., & Luebker, A. (1993). Color improves object recognition in normal and low vision. *Journal of Experimental Psychology: Human Perception and Performance, 19*(4), 899-911.
- Xu, Y. (2005). Revisiting the Role of the Fusiform Face Area in Visual Expertise. *Cerebral Cortex, 15*(8), 1234-1242.
- Yoon, E. Y., Heinke, D., & Humphreys, G. W. (2002). Modelling direct perceptual constraints on action selection: The Naming and Action Model (NAM). *Visual Cognition, 9*(4-5), 615-661.
- Yoon, E. Y., & Humphreys, G. W. (2007). Dissociative effects of viewpoint and semantic priming on action and semantic decisions: Evidence for dual routes to action from vision. *The Quarterly Journal of Experimental Psychology, 60*(4), 601-623.
- Zwann, R. A. (1999). Embodied cognition, perceptual symbols, and situation models. *Discourse Processes, 28*(1), 81-88.

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