THE INFLUENCE OF COLOUR ON THE SIZE-WEIGHT ILLUSION: REDEFINING EXPECTATION

by

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ABSTRACT

A size-weight illusion (SWI) occurs when a large object and small object of equal mass but different volume are lifted and the small object is perceived as heavier than the large object. All previous studies of the SWI used similar coloured objects and found that individuals initially use more force to lift the large object, compared to the small object but then use similar forces for the two objects on subsequent lifts. In contrast to the change in lifting forces over trials, the perceptual illusion stays consistent across all trials. The goal of the current study was to determine if introducing different colours for the SWI stimuli could alter participants' expectations about the masses of the two objects and therefore modify the perceptual SWI. Participants lifted SWI stimuli that were either identical in colour (2 yellow or 2 red objects) or stimuli where one object was yellow and the other red (large red and small yellow and vice versa). Perceptually a main effect of lift was found (F[14,952] = 29.0, P < .001): participants reported that both objects felt heavier on subsequent trials; a main effect of object was also found (F[1,68] = 144.6, P < .001): the small object was incorrectly perceived to be heavier than the large object; and a lift x object interaction was also revealed (F[14,952] = 9.8, P < .001): initially participants believed the two objects to be similar in mass and that the small object felt increasingly heavier than the large object as trials continued. Lifting force results revealed a group x object interaction for peak load force (F[1,45] = 4.12, P < .05) on the first trial, demonstrating that the same colour group initially used more force to lift the large object than the small object on the first trial whereas the different colour group used relatively the same amount of force to lift each object on the first trial. Following this trial each group used similar amounts of force to lift each block on all subsequent trials. A main effect of lift for both PGF (F[14,630] = 13.12, P < .001) and PGFR (F[14,630] = 4.54, P < .001) was found indicating that participants used less force to grip both objects over the course of the experiment, and a lift x group interaction (F[14,630] = 1.75, P < .05) was also found for PGFR where the same colour group demonstrated a much more marked decrease in PGFR after the first few trials compared to the different colour group. As well, analysis of the first trial for PGFR revealed a significant main effect of object (F[1,45] = 4.41, P < .05) indicating that both groups used more force to lift the large object than the small object and on all other trials used similar forces to lift both blocks. These results suggest that simply having 2 objects of different colour can indeed change participants' expectations about the masses of the objects in the SWI, but the perceptual illusion is unchanged. Implications concerning the SWI and effects of colour on a SWI, internal models, the density model, and grip and load force coupling, are also discussed.

List of Abbreviations Used

LPD	Load Phase Duration
RedS	Red Small (signifying stimuli where red object small and yellow large)
SWI	Size-Weight Illusion
PLF	Peak Load Force
PLFR	Peak Load Force Rate
PGF	Peak Grip Force
PGFR	Peak Grip Force Rate
PLFR	Peak Load Force Rate
YellowS	Yellow Small (signifying stimuli where yellow small and red large)

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CHAPTER 1: INTRODUCTION

Humans are fortunate enough to have appendages capable of fine motor movements, and also fortunate to be able to control these fine motor movements. Take for example the process of lifting an object off of a table. When an individual lifts an object, the following series of phases occurs: an individual will first approach the object to lift it. Once the object is approached, the first phase of the lift is the preload phase where the individual first establishes a grip on the object. The next phase is the loading phase where the individual applies sufficient force for the object to come off the table. Next is the transitional phase where the object is lifted in the air followed by the static phase where the object is held at the top of the lift. The replacement and unloading phases then occur as the individual lowers the object and then removes his or her fingers from it (Johansson & Westling, 1988a; Johansson & Westling, 1988b). During the preload phase an individual grips the object, thus increasing the grip force on the object while the force used to lift the object (load force) remains unchanged. During the load phase the grip and load forces increase in parallel until the load force surpasses the weight of the object and it comes off the table and then the forces reach peak values during the transition phase. During the static phase at the top of the lift both the grip and load forces remain constant and then both forces decline in parallel during the replacement phase and stop when the object is released during the unloading phase (Johansson & Westling, 1988a; Johansson & Westling, 1988b).

In order to perform a lifting movement using a precision grip (i.e., gripping an object between the thumb and index finger), one of two possible scenarios could occur. The motor system could initially use little force and gradually increase the force using feedback from the muscles until enough force was applied to lift the object (causing the load phase to be a very lengthy process). Alternatively, the motor system could use visual cues such as size, shape and material to make an estimation of the object's mass and then correct any mismatches between the force used and force necessary using feedback (causing the loading phase to be considerably faster than if the whole action was executed using reflexive feedback) (Flanagan, King, Wolpert, & Johansson, 2001) or the motor system could recognize the object from past experience (Gordon, Westling, Cole, & Johansson, 1993).

Past research has demonstrated that the second scenario is the more likely of the two for describing how lifting movements are performed. When an individual is presented with a novel object, he or she will use either visual size cues when allowed to view the object (Gordon, Forssberg, Johansson, & Westling, 1991c) or haptic size cues when blindfolded (Gordon, Forssberg, Johansson, & Westling, 1991a) in order to generate an estimation of the mass of the objects. This conclusion was reached because participants will always (and often erroneously in experimental procedures) initially scale lifting forces to the size of the objects, using more force to lift larger objects than smaller objects and then performing the necessary corrections using sensory feedback (Gordon et al., 1993). More evidence supporting that individuals anticipate the mass of objects before lifting is provided by the phenomenon that occurs when individuals lift objects they are already familiar with. Gordon et al. (1993) found that when individuals lift familiar objects, they use a similar amount of force to lift the objects on each trial, indicating that the motor system has an accurate estimation of the object's mass due to previous experience with the object.

Skillful object interactions are likely due to internal models used by the motor system. An internal model is a system that mimics the inputs (sensory information) or outputs (motor program) of the motor system (Jordan & Rumelhart, 1992; Kawato, 1999; Miall & Wolpert, 1996; Wolpert, Ghahramani, & Jordan, 1995; Wolpert, Miall, & Kawato, 1998). There are two types of internal models; forward models and inverse models. Forward models use the "forward" relation between one's actions and consequences to anticipate the sensory consequences of a given action and inverse models estimate the output (motor program) necessary to produce a particular movement (Jakobson & Goodale, 1991; Jordan & Rumelhart, 1992; Miall & Wolpert, 1996). If there is an error made such that too much or too little force is used to lift an object, or if the mass of an object is different than expected, there will be a discrepancy between the actual consequences and predicted sensory consequences from the forward model. Based on these sensory errors, the motor program will be revised on-line (as the lift is occuring) to correct for these sensory errors until there is no discrepancy between the actual and estimated feedback (Jordan & Rumelhart, 1992). Even though the motor system is capable of correcting these mismatches between actual and predicted sensory consequences, a very interesting perceptual illusion can emerge when these mismatches occur.

A size-weight illusion (SWI) occurs when an individual lifts two objects of equal mass and different volume. Under all circumstances measured to date, people perceive the small object as being heavier than the large object. First discovered by Charpentier in 1881 when he had participants lift 2 spheres of equal mass and varying density (thus one was larger than the other) (Murray, Ellis, & Bandomir, 1999), this illusion has been replicated hundreds of times, yet the mechanisms behind why this illusion occurs still elude researchers today. One of the leading hypotheses for the mechanism of the SWI is the expectation model which suggests that due to density constancy (i.e. most objects in the world have a similar density of approximately 1kg/L (Ellis & Lederman, 1993)), over the course of an individual's life he or she will learn to associate large objects as being heavy and small objects as being light (Davis & Roberts, 1976; Koseleff, 1957; Ross, 1966; Ross, 1969). According to this model, the SWI occurs due to an individual's initial expectation that a large object will be heavier than a small object of apparently similar material composition. When this individual programs the lifting forces to interact with the objects, he or she will use more force to lift the large object compared to the small object, causing the large object to accelerate more quickly than the small object and generating an illusion that the large object is light and the small object is heavy. This misperception of object weight occurs because the expectation that the large object is heavy and small object is light is not satisfied by the actual sensory feedback, therefore individuals pay attention to their error and let it dominate their perceptual judgments. (Davis & Roberts, 1976; Grandy & Westwood, 2006; Koseleff, 1957; Ross, 1966; Ross, 1969; Westwood & Goodale, 2003; Woodworth, 1921).

There has been much evidence supporting the expectation model. Many studies have shown that participants do use more force to lift the large object compared to the small object by examining 4 common lifting parameters: peak load force (PLF), peak load force rate (PLFR), peak grip force (PGF) and peak grip force rate (PGFR). Even though the objects are identical in mass, participants will use much higher forces and rates of force to lift the large object than the small object on the first trial before sensory feedback corrects the mismatch on all subsequent trials (Davis & Roberts, 1976; Flanagan & Beltzner, 2000; Flanagan et al., 2001; Grandy & Westwood, 2006). Flanagan, Bittner, and Johansson (2008) have demonstrated that when varying size-weight correspondences though extensive practice, the way the illusion is perceived changes and an individual's expectation of object weight also changes. When an individual repeatedly lifts a series of practice objects (1050 lifts) where the normal relationship between size and weight is inverted such that small objects are heavier than large objects, they are capable of learning and retaining an inverse relationship that small objects are heavy and large objects are light (Flanagan et al., 2008). When these individuals are given SWI stimuli (small object more dense than the large object) that match the outward appearance of the practice objects, they experience an inverse SWI such that the large object is perceived as being heavy and the small object is perceived as being light. To gauge perception, participants could use any number, including fractions and decimal points, to describe the mass of the objects and were not given any range restrictions This demonstrates that after repeated lifting with practice stimuli, participants change their expectation of object weight (for objects of identical outward appearance to the practice objects) so that they expect that small objects will be heavy and large objects will be light. Therefore, according to Flanagan et al. (2008), the expectation model is the leading hypothesis for the mechanisms behind the SWI because just changing an individual's expectation of object weight can alter the perception of object weight.

In spite of the research supporting the expectation model, it cannot account for all observations because there are several phenomena that the expectation model cannot account for. For example, when an individual repeatedly lifts SWI stimuli, he or she will correct the initial force mismatches on subsequent lifts, but will still perceive a SWI equal in intensity to the initial illusion for the duration of the trials (Flanagan & Beltzner, 2000; Flanagan et al., 2001). This is true for SWI that are equal in mass (Flanagan & Beltzner, 2000) or for stimuli where the large object is slightly more massive than the small object (Grandy & Westwood, 2006). If the current expectation model was correct (and the SWI was caused by the erroneous expectation that a large object would be heavier than a small object of identical outward appearance), after an individual uses more force to lift the large object compared to the small object he or she will use a similar amount of force to lift each block on subsequent trials (Flanagan & Beltzner, 2000; Flanagan et al., 2001). This is due to the corrections made by the internal models from the sensory feedback. Once this mismatch between actual and predicted sensory consequences vanishes, the perceptual SWI should also vanish, as the individual would no longer expect the large object to be heavy and the small object to be light; rather, with subsequent lifts the large object should feel heavier and the small object should feel lighter until they feel approximately the same. Past research has demonstrated that if no mismatch exists (i.e. participants are not allowed to view the objects and lift them via a string) participants will judge both objects as being equal in mass (Ellis & Lederman, 1993; Murray, et al., 1999). Following this, if participants are then allowed to view the objects, the size-weight illusion emerges (Ellis & Lederman, 1993). As well, research on the expectation model has only been performed with objects that do not suggest different material properties or different densities (both objects being made out of wood, plastic, metal, having the same colour, etc.) when it is possible that objects of different outward appearance may change the way the SWI stimuli are perceived and manipulated. The change may occur because if the objects have different outward appearances, then the individual may not assume that the objects have equal densities and may not treat the large object as being heavy and small object as being light on the first trial as normally occurs when the objects are identical in outward appearance. As surface features provide a clue to what the object is made of and how heavy it is (Gordon, Forssberg, Johansson, & Westling, 1991b; Gordon, Forssberg, Johansson, & Westling, 1991c), one way to ensure that the objects have different surface features is to have the objects different colours.

Colour itself is capable of changing the way one perceives the weight of an object. When an individual is allowed to view objects of the same size but different colours, he or she will state that darker objects appear heavier than lighter objects as darker colours appear more dense than lighter colours (Payne, 1958; Pinkerton & Humphrey, 1974). When allowed to lift objects of the same size and mass but different colour, the reverse occurs; individuals will state that objects of lighter colour feel heavier than objects of darker colour (DeCamp, 1917; Taylor, 1930). These findings support an expectation model of weight perception; people expect darker objects to be heavier than lighter objects much like they expect large objects to be heavier than small objects. How these objects would be manipulated is analogous to the expectation provided for large and small objects; dark coloured objects appear heavier than lighter coloured objects, therefore when faced with two objects of equal size and mass, an individual expects the dark object to be heavier than the light object and will erroneously use more force to lift the dark object than the light object, creating the illusion that the light object is heavier than the dark object.

As well, surface features such as colour can affect how an individual interacts with objects as he or she can learn to associate the mass of an object with an arbitrary colour such that they know what the mass of the object will be based on the colour of a cue presented before the object is lifted. Chouinard, Leonard, and Paus (2005) found that when individuals are given a colour cue on a computer screen before lifting an object (where an object of 325g is given a pink colour cue and an object of 525g is given a blue colour cue) and given 21 lifts with each object to learn to associate the colour cue with the masses of the objects, he or she will use the correct lifting forces to lift either the light or heavy object when instructed to lift the objects without any type of incapacitation or if the primary motor cortex has experienced a virtual lesion via rTMS. This demonstrates that the motor system is capable of associating mass with colour and therefore when given SWI stimuli that are different colours, the motor system may act on them differently than if they are identical in outward appearance.

Preliminary research by White and Westwood (2009), like Chouinard et al. (2005), demonstrated that individuals are able to associate colour with some property of the object; Chouinard et al. (2005) associated colour with mass whereas White and Westwood (2009)'s pilot study associated colour with density. In their study, there were 3 groups; 2 experimental groups and 1 control group. The experimental groups were each given a series of practice objects first. This was a set of 6 objects where 3 of them had a density of $0.25g/cm^3$ and the other three had a density of $0.5g/cm^3$. The more dense objects were one colour and the less dense objects were another colour. One experimental group had objects that were matched for volume (and therefore the more dense objects were more massive) and the other had objects that were matched for mass (and therefore the more dense objects were smaller). After 10 lifts with each object (60 total lifts) they were then exposed to SWI stimuli that shared the colour density relationship as the practice objects and lifted them 15 times each alternating between the small and large object (White & Westwood, 2009). The control group received the SWI stimuli that the experimental groups used but had no prior practice with the practice objects and were not told that colour signified the relative densities of the objects (one colour was more dense than the other). As with the experimental groups, they lifted each object 15 times each, alternating between the small and large object. White and Westwood (2009)'s pilot study found that each of the experimental groups consistently used more force to lift the large object than the small object, yet consistently perceived the small object as being heavier than the large object. This demonstrates a complete mismatch between how an individual perceives and acts on objects which not only provides support for (Milner & Goodale, 1995)'s theory that perception and action are distinct, but also demonstrates a phenomenon that has never before been seen in size-weight illusion research. Typically individuals lift objects that are identical in outward appearance (other than size) and initially use more force to lift the large object compared to the small object and then respond to this error by using similar forces for the two objects on subsequent lifts. The individuals in White and Westwood (2009)'s pilot study lifted the different coloured objects after the practice trials and consistently used more force to lift the large object compared to the small object and therefore did not correct the forces on subsequent lifts. Also interesting, the control group that only interacted with size-weight illusion stimuli of different outward appearance (for example a small object that was yellow and a large object that was red) also consistently used more force to lift the large object than the small object yet perceived the small object as heavier than the large object. The experimental procedure in the control group was identical to the procedure used by (Flanagan et al., 2001), with the only difference being the outward appearance of the objects lifted; Flanagan et al. (2001) used objects of identical material properties whereas the pilot study by White and Westwood (2009) used objects of different material properties This suggests that when the size-weight illusion stimuli are different colours, the participants interact with the stimuli in different ways than if they were identical in colour.

The current expectation model states that individuals perceive the large object as being light and the small object as being heavy due to the erroneous assumption that the large object is going to be heavy and small object is going to be light. He or she is surprised when the small object is heavier than expected and the large object is lighter than expected (Ross, 1966; Ross, 1969). The results of White and Westwood (2009)'s pilot study support this view because participants consistently used more force to lift the large object compared to the small object, yet consistently perceived the small object as being heavier than the large object. However, the results of White and Westwood (2009)'s pilot study do not replicate those found in past research. After the first lift participants should have expected the small object to be heavier and the large object to be lighter and programmed their forces accordingly until they used the same amount of force to lift each object as has been found in previous studies (Flanagan & Beltzner, 2000; Flanagan et al., 2001). White and Westwood (2009)'s pilot study results suggest that when the objects have different material properties, the perceptual and motor system generate separate expectations as participants' motor system expected the large object to be heavier than the small object, yet the perceptual system expected the small object to be heavier than the large object.

It would appear that the result found in past research is only true when the SWI stimuli are similar in outward appearance, which suggests similar material properties such as density. Therefore the goal of this study was to determine whether the colour per se of the SWI stimuli (and therefore not the specific effects of colour but rather just the fact that the objects are not identical in outward appearance), in absence of any association with density or mass, is responsible for creating the separate motor and perceptual expectations demonstrated by White and Westwood (2009)'s pilot study. To do this, there were two groups of participants: one that interacted with SWI stimuli that were identical in colour (and thus replicating past research as all previous studies have used objects that are identical in colour) and one that interacted with SWI stimuli that were different in colour. For the perception of heaviness the hypothesis was that participants in the different colour group and participants in the same colour group would both perceive a similar, persistent size weight illusion (i.e., they will perceive the small object as being heavier than the large object) for the duration of the experiment because

White and Westwood (2009)'s pilot study and all past research has demonstrated that the strength of the perceptual size-weight illusion does not change over the course of an experiment regardless of whether the objects are different colours. For the motor system the hypothesis was that individuals in the same colour group will replicate the results found by Flanagan and Beltzner (2000); they will initially generate too much force to lift the large object compared to the force used to lift the small object and then begin to use similar lifting forces on subsequent trials. This would demonstrate that one model is used for both objects when the objects are identical in material properties the different colour group will replicate the results found by White and Westwood (2009)'s pilot study; they will always use more force to lift the large object than the small object for the duration of the experiment. This would demonstrate that a different model is used for each colour and that colours are not integrated with each other.

Chapter 2: Review of the Literature

The goal of this literature review is to provide a rationale for the current study by examining past research on the subject of human interactions with objects and the size-weight illusion. First, this literature review will describe how forces are employed to lift objects as well as how these forces are coupled. Secondly, the internal models responsible for the employment and coupling of forces are discussed. Thirdly, the size-weight illusion is discussed. This illusion is a byproduct of errors produced by internal models. Next, the most prominent theory as to why the size-weight illusion occurs, the expectation model is discussed. Following this discussion, the effects of colour on lifting forces and weight perception are examined along with new discoveries about how colour may affect a size-weight illusion paradigm. Finally, a rationale is provided for the current study.

2.1 Grip Force and Load Force Coupling

When an object is held stationary in a precision grip, the grip force used to maintain the grip is dependent on the weight of the object and the frictional force between the pads of the fingers and the gripping surface (Eliasson et al., 1995; Johansson, 1984; Johansson & Westling, 1987; Johansson & Westling, 1988a; Johansson & Westling, 1988b; Nowak et al., 2001). The grip force is economically employed such that it is slightly higher than the minimum force necessary to prevent the slipping of the object (Johansson, 1984; Nowak et al., 2001) and changes in parallel with the force required to lift the object (load force) (Forssberg et al., 1992; Johansson, 1984; Johansson & Westling, 1987; Johansson, Hager, & Backstrom, 1992; Johansson, Hager, & Riso, 1992; Westling & Johansson, 1984). During development, grip force increases before load force in children under two years of age, and this force is much greater than the minimum safety margin (Forssberg et al., 1992); this occurs because at this point in life the motor system is not mature enough to allow for coupling. Loose coupling is observed as children reach two years of age and it takes about 10 years before grip and load force coupling is fully developed (Eliasson et al., 1995; Forssberg et al., 1992). Clearly the motor system learns very early in life that grip force is to be coupled with load force.

Grip and load force coupling appears to be a universal strategy for lifting and maintaining grip. Coupling between grip and load forces has been discovered in vertical and horizontal point to point movements and vertical and horizontal cyclic movements at various speeds and with various surface textures. When individuals repeatedly move an object upward or downward in either a point to point movement or an oscillating motion, grip force and load force maxima occur at the same time (Flanagan & Wing, 1993; Flanagan & Wing, 1995). Grip force increases as the speed of the movement increases and as the surface texture of the object becomes more slippery, but is still modulated with load force (Flanagan & Wing, 1993; Flanagan & Wing, 1995). As well, it would appear that the grip and load force coupling is not dependent on the type of grip used as coupling has been observed with a variety of different grips and inverse grips (Flanagan & Tresilian, 1994).

Grip and Load forces help to explain the motor component of weight perception. When lifting an object, one must either base the lifting forces on a past experience with the object (Forssberg et al., 1992; Gordon et al., 1993; Johansson, Hager, & Backstrom, 1992; Nowak et al., 2001; Schmitz, Jenmalm, Ehrsson, & Forssberg, 2005), or on an estimate of the object's mass based on the size of the object (Gordon, Forssberg, Johansson, & Westling, 1991a; Gordon, Forssberg, Johansson, & Westling, 1991c; Kawai, Summers, MacKenzie, Ivens, & Yamamoto, 2002; Kingma, Van Dieen, & Toussaint, 2005; Mon-Williams & Murray, 2000). When individuals lift objects that they are familiar with, they are able to accurately reproduce the force necessary to lift the object from the very first lift, and are able to take into account object characteristics such as fragility when lifting the objects (Gordon et al., 1993). When lifting new objects, one does not have prior information about the objects and will scale his or her initial forces based on the size of the object. This occurs when individuals are allowed to view the objects prior to lifting (Gordon, Forssberg, Johansson, & Westling, 1991c; Mon-Williams & Murray, 2000), and when they are blindfolded and allowed to run their hands over the object (Gordon, Forssberg, Johansson, & Westling, 1991a).

Estimating weight based on object size is usually a useful strategy for generating lifting forces. If an error occurs, it is quickly corrected from somatosensory feedback once the individual tries to lift the object and either initially fails, or uses too much force to lift the object (Gordon, Forssberg, Johansson, & Westling, 1991b; Gordon et al., 1993; Kingma, Savelsbergh, & Toussaint, 1999; Kingma et al., 2005; Mon-Williams & Murray, 2000). Somatosensory feedback is also used to correct lifting forces when the mass of familiar objects is unexpectedly changed (Gordon et al., 1993; Johansson & Westling, 1988a; Johansson & Westling, 1988b). When an individual is presented with an object which they have lifted previously, they will generate lifting forces that they have used in the past to lift the object as past experience has taught them how much force to use. When the mass of the object is unexpectedly changed, the individual uses somatosensory feedback to correct the lifting forces and will use the corrected lifting forces on all subsequent lifts with the objects until the weight is unexpectedly changed again (Gordon et al., 1993; Johansson & Westling, 1988a; Johansson & Westling, 1988b).

Clearly, grip and load forces are coupled such that grip force increases in parallel, and in phase with load force, and this appears to be a universal transporting mechanism. When interacting with objects that individuals normally handle, he or she is able to accurately predict the grip and load force necessary to lift them without recent prior proprioceptive information from the object (Morioka, Matsuo, & Yagi, 2006). With new objects one can use cues such as size and colour to predict the necessary lifting force, but these cues can be incorrect causing muscles to produce too much or too little force to lift an object (Blakemore, Goodbody, & Wolpert, 1988; Diedrichsen, Verstynen, Hon, Lehman, & Ivry, 2003). This error is corrected on subsequent lifts and the corrections are long lasting (Flanagan et al., 2001; Morioka et al., 2006). The abilities to modulate grip force in parallel with load force, to accurately predict forces for familiar objects and to quickly correct errors with somatosensory feedback exist due to internal models.

2.2 Internal Models

An internal model is a system that mimics the input/output, or their inverses, of the motor system (Jordan & Rumelhart, 1992; Kawato, 1999; Miall & Wolpert, 1996; Nowak, Glasauer, & Hermsdorfer, 2004; Wolpert et al., 1995; Wolpert & Kawato, 1998). There are two different types of internal models, a forward model which uses the causal (or forward) relation between an action and its consequence to estimate the sensory feedback one will feel when a movement is performed, and an inverse model which estimates the motor command necessary to cause a particular movement (Jakobson & Goodale, 1991; Jordan & Rumelhart, 1992; Kawato, 1999; Miall & Wolpert, 1996). The forward model uses the current state of the system (limb position/velocity) and a copy of the motor command (efference copy) to estimate the next state of the system when the motor command has been completed whereas the inverse model uses the current and desired state of the system to generate an estimate of the motor command which would cause the system to shift from the current state to the desired state (Miall & Wolpert, 1996). These models are believed to be located in the cerebellum (Blakemore, Frith, & Wolpert, 2001; Blakemore & Sirigu, 2003; Kawato, 1999; Wolpert & Kawato, 1998) .

There is currently a debate over how the internal models function in motor control. Some believe that there is only one forward and inverse model per action type that is continuously updated using feedback. For example, before an object is lifted, the sensory feedback about the weight of the object is predicted based on the forward model. This prediction is then compared to the actual sensory feedback obtained while lifting the object. If the appropriate motor command has been generated, the expected sensory feedback will match the actual sensory feedback and the movement will be completed successfully; however, if there is a mismatch between expected and actual sensory feedback, then an error has occurred (Morioka et al., 2006; Nowak et al., 2004). If an error between expected and actual sensory consequences occurs, the forward model transforms these errors into corresponding errors in the motor command with help from the inverse model. These errors are then used to update the internal models so that the errors are not repeated (Nowak et al., 2004; Wolpert et al., 1995; Wolpert & Flanagan, 2001).

Others believe that there are multiple forward and inverse models such that when an object is lifted, multiple forward models operate to predict the behavior of the motor system when interacting with different previously learned objects. Each forward model is paired with an inverse model and generates a prediction of sensory consequences. If the prediction of one of the forward models matches the actual sensory feedback, its paired inverse model is used to determine future motor commands with this object. This system is called the MOSAIC model (Modular Selection and Identification for Control) and uses probability to determine which forward/inverse model pairing best suits an object; if the error is small then there is a high probability that the forward/inverse pairing used was appropriate (Wolpert & Kawato, 1998; Wolpert & Flanagan, 2001).

Currently it is not possible to determine which of these two theories for the function of internal models better describes anticipatory behavior. The important point to glean from the different views is that regardless of the explanation, simultaneous grip force/load force coupling for familiar objects (Flanagan & Wing, 1997; Nowak et al., 2004), and the corrected grip force lag that occurs for new objects (Nowak et al., 2004) are a result of internal models. The models provide the motor system with the capacity to predict the mass of objects before they are lifted, and to correct the forces used when the actual mass of the object differs from the predicted mass. Although the motor system is capable of fixing errors through the use of internal models, the perceptual system is not always able to follow suit. The size-weight illusion is a perfect example of such a phenomenon.

2.3 Size-Weight Illusion

The observation that objects of equal mass and different size could have different perceived weights was not discovered until 1881 when Charpentier discovered that when participants lifted 2 spheres with equal mass and varying densities (thus one object was larger than the other), the smaller of the two spheres was judged to be heavier (Murray et al., 1999) when participants were required to provide a relative (for example, a 1-10 rating scale with 1 being light and 10 being heavy) judgment of object weight. Charpentier also found that this illusion vanished if both haptic and visual information was denied to participants. By having participants lift the objects by strings and having them blindfolded, visual and haptic feedback was not possible and the illusion disappeared; however, the illusion reappeared if the blindfold was removed or if participants were allowed to pick up the spheres with their hands (Murray et al., 1999). This illustrates that either a visual or a haptic cue about the size of the object is necessary for the illusion to occur. Without any cue about the size of the objects the only discriminating factor between the two objects lifted would be their mass, but as the masses are equal the participants do not notice a difference between the two objects.

These results have been replicated in numerous studies (Ellis & Lederman, 1993; Ross, 1969; Scripture, 1897; Wolfe, 1898; Woodworth, 1921); for example).

The size-weight illusion is one of the most robust illusions as it persists even when participants are told that the size-weight illusion stimuli have the same mass before actually seeing or lifting the objects (Davis & Roberts, 1976; Ellis & Lederman, 1993; Flournoy, 1894; Harshfield & DeHardt, 1970; Jones & Hunter, 1983; Koseleff, 1957) and the illusion does not diminish in strength with repeated lifting (Flanagan & Beltzner, 2000; Grandy & Westwood, 2006) or when one is given the opportunity to learn a relationship between the colour of an object and its density (White & Westwood, 2009). The illusion also occurs in congenitally blind individuals as they report the small object being heavier than the large object when asked to provide a relative judgment of object weight during testing (Ellis & Lederman, 1993). This supports the research performed by Gordon et al. (1991a) as haptic input alone can cause anticipatory grip force production; however, with the size-weight illusion this input causes an incorrect scaling of forces based on object size. Research on children indicates that the illusion is present from two years of age and increases in intensity with age until adulthood, where it decreases in intensity slightly (Robinson, 1964). This suggests that as infants have not yet learned to associate a relationship between an object's size and its weight, they are unable to experience a size-weight illusion. As development occurs and these relationships develop, the size-weight illusion also emerges which is important for the expectation model of the size-weight illusion (discussed subsequently).

As discussed earlier, visual cues can affect the anticipatory scaling of forces, either to correctly scale the lifting forces based on familiar objects (Gordon et al., 1993) or to scale lifting forces based on the size of the object to be lifted (which can sometimes be correct and sometimes lead to error) (Gordon, Forssberg, Johansson, & Westling, 1991c). Therefore it should not be surprising that the intensity of the size-weight illusion can be affected solely by visual cues in absence of haptic cues. Studies have shown that there are many ways to visually alter the objects to induce a size-weight illusion. Having participants lift the same object via a string while wearing convex and concave lenses can cause a size-weight illusion as the lenses affect how big the participants perceive the object to be; when the object is believed to be smaller it is considered to be heavier and when it is believed to be larger it is considered to be lighter even though it is the same object being lifted (Koseleff, 1957). Color can also have an effect on weight perception as objects of lighter colors tend to be perceived as less heavy than objects of darker colors when allowed to view the objects (DeCamp, 1917; Payne, 1958; Payne, 1961). As colour effects may play a significant role in the size-weight illusion, it will be discussed in greater detail later.

The size-weight illusion can also be created with haptic cues in absence of visual cues (Ellis & Lederman, 1993; Masin & Crestoni, 1988; Pick & Pick, 1967). As described by (Gordon, Forssberg, Johansson, & Westling, 1991a), and (Ellis & Lederman, 1993), individuals are capable of anticipating object weight based solely on feeling the objects with their fingers. From this haptic exploration, one can discern the size of the object and then make an approximation of weight based on size. When the illusion is produced haptically, there are many factors taken into account. Pressure can play a role in perception of weight because heavier objects put more pressure on receptors than lighter objects (Brodie & Ross, 1984; Brodie & Ross, 1985; Ross, 1966; Sekuler, Hartings, & Bauer, 1974); however, more dense objects also cause more pressure on receptors than less dense objects. The size-weight illusion can be induced by changing the weight to grip aperture ratio between two objects. As it is possible to create the perception that an object with a mass of 55g and an object with a mass of 150g have the same mass by manipulating this ratio (Kawai, 2003a; Kawai, 2003b), it would also be possible to create the perception that objects with equal mass have different masses.

As well, surface texture is an important haptic characteristic for the perception of weight as the surface texture affects how much friction there is to aid the grip (Cadoret & Smith, 1996). Research has demonstrated that more force is needed to maintain grip on heavy objects and slippery objects (Flanagan & Wing, 1995; Johansson & Westling, 1988a), and that participants are not able to completely distinguish normal forces used during grip from the frictional force needed to maintain the grip on the object (Flanagan & Wing, 1995). Therefore, two objects of equal mass and size could be perceived as having different masses if one object has a more slippery surface texture than the other. The amount of force used to grip the object can also have a large effect on the perception of the size-weight illusion. If one is told to purposely grip the objects as hard as they can, the strength of the size-weight illusion can be diminished or completely eliminated if he or she is not allowed to view the objects while grasping (Ellis & Lederman, 1993).

Clearly there are many different cues, both visual and haptic that can cause a size-weight illusion to occur. Either visual, haptic, or a combination of both visual and haptic cues can produce this illusion. There have been many different models used to explain the mechanisms for the size-weight illusion, each with its own merits and faults. Mathematical models that used power functions to explain the ratio between an object's size and its perceived weight (Anderson, 1970; Birnbaum & Veit, 1974), density models (Ross, 1969; Ross & DiLollo, 1970) that state that density is the most salient feature for the perception of object weight and therefore more dense objects are considered to be more heavy, inertia tensor models (Amazeen & Turvey, 1996; Greer, 1989) that state that the object's moment of inertia is the most salient feature for the perception of weight, and expectation models (Ross & Gregory, 1970; Stevens & Cain, 1970) which state that it is a learned relationship between size and mass such that large objects are expected to be heavier than small objects that causes the illusion to occur when the expectations are incorrect. Today, the expectation model has emerged as the leading explanation for the size-weight illusion.

2.4 The Expectation Model

As discussed above, the expectation model suggests that through the interaction with objects over the course of one's life, one comes to associate large objects as being heavy and smaller objects as being light because most objects in the world have similar densities (density constancy); therefore, when one lifts two objects of different volume but equal mass, at first he or she overestimates the weight of the larger object compared to the smaller object. The individual uses more force when lifting the larger object compared to the small object, causing it to accelerate more quickly than the small object and creates an illusion that the large object is light and the small object is heavy. This occurs because individuals pay attention to the error between expected and actual sensory consequences (Davis & Roberts, 1976; Grandy & Westwood, 2006; Koseleff, 1957; Ross, 1966; Ross, 1969; Westwood & Goodale, 2003; Woodworth, 1921).

According to the expectation model, the size-weight illusion occurs due to an initial mismatch between expected and actual sensory feedback concerning object weight (Davis & Roberts, 1976; Flanagan & Beltzner, 2000; Grandy & Westwood, 2006). Participants generate inaccurate forces on the first trial of a lifting task when a size-weight illusion is presented, which illustrates that they made an estimation of the weight of the objects based on past experience. Participants use smaller forces and force rates to lift smaller objects and larger forces and force rates to lift larger objects initially, which support the expectation models (Davis & Roberts, 1976; Grandy & Westwood, 2006). Further support for the expectation model has been provided by Flanagan, Bittner, and Johansson (2008). When one repeatedly lifts a series of practice objects where the normal relationship between size and weight is inverted (as objects became smaller, they also became more heavy) in a continuous manner, he or she is capable of learning and retaining the inverse relationship that small objects are heavy and large objects are light (Flanagan et al., 2008). When these individuals are given traditional SWI stimuli (a large and small object of equal mass) they experience an inverse size-weight illusion (the large object is perceived as being heavier and the small object is perceived as being lighter when participants are asked to provide relative weight judgments). Flanagan et al. (2008) believe that after repeated lifting with the practice stimuli, participants are able to change their expectation so that they believe that small objects are be heavier than large objects. Therefore, the expectation model better explains the size weight illusion because the perception of object weight can be altered just by changing an individual's expectation of the weights of the objects (Flanagan et al., 2008). Flanagan et al. (2008) only examined perceptual reports during this experiment; it would have been beneficial to determine if participants also correct their lifting forces over repeated lifting or if the repeated lifting changed participants' perception of the illusion as they were first taught an unnatural relationship to begin with and the illusion may diminish in strength or disappear, or return to the normal illusion with repeated lifting.

There is an issue with the expectation model as it cannot explain how with repeated lifting one will fix the initial lifting force mismatch (so that they use the proper force to lift the two objects), but will still experience the illusion that the small object is heavier than the large object. This occurs when the two objects have the same mass

(Flanagan & Beltzner, 2000) or when the large object is actually more massive than the small object (Grandy & Westwood, 2006); participants will correctly scale forces to the true weights of the objects, but will perceive a size-weight illusion that does not diminish in strength over repeated lifting (Flanagan & Beltzner, 2000; Grandy & Westwood, 2006). Both Flanagan & Beltzner (2000) and Grandy and Westwood (2006) suggest that if the expectation model was correct, when there was no longer a mismatch in forces applied and developed between the large and small objects, the perceptual size-weight illusion should also disappear because the participants are no longer expecting one object to be heavier than the other. One issue with this view is that vision for perception and vision for action are distinct and anatomically separate (Milner & Goodale, 2006) and one can also use haptic information for perception differently than haptic information for action (Westwood & Goodale, 2003). Therefore it is possible that the motor system is capable of fixing the mismatch while the perceptual system is unable to fix the perception that the small object is heavier than the larger object and that the expectation model holds true for the perceptual size-weight illusion.

The expectation of object weight based on visual and haptic cues has been well documented. As discussed earlier, when objects are familiar, one can produce the correct lifting forces without error from the first lift (Gordon et al., 1993); the object has the expected mass and is lifted with the forces needed to lift this mass. This expectation is further supported by the fact that when a familiar object suddenly and unknowingly changes mass, the lifting forces for a prior lift are used in error because one expects the object to be the same mass as it was the first time (Gordon et al., 1993). The role of expectation in lifting is critical and usually provides appropriate lifting forces unless an individual is tricked under experimental conditions. What has not been as well documented is the role that colour plays in the perception of the size-weight illusion. It is possible that colour may change how objects are lifted and how their weight is perceived.

2.5 Colour & Weight Perception

Although there has been over one hundred years of research on the SWI, there have not been any published studies performed in which the colour of the SWI stimuli were different. This could have potential effects on perceptual reports and lifting dynamics. When individuals view objects of the same size but different colours, they tend to state that objects appear lighter as the colour becomes lighter. (Warden & Flynn, 1926) discovered that when participants are allowed to view several cardboard boxes of the same size and different colour at the same time, they believe that boxes get progressively heavier as the colours change from white to grey to black. When allowed to view objects individually (so that the colour of surrounding objects cannot influence the weight judgment), individuals will state that there is no difference in weight between yellow, green, and grey objects and no difference between blue, red and purple objects (Payne, 1961). Participants will report however that yellow, green, and grey objects are significantly lighter than objects that are blue, red, or purple (Payne, 1961).It would also appear that the size of the object does not matter in weight judgments of objects that are different colours as long as the objects being compared are the same size. Objects of the same size but different colour vary significantly in their perceived heaviness; darker objects tend to appear heavier than lighter objects (Payne, 1958; Pinkerton & Humphrey, 1974). Clearly then, along with cues such as size and shape, colour is capable of providing a cue of object weight that helps an individual's perception of weight.

While this research demonstrates how simply viewing objects of different colours can influence the perception of weight, it is equally important to consider how individuals perceive objects of different colours while hefting them. When pairs of equally weighted and sized objects of different colours are lifted, individuals will perceive the light coloured objects as being heavier than the darker coloured objects; a complete reversal from when individuals are solely allowed to view the objects (DeCamp, 1917; Taylor, 1930). This could be interpreted as supporting evidence for the expectation model of weight perception. Participants are expecting the light objects to be light than the darker objects to be heavy and will therefore use less force when lifting the light coloured object compared to when lifting the dark coloured object, thus creating the illusion of heaviness for the light object and the illusion of lightness for the dark object.

As there is both vision for perception and vision for action it is necessary to examine the role colour plays in lifting dynamics. When one is exposed to an object where the outward appearance does not change between trials but the weight does he or she will scale their grip force based on the previous lift. When rTMS is applied to the primary motor cortex, there is no difference between the forces used regardless of whether the object changes weight or not (Chouinard et al., 2005). Therefore, when the primary motor cortex is virtually lesioned, it disrupts one's ability to accurately apply rates of grip force when lifting different weights and to scale the grip force based on a previous weight (Chouinard et al., 2005). This also occurs for the load force, which again signifies how grip and load force are modulated together. When an individual is exposed to an object where an arbitrary colour signifies the weight of the object, there is no change in the rate of grip force after the object becomes heavier or lighter because the individual is able to use the colour to scale the grip force based on the current weight of the object. In essence, they are able to assign a mass to an arbitrary colour (Chouinard et al., 2005). Again, the same result is found for the load force. Arbitrary colour cues can provide information about what weight one is lifting so it is quite possible that colour can influence a size-weight illusion. If participants initially believe that the large object is heavier than the small object, they may always assign a larger force to the large object and a smaller force to the small object

2.6 New Discoveries

A recent pilot study by (White & Westwood, 2009) did not find results that have been typically found in all previous research. As such, this could have ramifications in the way that grip and load force coupling, internal models, and the size-weight illusion are considered in the future. It would appear that when the colour of the SWI stimuli are different, with repeated lifting individuals always use more force when lifting the large object compared to the small object; however, perceptually one always states that the large object feels lighter than the small object (White & Westwood, 2009). As well, unlike any previous studies, the grip and load force showed different tendencies; participants scaled the grip force to the mass of the object, but always used more load force to lift the large object than the small object (White & Westwood, 2009). This would suggest that grip and load forces were not modulated together and that the internal models may use cues other than size when the SWI stimuli are different colours and are unable to reconcile that the SWI stimuli were the same two objects being lifted repeatedly. Based on this pilot study, the expectation model needs to be considered differently as traditionally it is believed that there is only one expectation for the SWI stimuli; the stimuli are believed to have similar densities and difference in size erroneously causes one object to be lifted with more force than the other. White and Westwood (2009)'s pilot study demonstrates that this may not be true when the SWI stimuli are different colours. There may be two different expectations of the SWI stimuli, as perceptually participants believe the small object is heavier than the large object but the motor system always expects that the large object to be heavier than the small object; participants' actions do not correlate with their perceptions. Future research is essential to determine if the discrepancy between grip and load force and the unusual lifting patterns found by White and Westwood, (2009)'s pilot study is caused by having different coloured SWI stimuli.

2.7 Conclusion

When individuals lift novel objects, different cues are used to generate the lifting forces and size appears to be one of the more important cues. The lifting forces are generated such that there is a tight coupling between the grip force and the load force. Internal models are responsible for using the cues, such as size, to anticipate the forces necessary to lift an object, and to ensure that the grip force is modulated in parallel with the load force. When two objects of equal mass and different volume are lifted, internal models erroneously use size to scale the forces, such that too much force is used to lift the large object, compared to the small object. According to the expectation model, this error occurs because one expects the large object to be heavy and the small object to be light, and when this expectation is incorrect, perceptually one believes that the large object is lighter than the small object. Previous studies have demonstrated that colour can act as a cue for weight perception; an individual can perceive an object of one colour as being heavier/lighter than an identical object of a different colour and can also learn to associate a mass with a colour such that when the motor system is virtually lesioned, he or she can still produce lifting forces appropriate for the weight of the object they are lifting. However, a study has not been conducted that has examined the effects of colour on the size-weight illusion and the results found by White and Westwood (2009)'s pilot study further demonstrates the need to conduct such a study.

CHAPTER 3: METHODS

3.1 PARTICIPANTS

Seventy-two Dalhousie University undergraduate students were used for this experiment and the participants were completely naive to the purpose of the investigation. Of the 72 participants, 23 were male, 49 were female, 64 were right hand dominant and 8 were left hand dominant. The mean age of the participants was 19.9 years with a standard deviation of 1.9. Participants were recruited by word of mouth (see Appendix A for the script used for word of mouth recruiting) as well as through the Dalhousie University Psychology undergradute subject pool (see Appendix B for the participant contact form used for the subject pool). Participants recruited through the subject pool received 1 credit point for their participation, which went toward his or her final course grade in the psychology course they were currently enrolled in. No compensation was offered to participants recruited by word of mouth. Participants were able to participate in the study if they had no history of neurological illness or impairment and if they had normal or corrected-to-normal vision (the screening questionnaire in appendix C provides what was considered normal vision). All participants provided written informed consent (see Appendix D and E for the consent forms for participants recruited via the psychology subject pool and word of mouth) and the study received approval from the Dalhousie University Health Sciences Research Ethics Board (approval code 2009-2047, see Appendix F for the letter of approval).

3.2 APPARATUS

The materials required for this study were 4 plywood cubes. Two were coloured red and 2 were coloured yellow. The masses/volumes for the red cubes were 200g/800cm^3 (9.3cm x 9.3 cm x 9.3cm), 200g/400cm^3 (7.4 cm x 7.4cm x 7.4cm) and the masses/volumes for the yellow cubes were 200g/800cm^3 (9.3cm x 9.3 cm x 9.3cm), 200g/400cm^3 (7.4 cm x 7.4cm x 7.4cm). These cubes were hollow and to obtain the desired masses they were loaded with clay. Both of the large objects had a density of .25 g/cm^3 and both of the small objects had a density of .5g/cm^3. These densities were atypical from the normal relative density of objects (1.0 g/cm^3). The red and yellow cubes are displayed together in figures 1 and 2 respectively. A transferable force transducer (Nano 17 F/T, 6-axis force transducer, ATI Industrial Automation, Apex, NC) was mounted to each box via magnet to measure force when lifted by the participants and a switch was used to determine the time between when force was produced to the time the object was lifted from the table. Figure 3 demonstrates the experimental setup.

Figure 1: SWI stimuli for the subgroup lifting red objects. Each object was matched for mass and differed in volume

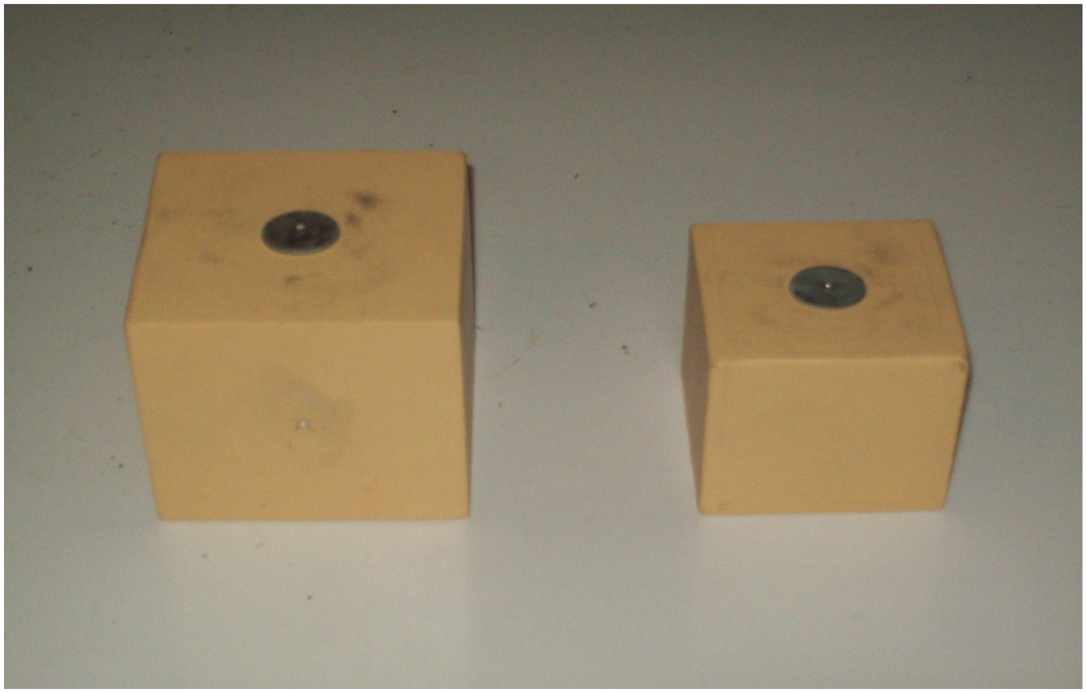


Figure 2: SWI stimuli for the subgroup lifting yellow objects. Each object was matched for mass and differed in volume

Figure 3: Experimental Setup. The force transducer was anchored to the cradle, which was then attached to the object via magnet. The blue object with the clear surface is the switch, which was triggered when the object was lifted from it.

3.3 PROCEDURE

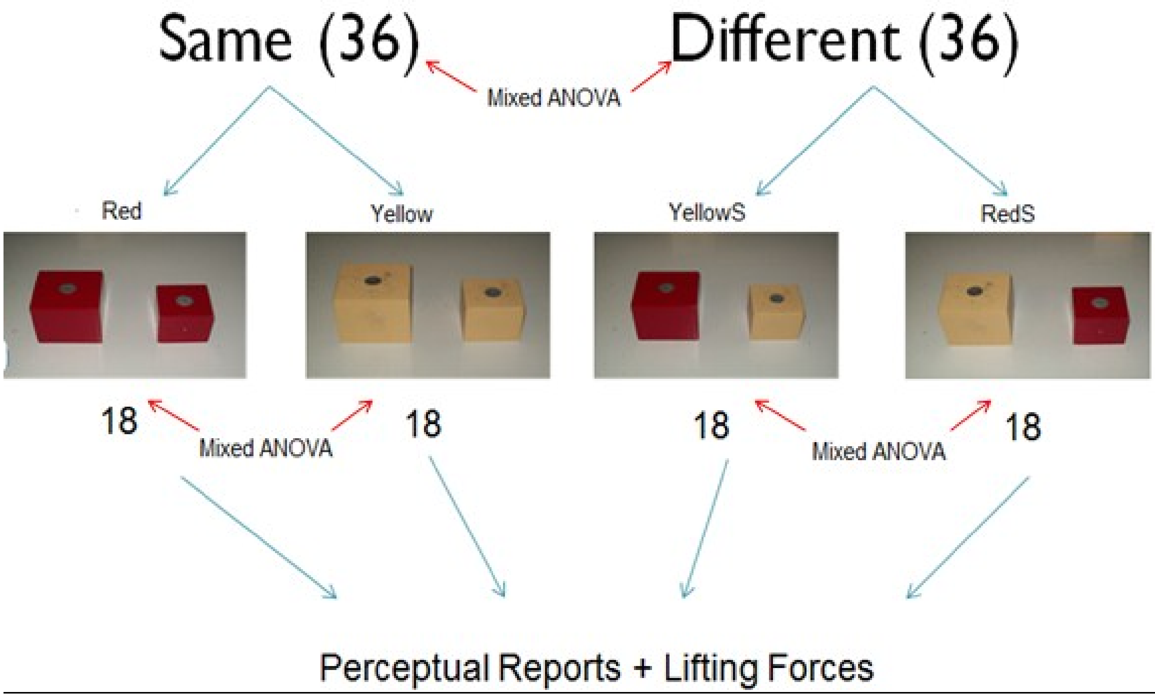


Figure 4: Procedure Summary. Highlights the experimental procedure used by participants and maps where the statistical analyses occurred. The participants were initially divided into two groups (same vs different) of 36 (as indicated by the 36 in parentheses above) and were further divided into subgroups (red, yellow, yellowS [yellow object was small] and redS [red object was small] of 18 (denoted by the 18 below the pictures of the objects). The mixed ANOVA indicates where the statistical comparisons occurred as a comparison was made between the same and different groups and also between the subgroups within the Same and Different groups (red vs. yellow and redS vs. yellowS).

The participants were randomly allocated into 2 groups with 36 participants in each group. The first group of 36 was presented with SWI stimuli (a large and a small object of equal mass) that were matched for colour. The second group was presented with SWI stimuli that were different colours. Each group was further divided into 2 groups of 18. For the group lifting the stimuli that were matched for colour, one subgroup received 2 red objects and the other received 2 yellow objects (see figures 1 and 2). For the group lifting the stimuli of different colour, one subgroup received objects where the large object was red and the small object was yellow. The other subgroup received objects where the large object was yellow and the small object was red (see figures 5 and 6). Each group had the following procedure that they were required to adhere to:

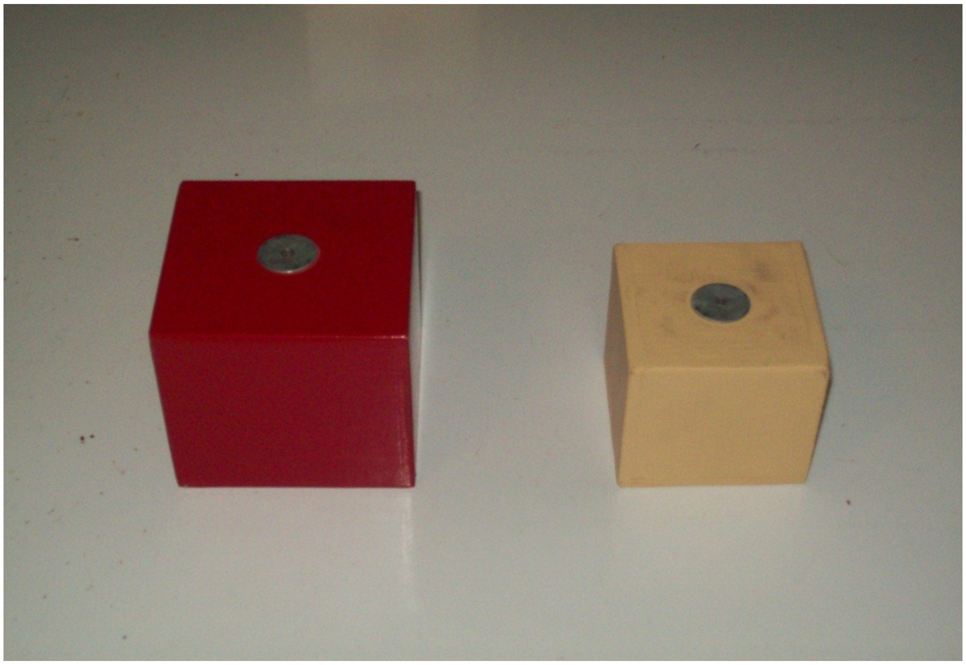


Figure 5: SWI stimuli for the subgroup lifting objects where the small object was yellow and the large object was red. Each object was matched for mass and differed in volume

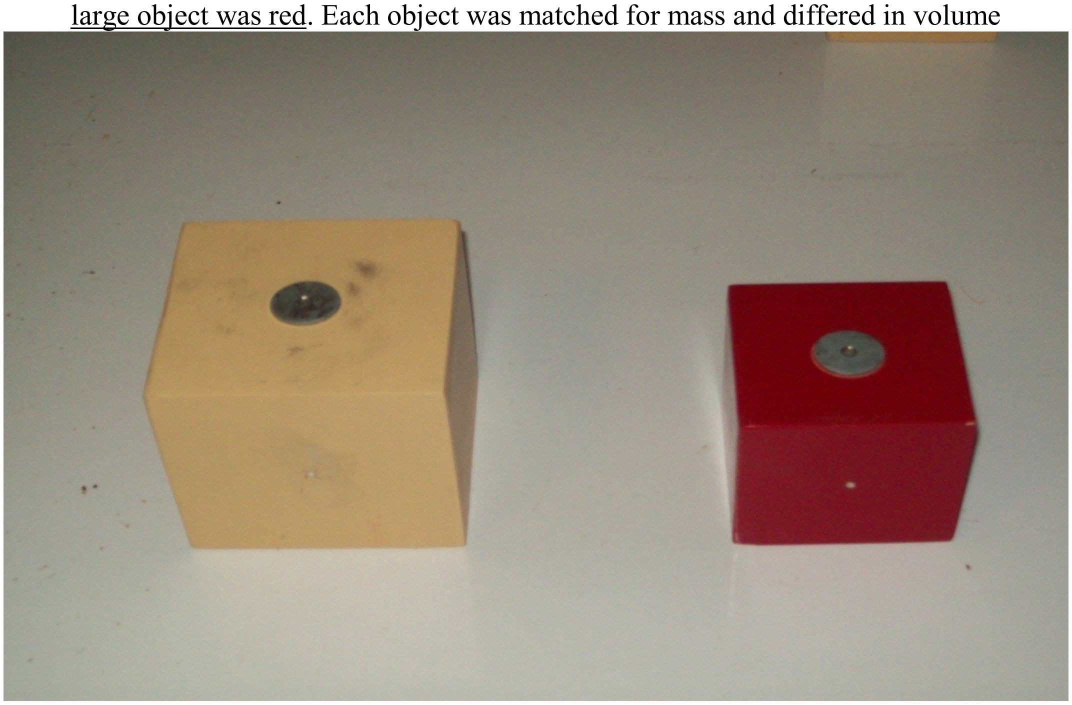


Figure 6: SWI stimuli for the subgroup lifting objects where the small object was red and the large object was yellow. Each object was matched for mass and differed in volume

3.3.1 Group 1: Stimuli with the Same Colour

The participants spent one 30 minute session lifting 2 objects, 2 yellow or 2 red. The force transducer was attached to each object via magnet and participants were presented with each object 15 times. The objects were alternated such that each participant lifted the small object first, followed by the large object, and this sequence was repeated until each participant had lifted each object 15 times.Whichever object was presented, the other was kept hidden from the participant's view. For each trial the experimenter took the object being presented, attached it to the force transducer and placed it on the switch. Once the object was presented the participants were asked to use their preferred hand and lift the object via precision grip (between the thumb and index finger) on the transducer. For the lift participants were instructed to heft the block at least one foot above the switch as quickly as possible and without deviating from a vertical lift, to hold the object at the top of the lift for a second, and then to replace the object back onto the switch. Participants were also instructed not to extend their arm further than shoulder height unless it was required to lift the object at least one foot above the switch. Any trials that did not adhere to these instructions were repeated. After each lift participants verbally judged the heaviness of the object using a numerical rating scale. This was a 1-10 scale with 1 being light and 10 being heavy. Participants were not given any assistance to assign the heaviness judgments.

3.3.2 Group 2: SWI Stimuli with Different Colours

The participants in this group followed the identical procedure as group 1, with the only difference being the characteristics of the 2 objects lifted. Instead of the objects being either yellow or red, one object was red and the other yellow.

3.4 Data Collection

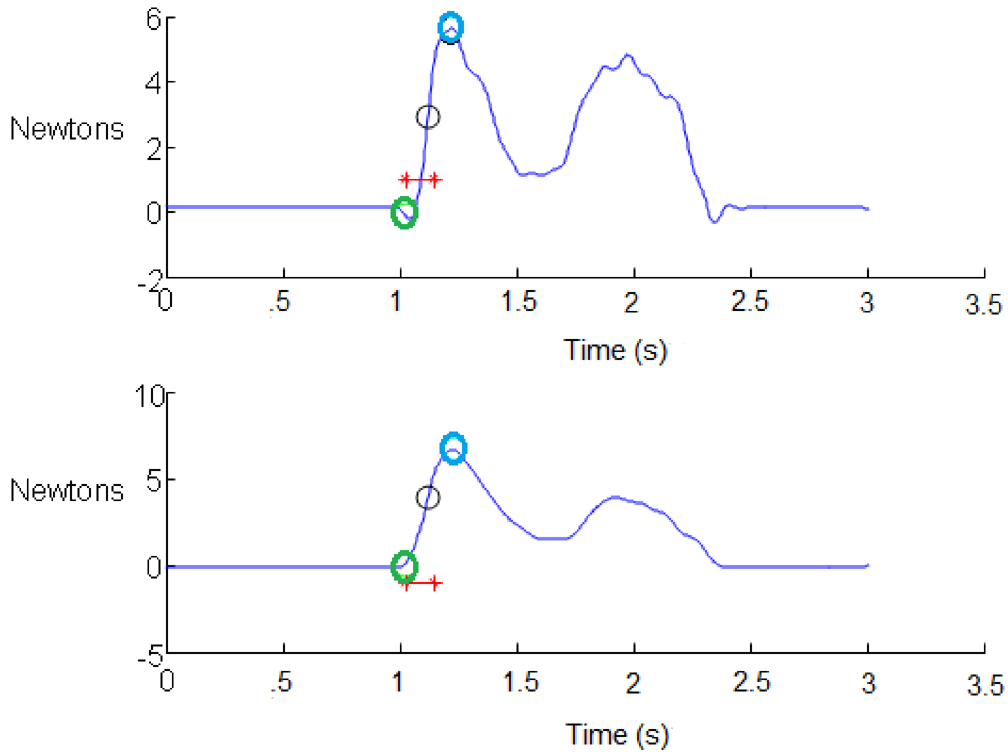
As stated in the procedure the perceptual report scale was a 1-10 scale with 1 considered to be light and 10 considered to be heavy. This scale has been shown to be a reliable scale capable of demonstrating significant differences and has been used before (Grandy & Westwood, 2006; White & Westwood, 2009). Perceptual report data were coded as 15 lifts where a lift included the small object trial and the corresponding large object trial. This was analyzed as object x lift number.

The lifting force data collected consisted of PLF, PLFR, PGF, PGFR and LPD. These are the lifting forces that have been collected and compared in many different studies and are those that best describe how individuals act on objects (Flanagan &

Beltzner, 2000; Flanagan, King, Wolpert & Johansson, 2001; Grandy & Westwood, 2006). The load force parameters specifically describe how the object is lifted; PLF describes the highest load force that is applied to the object whereas PLFR describes the highest rate of load force that is applied to the object. The grip force parameters examine the forces used to grip the object; PGF describes the highest grip force used to grip the object whereas PGFR describes the highest rate of grip force used during the lift. The LPD is the time between when the object is first gripped to when the load force of the object surpasses the weight of the object and the object comes off the ground.

All lifting force data were collected using an analog to digital convertor and a program designed in Labview v. 8.2. This program collected all of the force data at a frequency of 200Hz and converted the electrical signal produced by the force transducer into Newtons. Before experimental trials were conducted, calibration of the force transducer was performed first by placing the transducer on its side and placing objects of known mass on top of it to determine if the transducer was accurately measuring grip force (this was force in the z-direction; compression of the force transducer); if the force recorded was within .05 N (5g) of the mass of the object then the device was accurately measuring grip force. Next, the load force calibration was performed by mounting the force transducer via magnet to the objects and lifting them (this was force in the y direction; force of the weight [m x g] of the object on the force transducer). Again if the force was within .05 N (5g) of the mass of the object the device was accurately measuring grip force.

Before each participant lifted the objects in experimental trials, the forces measured by the force transducer were zeroed by using the built-in button in the labview program. This button reset all forces back to zero. This zeroing process was performed to eliminate any misreading (the forces tended to drift from zero from participant to participant) and to keep the experimental procedure consistent. This also eliminated any small fluctuations that may have occured with the force transducer between participants. After the data were collected, the force signals were smoothed using a dual pass butterworth filter (cut-off frequency 14Hz) and analyzed using Matlab 2007. The Matlab program plotted grip force and load force over time as well as when the switch was triggered. The switch function worked in the following way: the program used a binary function where the default setting was zero. Once the switch was triggered the switch status was changed from zero to 1. To calcuate the LPD the Matlab program used the onset of grip force (because to lift an object one first needs to grip the object) as the start of force production and measured the time between that onset and when the switch was triggered. The onset of grip force occurred when a grip force value was 0.5 N higher than the value that preceded it. The preceding grip force value was deemed the onset of grip force. The PLF and PLFR were collected in the following way: once the onset was determined by the onset of grip force, the program searched for a peak that was greater than 1N (in order to prevent random noise from causing a "peak", peaks greater than 1N were arbitrarily chosen as it took at least 1.96 N (200g) of force to lift the object of the ground) as well as the largest slope between onset and the peak. The first peak that was larger than 1N was considered to be PLF by the program (and could be manually edited following review if this peak was still not the maximum peak value) and the greatest slope between onset and PLF was considered to be PLFR (again, if PLF was incorrect, the program would reassign the PLFR to correspond to the correct slope once PLF was reassigned). The PGF and PGFR were calculated in the same way as the PLF and PLFR. Figure 7 demonstrates a sample trial from one participant.



<u>Figure 7: Sample trial from a participant.</u> This figure illustrates all measures with the load force on top and grip force on bottom. On both lines the first circle represents the onset of the trial, the second circle represents the peak rate and the third circle represents the peak force. The line with stars at either end represents the time between the initial force application (left star) and when the switch was triggered indicating the object came off the switch.

As with the perceptual data, the lifting force data were reduced to 15 lifts where one lift was considered to be a small object trial and the corresponding large block trial. This reduction was performed for the same reason that the reductions were performed for the perceptual data.

3.5 Data Analysis

Separate analyses were performed for each of the four lifting measures (PLF, PLFR, PGF, PGFR) and for the perceptual reports. These analyses were mixed ANOVAs with repeated measures of object (2: [small/large]) and lift number (15: [1-15]), and between-subjects factor of group (2: [same colour/different colour]. Due to inconsistent performance by the switch, appropriate analyses for LPD were unable to be conducted. To determine if the specific colour combinations used in the Same and Different colour groups affected the lifting force data, subsequent mixed ANOVAs were performed for each lifting parameter (PLF, PLFR, PGF and PGFR) for the subgroups within the Same and Different Colour groups. For the Same colour group, the ANOVA contained repeated measures of object (2: [large/small] and lift (15: [1-15]) and between subjects factor of subgroup (2: [red objects/yellow objects]). For the Different colour group the ANOVA contained repeated measures of object (2: [large/small]) and lift (15: [1-15]) and between subjects factor of subgroup (2: [red large+yellow small/yellow large+red small]).

For the perceptual reports a mixed ANOVA with repeated measures of object (2: [large/small]) and lift number (15: [1-15]) and between subjects factor of group (2: [same colour/different colour]) was performed using SPSS v. 15. As with the lifting data, subsequent mixed ANOVAs were performed for the colour subgroups within the Same and Different colour groups. For the Same colour group the ANOVA contained repeated measures of object (2: [large/small] and lift (15: [1-15]) and between subjects factor of subgroup (2: [red objects/yellow objects]). For the Different colour group the ANOVA contained repeated measures of object (2: [large/small]) and lift (15: [1-15]) and between subjects factor of subgroup (2: [red large+yellow small/yellow large+red small]). These were both performed using SPSS v. 15.

Chapter 4: Results

4.1 Perceptual Data

4.1.1 Comparison Between Same Colour and Different Colour Groups

The following factors were investigated: Object, which would indicate if there was a difference between the perceptual reports for the large and small object; Lift, which would indicate whether there was a difference between the perceptual reports as the number of lifts changes (as participants progress through the experiment); and Group, which would indicate whether one group perceived the objects differently from the other. The interactions between each of these factors were also considered. Figure 8 depicts the perceptual reports. The participants' perceived heaviness of both the large and small object increased with trial number as illustrated by a main effect of lift found from the mixed ANOVA , $F(14,952) = 29.0$, $P < .001$. The participants also consistently perceived the small object as heavier than the large object. This was reflected by the mixed ANOVA as a main effect of object on the perception of object weight, $F(1,68) = 144.6$, $P < .001$. The mixed ANOVA also revealed a lift x object interaction $F(14, 952) = 9.8$, $P < .001$ indicating that participants initially believed that the objects were similar in mass during the first trial with the small object feeling heavier than the large objects on all other trials. There was no significant group x object ($P = .627$), group x lift ($P = .056$), or group x object x lift ($P = .501$) interactions indicating that both groups perceived the illusion in the same manner.

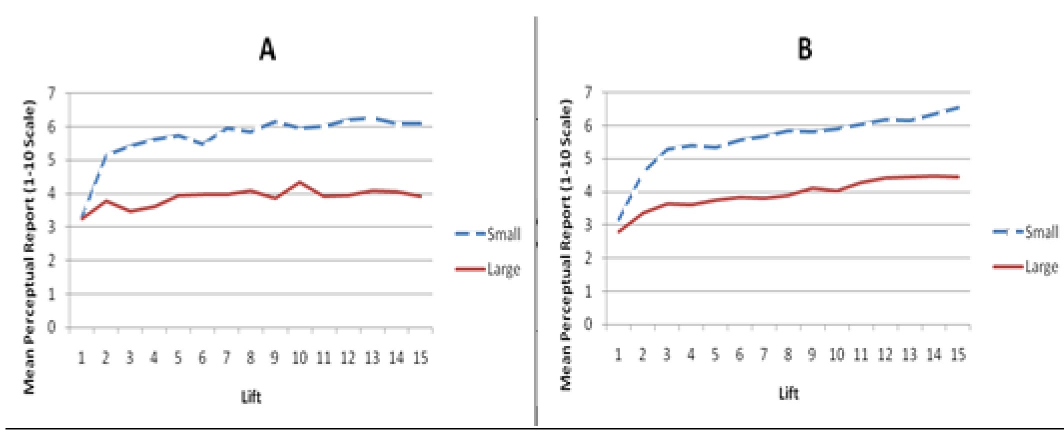


Figure 8: Perceptual reports of different colour and same colour groups. This figure demonstrates the change in perceptual reports for the different colour group (A) and the same colour group (B) over repeated lifts. The results showed a main effect of object and a lift x object interaction.

4.1.2 Comparison of Colour Subgroups Within Same-Colour Group

For this analysis each of the factors examined earlier remained the same with the exception of group. This analysis replaced group (same/different) with the subgroup (red/yellow). The mixed ANOVA for the comparison of the red and yellow subgroups revealed no main effect of subgroup or any significant subgroup x object or subgroup x lift interactions. This indicates that there was no difference in the perception of the objects if they were coloured red or if they were coloured yellow. Figure 9 A and B display the perceptual reports for the red and yellow objects respectively.

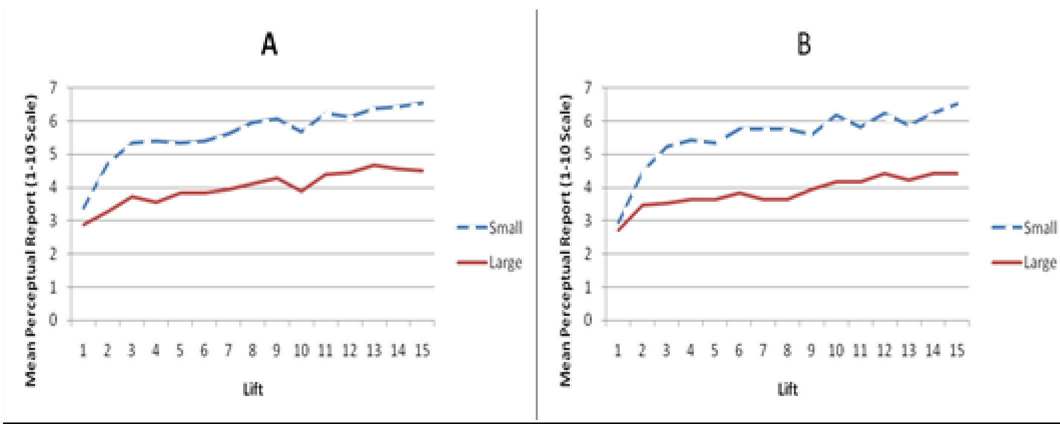


Figure 9: Perceptual reports for the red vs. yellow subgroups. Illustrates the change in perceptual reports when the objects are both red (A) or both yellow (B).

4.1.3 Comparison of Colour Subgroups Within Different-Colour Group

For this analysis each of the factors examined earlier remained the same with the exception of group. This analysis replaced group (same/different) with the subgroup (redS/yellowS). The mixed ANOVA for the comparison of the comparison of the redS and yellowS subgroups revealed no main effect of subgroup or any significant subgroup x object or subgroup x lift interactions. This indicates that there was no difference in the perception of the objects if the small object was red and the large object was yellow or if the small object was yellow and the large object was red. Figure 10 A and B illustrate the perceptual reports for the redS and yellowS respectively.

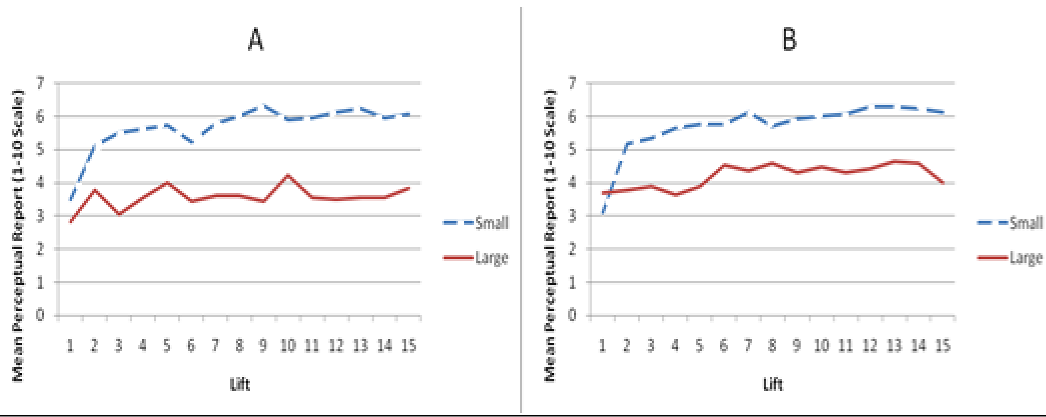


Figure 10: Perceptual reports for the redS vs. yellowS subgroups. Illustrates the change in perceptual reports when the red object is small (A) and yellow object is small (B).

4.2 Lifting Force Data

The participants performed well on the lifting task. Repeated trials due to errors in the lifts only occurred on average once per participant. Data concerning which lifts were repeated were not collected as it was deemed unnecessary as there were so few errors. As well, in order to ensure that any outlying points caused by instrumentation malfunctions or overzealous hefting did not affect the analysis, outlier analysis was performed on each trial. To perform this outlier analysis, the mean and standard deviation was calculated for each trial across all participants (for example, mean and standard deviation was calculated for trial 1 across all participants, and then for trial 2 and so on) and any point that was either above or below 2 standard deviations from the mean were excluded. The 2 standard deviations above and below the mean method of outlier analysis was chosen due to its simplicity and because it is a commonly used method that has been demonstrated to reliably remove outliers (DeVeaux, Velleman, & Bock, 2005). Also the goal was to find obvious outliers only as to keep as many participants as possible in the analysis. Although this did eliminate any large outlying data points, due to the nature of the repeated measures analysis procedure in SPSS v15, any participant missing a single value for any trial required that the participant's entire data set was dropped from the analysis. Due to the removal of outlier data points and the presence of missing values due to instrumentation problems, the initial sample of 72 participants was reduced to 47 for the lifting force data. Of these 47, 20 were in the same colour group (10 in the yellow subgroup and 10 in the red subgroup) and 27 were in the different colour group (14 in the redS subgroup and 13 in the yellowS subgroup). Also important to the understanding of how the results are presented is that with lifting force data, previous research has demonstrated that any differences found between objects for lifting forces are likely to occur on the first trial and then disappear due to the correction of lifting forces from feedback on subsquent trials (Flanagan & Beltzner, 2000; Grandy & Westwood, 2006); therefore analysis of the first trial was performed for each of the lifting forces to determine if an initial mismatch between the force used to interact with the large object and small object occurred and then disappeared on all other lifts.

The factors that were examined for these analyses were the same as for the perceptual data with the exception that instead of there being differences between perceptual reports these analyses examined differences in each of the lifting forces (PLF, PLFR, PGF, PGFR).

4.2.1 Peak Load Force

There were no significant main effects or interactions found for PLF overall; however, upon analyzing the data from only the first trial there was a significant group x object interaction $F(1,45) = 4.12$, $P < .05$. The different colour group used approximately the same amount of force to lift the large object compared to the small object whereas the same colour group used more force to lift the large object compared to the small object. Figure 11 A and B depict the PLF for the different colour group and same colour group respectively.

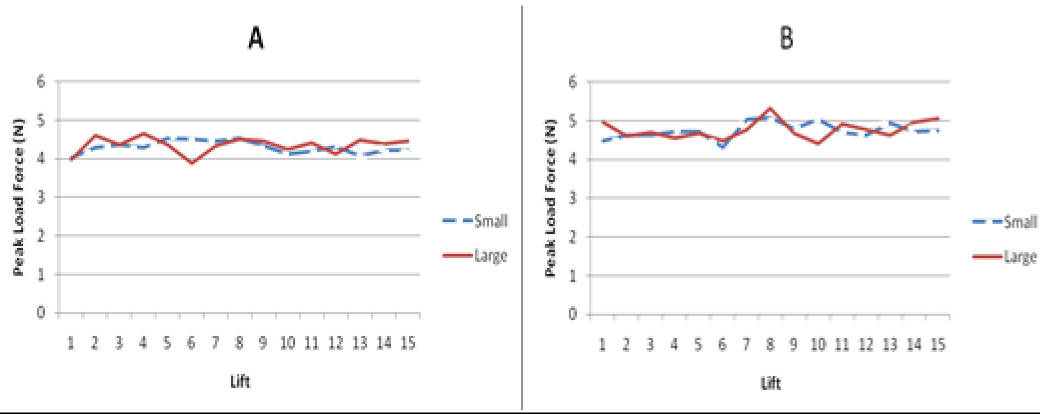


Figure 11: Peak load force parameter for the same colour vs different colour group. This figure demonstrates the average peak load force for the different colour (A) vs. same colour (B) group.

4.2.2 Peak Load Force Rate

There were no significant main effects or interactions. Analysis of the first trial also revealed no significant findings. Figure 12 A and B demonstrate the PLFR for the different colour group and same colour group respectively.

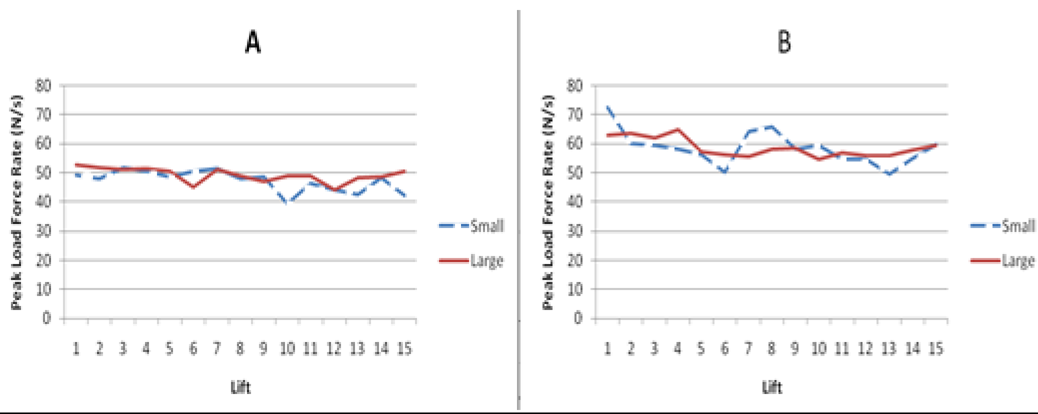


Figure 12: Peak load force rate parameter for the same colour vs. different colour group. This figure demonstrates the average peak load force rates for the different colour (A) vs. same colour group as a function of lift.

4.2.3 Peak Grip Force

There was a significant main effect of lift $F(14,630) = 13.12$, $P < .001$; both groups used significantly higher grip forces on the objects during the early trials compared to the later trials. The main effect of object was not significant and there were no significant interactions. Analysis of the first trial also revealed no significant findings. Figure 13 A and B depict the PGF for the different colour group and same colour group respectively.

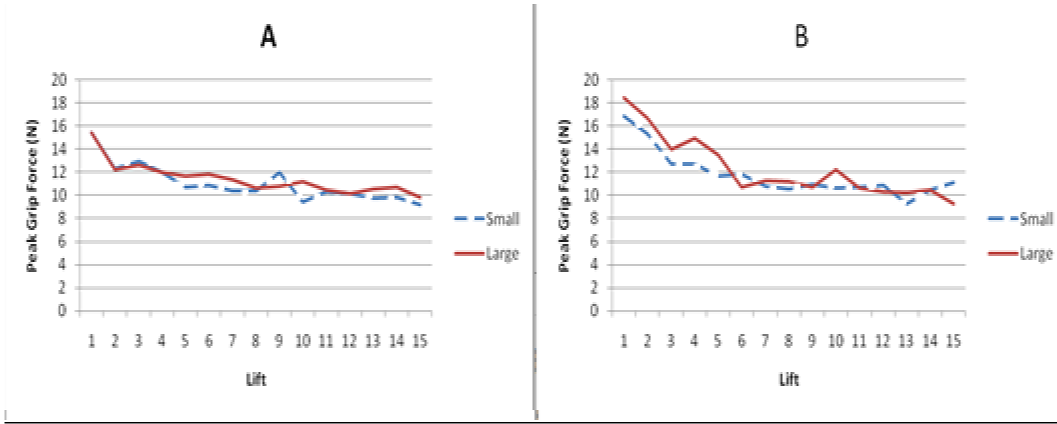


Figure 13: Peak grip force parameter for the same colour vs different colour group. This figure depicts the average peak grip force for the same colour (A) vs. different colour (B) group.

4.2.4 Peak Grip Force Rate

There was a significant main effect of lift $F(14,630) = 4.54$, $P < .001$ and a lift x group interaction $F(14,630) = 1.75$, $P < .05$. Although both groups demonstrated the same pattern, the same colour group used higher rates of grip force in early trials than the different colour group before decreasing the rate on subsequent trials. Analysis of the first trial revealed a significant main effect of object $F(1,45) = 4.41$, $P < .05$, where the participants used more force to lift the large object than the small object, but no other significant findings. Figure 14 A and B demonstrate the PGFR for the same colour group and different colour group.

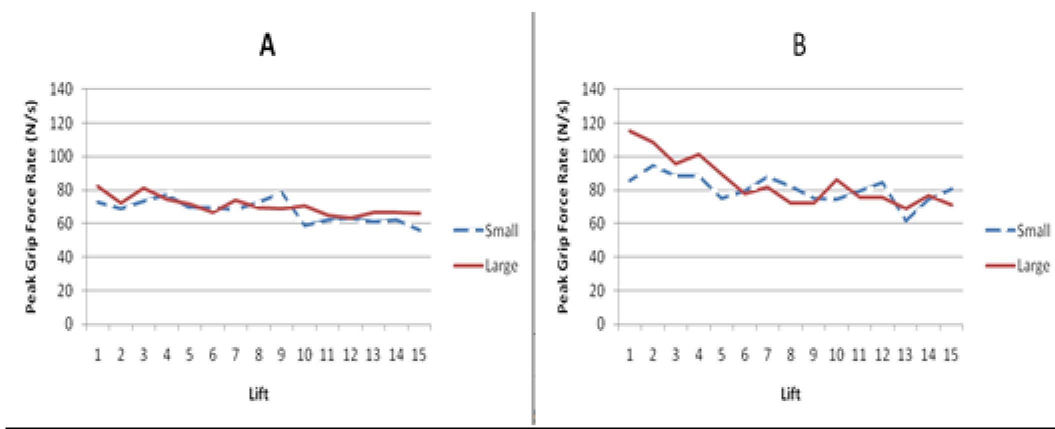


Figure 14: Peak grip force rate parameter for the same colour vs different colour group. This figure depicts the average peak grip force rate for the different (A) vs same colour (B) group as a function of lift.

4.2.5 Comparison of Red and Yellow Subgroups

There were no significant main effects or any interactions with subgroup for any of the lifting force measures (PLF, PLFR, PGF, PGFR). Therefore each subgroup applied PLF and PLFR in a similar manner regardless of whether the objects were red or yellow and each subgroup applied similar PGF and PGFR regardless of whether the objects were red or yellow.

4.2.6 Comparison of redS and yellowS Subgroups

There were no significant main effects or any interactions with subgroup for any of the lifting force measures (PLF, PLFR, PGF, PGFR). Therefore each subgroup applied PLF and PLFR in a similar manner regardless of whether the small object was red and large object was yellow or the small object was yellow and large object was red. Each subgroup applied similar PGF and PGFR regardless of whether the small object was red and the large object was yellow or the small object was yellow and the large object was red.

Chapter 5: Discussion

The goal of this study was to ascertain whether arbitrary colour cues provided during a SWI paradigm are responsible for causing individuals to consistently use more force to lift the large object than the small object yet consistently perceive the small object as being heavier than the large object as demonstrated by the pilot study performed by White and Westwood (2009). This was studied by having participants interact with SWI stimuli that were either identical in colour (thus replicating past research methods as all previous studies have used objects that are identical in colour) or were different in colour. The expectations were that participants in both groups would experience similar perceptual illusion as past research with objects of same colour (Flanagan & Beltzner, 2000; Flanagan et al., 2001; Grandy & Westwood, 2006) and objects of different colours (White & Westwood, 2009) has demonstrated similar perceptual SWIs. It was also expected that participants who interacted with objects of the same colour would use more force to lift the large object compared to the small object on the first trial but then use similar forces to lift the two objects all subsequent trials. This has been found in previous SWI studies (Flanagan & Beltzner, 2000; Flanagan et al., 2001; Grandy & Westwood, 2006). Participants who interacted with objects of different colour should have consistently used more force to lift the large object than the small object. This was found by White and Westwood (2009)'s pilot study and suggests that when the objects are different colours the motor system always expects the large object to be heavier than the small object.

5.1 Perceptual Results

The perceptual data demonstrated that the participants who lifted objects of the same colour and the participants who lifted objects of different colour had similar perceptual experiences; both groups initially judged the objects to be similar in mass in early trials but on subsequent trials judged that the small object felt heavier than the large object. This result does not support our hypothesis that both groups would experience a consistent SWI and also deviates from previous SWI studies. The previous studies consistently found that the perceptual SWI was just as strong at the beginning of the experiment as it was at the end (Flanagan & Beltzner, 2000; Flanagan et al., 2001). It is likely that the discrepancy that occurred on the first trial can be explained as a floor effect as 20 participants initially scored both objects as 1 or 2 (both objects being incredibly light), although they did remark that the large block felt lighter but could not either score the large object lower than 1 or did not want to use the extreme ends of the scale and did not want to rate either block lower than 2. Therefore with the exception of the first trial, the hypothesis for the perceptual experiences for both groups was correct, each group had a consistent perceptual experience of the small object feeling heavier than the large object. This indicates that the different colour cues between groups (either both objects were the same colour or one was a different colour from the other) did not affect SWI.

Analyses were also performed with subgroups within the same and different groups (2 analyses: red vs. yellow and redS vs. yellowS) to determine if the arbitrarily chosen colours red and yellow were causing an underlying effect on an individual's perception of the SWI. Past research concerning how colour affects weight perception has revealed that when individuals are allowed visual cues solely about object weight (so they are unable to touch and feel objects) they believe that objects of darker colours should be heavier than objects of lighter colours (Payne, 1958; Pinkerton & Humphrey, 1974; Warden & Flynn, 1926) and when individuals are allowed to lift objects of equal mass and size but different colour they perceive that lighter coloured objects are heavier than darker coloured objects. As the current study was the first study using SWI stimuli of different colour, it is possible that the specific colours chosen (red and yellow) might directly impact the results, above and beyond the effects of the size-weight illusion itself. For example, an individual faced with a small object that was yellow and a large object that was red would experience a more intense size-weight illusion because they were already primed to think that the yellow object would be light (as it is a lighter colour) and that the red object would be heavy (as it is a darker colour) and then would be surprised by the fact that not only does the lighter colour not signify a light object, but the small size of the object does not signify a light object either (and the same principle would apply to the large, darker object; it is neither heavier due to the size or colour of the object) (DeCamp, 1917; Taylor, 1930). Individuals faced with a small object that was red and a large object that was yellow would experience a less intense SWI because they would be primed to think that the red object would be heavy and the yellow object would be light. As discussed earlier, according to the expectation model the SWI occurs due to the expectation that the small object is light and the large object is heavy. If someone is primed to believe that the small object is heavy, they should either not experience a SWI at all or have a much less intense SWI experience. The separate analyses between subgroups revealed no differences in perceptual reports between the subgroup that lifted red objects and the subgroup that lifted yellow objects and no differences in perceptual reports between the redS subgroup and yellowS subgroup, which does not support past research concerning colour and demonstrates that our results were not affected by any underlying colour effects. If past research were to hold true, it would have been expected that the participants who lifted the yellow objects would have rated the objects heavier than the participants who lifted the red objects as objects of lighter colour would be perceived as being heavier than objects of darker colour. Likewise it was expected that differences would exist between the redS and yellowS subgroups with participants in the redS group experiencing less of an illusion than participants in the yellowS group. Clearly this did not occur, as the perceptual trends across all subgroups were statistically similar (see figures 9 and 10).

5.2 Lifting Force Results

Analysis of the peak load force revealed no difference between colour groups overall. Upon analysis of the first lift only however (mismatches are corrected after the first lift as discussed earlier), the participants in the same colour group used significantly more PLF to lift the large object than the small object. The different colour group used relatively the same amount of PLF to lift each object. The analysis of the PLFR revealed no difference between groups overall and no difference on the first lift indicating that the both groups used the same amount of PLFR for the duration of the experiment. The analysis for PGF revealed a main effect of lift, indicating that both groups used higher PGF in early trials compared to later trials and analysis of the first lift revealed no significant differences. Like PGF, the analysis for PGFR revealed a main effect of lift indicating that both groups used higher PGFR in early trials compared to later trials; however, analysis of the first lift revealed that both groups used significantly more PGFR to lift the large object than the small object. The difference between the lifting force parameters provides support for Milner and Goodale (1995)'s theory that action and perception are distinct because despite the difference in error signals between lifting forces (for example, the PLF and PGFR demonstrated different results as discussed above), the participants gave the same perceptual judgment. The lifting force trends that were observed are not supported in past research. Past studies that have used the same lifting force measures and had individuals lift objects that are the same colour have reported that individuals will use more force (PLF, PLFR, PGF, PGFR) to lift the large object compared to the small object on the first trial (Davis & Roberts, 1976; Flanagan & Beltzner, 2000; Flanagan et al., 2001; Grandy & Westwood, 2006). On all other trials participants will eliminate this error by using similar forces for the two objects. Reproduction of this scenario was attempted with the same colour group; however, this group did not consistently use more force to lift the large object compared to the small object. The individuals in the same colour group only adhered to our expectations for peak load force and peak grip force rate, for all other forces there were no statistically significant differences. Only White and Westwood (2009)'s pilot study has examined objects of different colour and they found that individuals will consistently overestimate the force necessary to lift the large object compared to the small object. The current study tried to replicate these results with the different colour group but this group did not demonstrate the expected trends. None of the lifting forces measured demonstrated this trend; this group treated both objects the same for the duration of the experiment for all lifting forces except PGFR, which demonstrated the same result as the same colour group.

This absence in consistency between lifting forces also does not agree with the results found by White and Westwood (2009)'s pilot study that found that when participants lift SWI stimuli of different colours they consistently use more force to lift the large object than the small object. The current study did not find this, which would suggest that their results were caused by some other aspect of their procedure other than the colour of their objects. In White and Westwood (2009)'s pilot study, there were 3 groups; 2 experimental groups and 1 control group. The experimental groups were each given a series of practice objects first. This was a set of 6 objects where 3 of them had a density of 0.25g/cm^3 and the other three had a density of 0.5g/cm^3. The more dense objects were one colour and the less dense objects were another colour. One experimental group had objects that were matched for volume (and therefore the more dense objects were more massive) and the other had objects that were matched for mass (and therefore the more dense objects were smaller). After 10 lifts with each object (60 total lifts) they were then exposed to SWI stimuli that shared the same colour-density relationship as the practice objects (White & Westwood, 2009). The control group received the SWI stimuli that the experimental groups used but had no prior practice with the practice objects and were not told that colour signified the relative density of the objects. The results of White and Westwood (2009)'s pilot study may be due to the size disparity of the practice stimuli. For example, in the practice sets, there were 3 subsets of 2 objects where each subset weighed more than the previous. Even though each subset shared the same colour density relationship it is possible that the different masses between subsets may have played a role in the outcome.

The current study performed analyses with subgroups (2 analyses: red vs. yellow and redS vs. yellowS) to determine if the arbitrarily chosen colours red and yellow were causing any underlying effects on an individual's lifting forces on the SWI stimuli. It was expected, based on what the expectation model predicts for the SWI, that colour would have confounded the lifting forces as if an individual was to think that objects of darker colour were heavier than objects of lighter colour, they should have used more force to lift the object of darker colour than the object of lighter colour. If this were the case, then there should have been differences in the lifting forces between subgroups; the subgroup who only lifted red objects should have initially used more force to lift the blocks than the subgroup who only lifted yellow objects on early trials because red objects "are heavier" than yellow objects. As trials progress, the subgroup that lifted red objects should use less force on subsequent trials and the subgroup that lifted only yellow objects should use more force on subsequent trials. This should occur because the red subgroup would realize that both objects were lighter than they thought and vice versa for the yellow group.

Past research concerning how colour affects lifting forces has revealed that a different outcome can occur rather than the outcome predicted in the current experiment.

For example, Chouinard et al. (2005) revealed that the motor system is capable of learning to associate a mass with an artibrary colour cue such that individuals will always assume that one object will weigh more or less than another based solely on that colour cue. When an individual lifts objects where an arbitrary colour cue provides mass information, there is no change in the rate of force production regardless if the object becomes heavier or lighter, even if the motor system is virtually lesioned by rTMS (Chouinard et al., 2005). Therefore the motor system is capable of stereotyping the forces necessary to lift an object based solely on a colour cue. This would be most noticeable in the different colour objects group as participants could associate the small object as being heavy throughout the experiment or the large object as being heavy throughout the experiment as found by White and Westwood (2009)'s pilot study.

The results of White and Westwood (2009)'s pilot study further suggest that the motor system may be capable of associating a colour cue with the expectation of object mass. In their study the two SWI stimuli were different colour so before any lifting occurred and an individual was allowed to view the objects, the motor system expected the large object to be heavier than the small object and could have maintained that expectation because it always expected the large object of one colour to be heavier than the small object of a different colour. The results of the current study do not support this as individuals in the current study study did not consistently use more force to lift the large object than the small object as found by White and Westwood (2009)'s pilot study. As the objects in the current study study had the same mass and for all lifting forces except PGFR (where participants used higher levels to grip the large object than the small object) the participants in the different colour group always treated the objects the same, it is likely that the motor system did associate mass with colour and were not affected by the initial expectation that the large object would be heavy and the small object would be light.

The results of the current study also suggest that the colour of the objects (red vs. yellow or small object red vs. small object yellow, etc.) does not play a role in lifting force generation as there were no differences between subgroups for any of the lifting force measures. Individuals demonstrated the same trends regardless of whether they lifted red or yellow objects or whether the small object was red or yellow. A possible explanation as to why this occurred is provided by Milner & Goodale (2006). They suggest that vision for action and vision for perception are two distinct and anatomically seperate pathways. Each of these pathways uses different cues from the objects to generate either the perceptual experience of the object or to generate a representation that the motor system can use to act on the object (Milner & Goodale, 2006). To generate the perceptual experience, the ventral system uses relative cues such as colour and material to distinguish between objects whereas the dorsal stream uses absolute cues such as size and shape to distinguish between objects to generate a representation for the motor system (Milner & Goodale, 2006). If Milner and Goodale (1995)'s theory was true, then it would be no surprise that there were no differences between subgroups because the representation of the object that the motor system uses does not contain colour; there should be no differences between colour sets as the 2 large objects were identical in size and shape and the two small objects were identical in size and shape and those are the absolute cues the motor system uses. The problem with this explanation is that expectation does occur and the concept of expectation implies the use of perception to access past knowledge of an object and use it to plan action. For the motor system, expectation of lifting forces is controlled by internal models.

When an individual interacts with an object, he or she will estimate the force necessary to lift the object based on visual or haptic size cues if the object is novel (Gordon, Forssberg, Johansson, & Westling, 1991a; Gordon, Forssberg, Johansson, & Westling, 1991c). Alternatively if the object is familiar he or she will be able to accurately predict the force necessary to lift the object based on past experience with the object (Gordon et al., 1993). An individual is able to do this due to forward models (which are models that predict the sensory consequences of an action given the current state of the effector [hand, fingers, arm, etc.] and the motor command), and inverse models (which are models that estimate the motor command used that caused a particular movement given the current state of the effector and the desired state of the effector) (Johansson, 1984; Jordan & Rumelhart, 1992; Kawato, 1999; Miall & Wolpert, 1996). The current study's results demonstrate that individuals employed these internal models while lifting SWI stimuli. As the individuals in the current study would have had no previous experience lifting the SWI stimuli, the internal models would have estimated the force necessary to lift each object based on the visual cues from the objects; size and colour. If size was used to estimate the force necessary to lift each object then the internal models would erroneously program the lifting forces such that more force was used to lift the large object and less force was used to lift the small object. Due to feedback, the internal models would correct this error on all subsequent lifts (Kawato, 1999; Miall & Wolpert, 1996). This was demonstrated in the lifting force data by the main effect of object on the first trial for the PGFR, and also by the group x object interaction for the PLF. Individuals in the same colour group used more PLF and PGFR on the first trial to lift the large object compared to the small object and then used similar forces to lift each block on all subsequent trials and individuals in the different colour group used more PGFR on the first trial to lift the large object compared to the small object and then used similar forces to lift each object on all subsequent trials. If colour was also used to estimate the force necessary to lift each object then the internal models may not erroneously program lifting forces. This was demonstrated in the lifting force data by participants in the different colour group using similar amounts of PLF, PLFR and PGF for both objects for the duration of the experiment. This was reflected in the results by the absence of significant main effects of object for these lifting forces.

The lifting force data leave some questions unanswered. Why did the same colour group only show significant differences between objects on the first trial for PLF and PGFR when this group should have demonstrated significant differences between objects on the first trial for all lifting force parameters? Why did the different colour group only show significant differences between objects on the first trial for PGFR when all of the lifting forces should demonstrate the same trend? Past research has demonstrated that individuals use more PLF, PLFR, PGF and PGFR for the large object compared to the small object on the first trial and are corrected on subsequent lifts (Flanagan & Beltzner, 2000; Flanagan et al., 2001; Grandy & Westwood, 2006) so these past findings should have been replicated by at least the same colour group who mirrored the experimental procedure of Flanagan et al. (2001). According to figures 11-14, the same colour group did use more force to lift the large object than the small object for all forces; however it was only statistically significant for PLF and PGFR. This could mean that there were issues with the procedural instructions or the SWI stimuli that caused some error. This will be discussed later in the limitations section of the discussion.

Another possible explanation as to why some forces demonstrated significant differences between objects and others did not could be due to different internal models controlling each of the lifting forces; forward and inverse models for each PLF, PLFR, PGF and PGFR. It has been suggested in past research that the motor system does not just use a single forward and inverse model to control action; rather the motor system employs multiple forward and inverse models to predict and correct how an individual interacts with objects in the world. Each forward model is paired with a corresponding inverse model such that the forward model generates a prediction of sensory consequences and the inverse model generates a prediction of the motor command used to accomplish desired movement. There are multiple forward/inverse model pairings used to predict and carry out actions and the best pair is chosen using probability. If the difference between actual and predicted sensory consequences is small than there is a very high probability that the forward/inverse model pairing used was the correct one and will be used again whereas if the difference between actual and predicted sensory consequences are large than there is a very high probability that the forward/inverse model pairing was not correct and a different pairing will be chosen until the correct one is found. With practice (i.e., repeated lifting of SWI stimuli) the appropriate pairing is able to be chosen immediately which leads to more accurate interactions (Wolpert & Kawato, 1998; Wolpert & Flanagan, 2001). As the current study's results demonstrated different trends between lifting forces (the same colour group showed an initial mismatch between large and small objects for PLF and PGFR, but not PLFR and PGF and the different colour group only showed an initial mismatch between large and small objects for PGFR) it is possible that a different forward/invese model pairing was used for each force. It is possible that when generating peak load forces, the forward/inverse model pairings for PLF, PLFR, and PGF for the different colour group were able to accurately predict the forces based on the size and colour of the objects which would explain why this group was able to perform accurate movements for the duration of the experiment whereas the forward/inverse model pairing for PGFR was unable to perform the same accurate predictions. This would also explain the mismatch in results found between other lifting forces; the peak load force rates should have demonstrated the same trend as the peak load forces yet this did not occur for the same colour group. If the same internal model was used for all lifting forces then it would not be possible for some forces to have different trends than others.

5.3 General Comments About the Size-Weight Illusion

A traditional SWI occurs when a large and small object of equal mass but different volumes are lifted and the small object is perceived as being heavier than the large object (Flanagan & Beltzner, 2000; Grandy & Westwood, 2006; Murray et al., 1999). Like previous studies, the current study was able to replicate this illusion, providing further evidence that the illusion exists and does not diminish in intensity over time as the participants (aside from the first trial) consistently experienced a SWI. There also was weak evidence that when participants first act on SWI stimuli that are the same colour they initially use more force to lift the large object compared to the small object which is consistent with past research; however, this difference was not significant for 2 of the 4 lifting forces.

The initial mismatch in lifting forces between the large object and small object is said to occur because an individual learns over the course of his or her life that large objects tend to be heavy and small objects tend to be light as most objects in the world have similar densities. As such, people generally scale lifting forces such that they use more to lift large objects compared to lifting small objects (Gordon, Forssberg, Johansson, & Westling, 1991a; Gordon, Forssberg, Johansson, & Westling, 1991b; S. Kawai et al., 2002; Mon-Williams & Murray, 2000). This is known as the expectation model as individuals come to expect large objects as heavy and small objects to be light (Koseleff, 1957; Ross, 1966; Ross, 1969). The current study's results, like those of Flanagan & Beltzner (2000) and Grandy and Westwood (2006) suggest that this way of interpreting the expectation model needs to be refined as even though there are changes in the way individuals interact with the size-weight illusion stimuli, there is a consistent perceptual illusion. If the expectation model were true then as the difference between objects disappears so to should the perceptual illusion.

While Flanagan and Beltzner (2000) and Grandy and Westwood (2006) outright dismiss the expectation model, the current study's findings suggest that the perception of object weight may not be based on expectation, but expectation can still play an important role in the interaction with SWI stimuli. Even though most of the results were nonsignificant, the trends still show some very interesting differences between the same colour group and different colour group. Figures 11-14 demonstrate the differences between the same and different colour groups. As the first trial truly demonstrates the initial mismatch between large and small objects (as feedback mechanisms will start to correct lifting forces on all subsequent lifts) this is the most important when examining differences between groups. There was a signficant difference in PLF between the same colour group and the different colour group on the first trial, which signifies that the different colour group did have different expectations than the same colour group going into the lifts; if they were each expecting the large object to be heavy and small object to be light they should have treated them as such. As well, for every other lifting force, the difference between the force used for the large and small object was smaller for those in the different colour group than the same colour group; the different colour group treated the objects as more similar in mass than the same colour group, even when no significance was found. This provides weak evidence that the different colour group had different expectations than the same colour group. In spite of finding little to no lifting errors in the different colour group, there was a robust error in perceived heaviness. Therefore, it is possible that judgments of heaviness are confounded by some parameter (like density for example) rather than erroneous expectations.

5.4 Density Model

According to the density model for the SWI, the SWI should not even be classified as an illusion; rather, it is a phenomenon that occurs due to the integration of size and mass information for the perception of object weight (Kawai, Henigman, MacKenzie, Kuang, & Faust, 2007). When generating the perceptual experience of "mass", density models take into account not only size information, but also what the object is made of. For example, when an individual is required to arrange cubes that are equal in mass and size from heaviest to lightest that are made of steel, brass, aluminum, mahogany and balsa wood (cubes were either bored out or filled with lead to make them equal in mass), they state that the order from heaviest to lightest is steel, brass, aluminum, mahogany, and balsa wood when only allowed visual cues (i.e. no handling of the objects) (Harshfield & DeHardt, 1970).When asked to lift the objects the order of perceived heaviness is reversed, individuals perceive the balsa wood object as being the heaviest and the steel object as being the lightest (Harshfield & DeHardt, 1970). These results demonstrate that even when objects are identical in size, the material that the object is made out of also plays a significant role in the perception of heaviness and material properties as well as size are perceptually important for perceptual heaviness judgments. As well it has been discovered that by having objects of identical material properties that are equal in mass but have different volumes, the perceived heaviness of the objects will decrease (feel lighter) as the volume of the object increases (Ross & DiLollo, 1970). Therefore, it is possible to change an individual's perception of heaviness solely by changing the density of the objects. As the objects become less dense, they are perceived as being heavier.

The past research described above demonstrates that the perception of mass is not just driven by the actual mass of the object but also the object's density. Using Milner and Goodale (1995)'s theory of sensorimotor and perceptual independence (described in more detail subsequently) as a template, the density model can be explained as follows. The forces used to lift the object reflect the brain's understanding of mass in the true physical sense; in order to lift an object the forces need to be scaled to the actual mass of the object. If the object is lifted with too much force it may be thrown or damaged, or if the object is lifted with too little force it may not be lifted at all. Perception, on the other hand, does not to have to reflect the true mass of the object since there is no physical consequence of an error in perception. Perception of heaviness should be affected by density because perception is based on constant features of objects that are meaningful. Density is meaningful because in a class of objects (i.e. those made out of wood, metal, plastic, etc) the density is constant and gives important information about the material the object is made of. For example, in the Harshfield and Dehardt (1970) study, participants erroneously believed the balsa wood cube to be heavier than the steel cube when lifted because from the outward appearance of the cubes, a steel cube of the same size as a balsa wood cube should be heavier due to steel being more dense than balsa wood and this is constant. In experimental conditions where the two cubes are actually equal in mass, the perceptual system is surprised that the steel cube is not heavier than the balsa wood cube and therefore generates the illusion that the steel cube is lighter than the balsa wood cube.

In a SWI paradigm, the large object has a low density and therefore a low perceived heaviness and the small object has a high density and therefore a high perceived heaviness. As the density difference between the two objects does not change over repeated lifts, the perceptual experience of object weight also does not change and the large object consistently feels lighter than the small object. Therefore the perception of object mass is not related to or affected by any previous expectations about object mass provided by visual or haptic cues. As Harshfield and DeHardt (1970) found, density is a useful tool for determining what an object is made of and therefore is more perceptually interesting than mass alone and therefore perception is affected by both mass and density.

5.5 Perception vs. Action

Aside from providing important information regarding the SWI, the current study has also supported the theory proposed by Milner and Goodale (1995). They suggested that vision for action and vision for perception are two distinct and anatomically separate entities, each using and being affected by different cues. The perceptual system distinguishes between objects in a relative manner using cues such as colour and material (which are salient features) whereas the sensorimotor system distinguishes between objects in a more absolute manner using cues such as size (Milner & Goodale, 1995). The current study's results demonstrate that participants experienced a perceptual illusion where they believed that the small object was heavier than the large object yet their actions did not conform to these perceptual experiences.

The same colour group demonstrated trends identical to those in past research; for all lifting forces they used more force to lift the large object compared to the small object on the first lift and then used similar forces to lift each object on subsquent lifts (although this difference was only significant for PLF and PGFR it did occur for PLFR and PGF also). This occurred despite the fact that participants consistently perceived the small object as being heavy and the large object as being light. If perception and action were not distinct and anatomically separate something much different should have occurred; either action would have affected perception or perception would have affected action. If perception affected action then participants should have started using more force to lift the small object than the large object because they believed that it was the heavier of the two objects. In this case, participants would still have first expected the large object to be heavier than the small object on the first lift, but then on all other lifts they would expect the small object to be heavy and the large object to be light. They would use more force to lift the large object on the first trial but then on all other trials use more force to lift the small object than the large object. If action affected perception, then individuals should have initially stated that the large object was light and the small object heavy, but then on subsequent trials rate each block the same as after the first trial individuals use relatively the same amount of force to lift each block. As neither of these two scenarios occurred, perception and action must be distinct.

The different colour group also experienced a perception/action mismatch, although this mismatch was different than the mismatch that occurred for the same colour group. Despite perceiving a consistent SWI (the large object felt lighter than the small object) participants consistently used similar amounts of force to lift each object except for peak grip force rate where on the first trial participants used more PGFR to lift the large object than the small object and on all other trials usedsimilar forces to lift each object.

Each group experienced mismatches not only between perception and action, but also within the lifting forces, further demonstrating how separate action and perception are as in each group the differences between lifting forces were not reflected in the perceptual reports and vice versa. As discussed previously, it was expected that the different aspects of action would differ from one another due to there being separate internal models for each parameter.

The current study's results also illustrate the point that even though the two different groups interacted with two different sets of objects, both groups ended up sharing the same perceptual experience (the small block felt heavier than the large block), yet the analysis of the lifting forces revealed differences between groups. For PLF, PGF, and PGFR, the different colour group either had no initial mismatch or not as strong a mismatch whereas the same colour group demonstrated an initial mismatch across all lifting forces. Therefore, identical perceptual experiences were reached regardless of the different actions taken by the groups. This further demonstrates the difference between action and perception and argues against the expectation/mismatch model.

5.6 Grip and Load Force Coupling

When an individual uses a precision grip to hold an object (for example, lifting a block off of a table and holding it steady at the top of the lift) the force used to maintain the grip is dependent on two variables. The first is the actual mass of the object, in order to get the object off the ground and to maintain a grip without the object slipping the mass of the object is very important. As slip has been mentioned the other obvious key variable is that of the frictional force between the pads of the fingers and the gripping surface; individuals need to grip harder when surfaces are smooth and less hard when surfaces are rough (Eliasson et al., 1995; Eliasson et al., 1995; Johansson, 1984; Johansson & Westling, 1987; Johansson & Westling, 1988a; Johansson & Westling, 1988b; Nowak et al., 2001). When lifting an object, the weight of the object and frictional force is taken into account so that the grip force is employed economically such that it is slightly higher than the minimum force necessary to prevent the slipping of the object (Chouinard et al., 2005; Johansson, 1984; Nowak et al., 2001). This grip force also changes in parallel with the load force, the force necessary to actually lift the object from some surface (Blakemore & Sirigu, 2003; Forssberg et al., 1992; Johansson, 1984; Johansson & Westling, 1987; Johansson, Hager, & Backstrom, 1992; Johansson, Hager, & Riso, 1992; Westling & Johansson, 1984).

Flanagan, Tresilian and Wing (1993) define grip and load force coupling as grip force being modulated in phase with load force while moving gripped objects. Evidence for grip and load force coupling has been extensively demonstrated in past research. Developmental research has demonstrated that in children that are under two years old grip force actually increases before load force and is much greater than the minimum force necessary to prevent slip (Blakemore & Sirigu, 2003; Forssberg et al., 1992) due to the immaturity of the motor system; the individual is still learning how to interact in the world and thus has not learned how to accurately interact with objects yet. As an individual actually reaches two years of age they begin to use loose grip and load force coupling to lift objects and the full development of grip and load force coupling takes approximately 10 years (Blakemore & Sirigu, 2003; Eliasson et al., 1995; Forssberg et al., 1992). As well it would appear that grip and load force coupling is a universal strategy for lifting and maintaining grip. Coupling between grip and load forces has been noted when an individual is instructed to lift objects from side to side or up and down either in a single motion (point to point movement) or a cyclic motion. It does not matter whether these motions are performed at the same or different speed or whether the surface friction of the object is smooth or rough. When individuals repeatedly move an object upward or downward in either a point to point movement or an oscillating motion, grip force and load force maxima occur at the same time (Flanagan & Wing, 1993; Flanagan & Wing, 1995). Grip force increases as the speed of the movement increases and as the surface texture of the object becomes more slippery, but is still modulated with load force (Flanagan & Wing, 1993; Flanagan & Wing, 1995). As well, it would appear that the grip and load force coupling is not dependent on the type of grip used as coupling has been observed with a variety of different grips and inverse grips (Flanagan & Tresilian, 1994).

White and Westwood (2009)'s pilot study found that individuals consistently use more PLF and PLFR to lift the large object compared to the small object, yet use identical PGF and PGFR. Like White and Westwood (2009)'s pilot study, the current study also found discrepancies between how grip and load forces are modulated as the load forces and grip forces showed different trends from each other; for the same colour group there were significant differences on the first trial between the large and small objects for PLF, but not PLFR and also significant differences between the large and small objects on the first trial for PGFR but not PGF. For the different colour group the only significant difference was on the first trial for PGFR. At first glimpse it would appear that the current study's results and the results of White and Westwood (2009)'s pilot study refute this suggestion, but after examining each trial individually (as described in the methods section each trial had to be analyzed individually to get the force measures) grip and load forces are clearly coupled; both the load force and grip force plots are nearly identical for most trials with the grip and load force maxima occuring at approximately the same time. It can be safely concluded that while the load force and grip forces may show different trends overall, load and grip force coupling does appear to be a universal transporting strategy. Figure 7 (p. 31) demonstrates the coupling observed in a single trial from one of the participants.

According to Johansson (1984) and Nowak et al. (2001) grip force is generated economically such that it is slightly higher than the minimum force necessary to prevent the object from slipping. As well with novel objects the grip and load forces are initially scaled to the size of the object before being properly scaled to the mass of the object (Gordon, et al., 1991a; Gordon, et al, 1991c; Mon-Williams & Murray, 2000). Our data is consistent with these assertions. The individuals who participated in our study would never have had any previous experience with the size-weight illusion stimuli we used. Therefore they would initially overestimate the grip forces to lift both objects and this occured for participants in both groups as well as for the individuals in White and Westwood (2009)'s pilot study. Over time the grip forces decreased for participants in both groups, which demonstrated that the motor system attempted to generate the most economic grip force possible as it became more familiar with the objects. This is also consistent with the findings of Johansson (1984) and Nowak et al. (2001) indicating that individuals do employ grip force economically.

5.7 Limitations

There were several limitations noted for the current study. Even though the perceptual experiences were measured on a scale (1-10; 1 = light, 10 = heavy) that has been demonstrated to be capable and reliable by past researchers (Flanagan & Beltzner, 2000; Grandy & Westwood, 2006), due to the relative nature of this scale some flaws do exist. Individuals frequently asked what "1" and "10" should feel like and even though they were instructed prior to lifting the objects that the maximum mass they would lift would be 500g (and therefore all objects were already fairly light), several still rated both objects as "1" or "2" on the first trial, because they believed that both of the objects were incredibly light. It is believed that this this is the reason for the lift x object interaction (very similar results on the first trial followed by a marked increase in the difference between the large and small objects) found in the perceptual data. Based on this scale it was hard to gauge how large the illusion really was, especially during the first trial.

Another possible limitation was with the size-weight illusion stimuli. The difference in size between large and small objects has been fairly large in prior studies. Flanagan and Beltzner, (2000) used objects in which there was an 8:1 volume ratio between the large and small object. Grandy and Westwood (2006) used objects in which the ratio in volume between the large and small object was 8:1 and Flanagan et al. (2001) also used objects with this ratio between the small and large objects. The stimuli in the current study only had a ratio of about 1.5:1 between the large and small object. The volume ratio discrepancy between the current study and those previously conducted is considerable. Given that the lifting forces in the current study did demonstrate the same trends observed in the 3 studies mentioned previously but for the most part were found to be insignificant could be due to a power or signal: noise issue. The relative difference in size between the two objects was not large enough to induce a significant difference in the lifting forces on the first trial in all parameters. In spite of this however, a robust perceptual effect was found indicating that at least the perceptual illusion was unaffected by the size of the objects.

Lastly, the procedural instructions to "heft" the objects could have introduced enough variability to cause the differences between the large and small objects on early trials to be considered insignificant. Even though individuals were given instructions to lift each object quickly and as straight as possible in a hefting motion, the differences in the speed of the lift varied between individuals; some hefted with more speed than others which would have introduced large differences within the lifting forces creating a mostly true effect with increased error variance. This "hefting" procedure was used because if participants lifted the objects slowly, they would be able to correct the lifting forces on-line during the movement and the initial mismatch in lifting forces would not occur. It is possible that our attempt to eliminate this on-line feedback could be responsible for the insignificant differences in lifting forces we observed.

5.8 Future Research

This study attempted to ascertain whether colour cues provided during a size-weight illusion paradigm are responsible for causing individuals to consistently use more force to lift the large object than the small object yet consistently perceive the small object as being heavier than the large object as demonstrated by White and Westwood (2009)'s pilot study. This was attempted by taking 4 size-weight illusion stimuli; 2 of which were one colour and 2 were another colour and that had a 1.5:1 volume ratio between large and small objects. It was found that the perceptual illusion was robust; however, in spite of showing the same trends as those found by Flanagan and Beltzner (2000), Flanagan et al. (2001) and Grandy and Westwood (2006), for the most part statistical significance was unable to be achieved. Due to the limitations previously identified, there is need for future research concerning the effects of colour on a size-weight illusion paradigm. Past studies have been unable to determine exactly how the size-weight illusion occurs and this study is no exception. Future studies should continue to examine how colour may affect a size-weight illusion, as question still has not been answered satisfactorily. If this study were to be repeated so that individuals were given reference objects when making perceptual reports (for example a 500g block to signify "10" a 250g block to signify "5", and "1" being weightless), it could eliminate the initial floor effect of each object scored "1". As well, the procedure used for this study should be repeated with size-weight illusion stimuli that vary more in size as most studies that have examined the size weight illusion have used objects that have an 8:1 volume ratio between the large and small objects (Flanagan & Beltzner, 2000; Flanagan et al., 2001; Grandy & Westwood, 2006). This could create a greater difference in lifting forces on the first lift than the stimuli employed in the current study. Finally, a future study should use a more standardized procedure where the lift is more properly defined and executed; the more similarly individuals lift the objects, the less likely there is to be large amounts of variation caused by the lift and not the objects themselves.

5.9 Conclusion

The goal of this study was to determine if adding colour cues to suggest different material properties would have any impact on the magnitude of the perceptual and motor response to a size-weight illusion. Past research by White and Westwood (2009) found that when participants lift SWI stimuli of different colours they will consistently use more force to lift the large object than the small object, yet consistently perceive the small object as being heavier than the large object. It was found that perceptually it did not matter whether individuals lifted objects that were identical or different in colour; both groups experienced a similar size-weight illusion. Analysis of the lifting forces revealed no significant differences between objects or between groups for any of the lifting forces. After analyzing the first trial of each lifting force, a group x object interaction was discovered for PLF, where the same colour group used more force to lift the large object than the small object and the different colour group used approximately the same amount of force to lift each block. As well, a main effect of object was found for PGFR where on the first trial both the same colour and different colour groups used more force to lift the large object than the small object. These results illustrate a number of important findings. First, further evidence for the perceptual size weight illusion was provided as both groups experienced the perceptual size-weight illusion equally. As well, the current study demonstrated the independence of the sensory and motor systems as in spite of there being different error signals between groups for the lifting parameters; both groups experienced a robust perceptual illusion. It was also demonstrated that the expectation model might not accurately depict the mechanism for the size-weight illusion, even when individuals accurately predict the lifting forces on the first trial the perceptual illusion remains. The lifting force data showed conflicting results. While for the most part all lifting forces for the same colour group showed the expected trends, they were not found to be significantly different in 2 of 4 lifting forces, and for the different colour group there were unusual lifting force patterns that we were unable to account for. Future studies should repeat the procedure used but should improve the measurement of perception, increase the statistical power by increasing volume disparities between objects, and by standardizing the lifting procedure. As well, it may be more appropriate to use objects of closer density to the standard 1kg/L, since the densities of our objects were .5kg/L for the small object and .25 kg/L for the large object.

REFERENCES

Amazeen, E. L., & Turvey, M. T. (1996). Weight perception and the haptic size-weight illusion are functions of the inertia tensor. *Journal of Experimental Psychology: Human Perception and Performance, 22*(1), 213-232.

Anderson, N. H. (1970). Averaging model applied to the size-weight illusion. *Perception & Psychophysics, 8*(1), 1-4.

Birnbaum, M. H., & Veit, C. T. (1974). Scale-free tests of an additive model for the size-weight illusion. *Perception & Psychophysics, 16*(2), 276-282.

Blakemore, S. J., Frith, C. D., & Wolpert, D. M. (2001). The cerebellum is involved in predicting the sensory consequences of action. *NeuroReport, 12*(9), 1879-1884.

Blakemore, S. J., Goodbody, S. J., & Wolpert, D. M. (1988). Predicting the consequences of our own actions: The role of sensorimotor context estimation. *The Journal of Neuroscience, 18*(18), 7511-7518.

Blakemore, S. J., & Sirigu, A. (2003). Action prediction in the cerebellum and in the parietal lobe. *Experimental Brain Research, 153*, 239-245.

Brodie, E. E., & Ross, H. E. (1984). Sensorimotor mechanisms in weight discrimination. *Perception & Psychophysics, 36*(5), 477-481.

Brodie, E. E., & Ross, H. E. (1985). Jiggling a lifted weight does aid discrimination. *American Journal of Psychology, 98*(3), 469-471.

Cadoret, G., & Smith, A. M. (1996). Friction, not texture, dictates grip forces used during object manipulation. *Journal of Neurophysiology, 75*(5), 1963-1969.

Chouinard, P. A., Leonard, G., & Paus, T. (2005). Role of the primary motor and dorsal premotor cortices in the anticipation of forces during object lifting. *Journal of Neuroscience, 25*(9), 2277-2284.

Davis, C. M., & Roberts, W. (1976). Lifting movements in the size weight illusion. *Perception & Psychophysics, 20*(1), 33-36.

DeCamp, J. E. (1917). The influence of color on apparent weight: A preliminary study. *Journal of Experimental Psychology, 62*, 347-370.

De Veaux, R.D., Velleman, P.F., & Bock, D.E. (2005). In Lynch, D., Guardino, K. and Reeve, R.S. (Eds), *Stats: Data and Models* (1st ed.). Boston: Pearson Addison Wesley.

Diedrichsen, J., Verstynen, T., Hon, A., Lehman, S. L., & Ivry, R. B. (2003). Anticipatory adjustments in the unloading task: Is an efference copy necessary for learning? *Experimental Brain Research, 148*, 272-276.

Eliasson, A. C., Forssberg, H., Ikuta, K., Apel, I., Westling, G., & Johansson, R. S. (1995). Development of human precision grip V: Anticipatory and triggered grip actions during sudden loading. *Experimental Brain Research, 106*, 425-433.

Ellis, R. R., & Lederman, S. J. (1993). The role of haptic versus visual volume cues in the size-weight illusion. *Perception & Psychophysics, 53*(3), 315-324.

Flanagan, J. R., & Beltzner, M. A. (2000). Independence of perceptual and sensorimotor predictions in the size-weight illusion. *Nature Neuroscience, 3*(7), 737-741.

Flanagan, J. R., Bittner, J. P., & Johansson, R. S. (2008). Experience can change distinct size-weight priors enganged when lifting objects and judging their weights. *Current Biology,18(*22), 1742-1747.

Flanagan, J. R., King, S., Wolpert, D. M., & Johansson, R. S. (2001). Sensorimotor prediction and memory in object manipulation. *Canadian Journal of Experimental Psychology, 55*(2), 87-95.

Flanagan, J. R., & Tresilian, J. R. (1994). Grip-load force coupling: A general control strategy for transporting objects. *Journal of Experimental Psychology: Human Perception and Performance, 20*(5), 944-957.

Flanagan, J.R. Tresilian, J.R. & Wing, A.M. (1993). Coupling of grip force and load force during arm movements with grasped objects. *Neuroscience Letters, 152*, 53-56.

Flanagan, J. R., & Wing, A. M. (1993). Modulation of grip force with load force during point-to-point arm movements. *Experimental Brain Research, 95*, 131-143.

Flanagan, J. R., & Wing, A. M. (1995). The stability of precision grip forces during cyclic arm movements with a hand-held load. *Experimental Brain Research, 105*, 455-464.

Flanagan, J. R., & Wing, A. M. (1997). The role of internal models in motion planning and control: Evidence from grip force adjustments during movements of hand held loads. *The Journal of Neuroscience, 17*(4), 1519-1528.

Flournoy, T. (1894). De l'influence de la perception visuelle des corps sur leur poids apparent [influence of visual perception on the apparent weight of objects]. *Annee Psychologique, 1*, 198-208.

Forssberg, H., Kinoshita, H., Eliasson, A. C., Johansson, R. S., Westling, G., & Gordon, A. M. (1992). Development of human precision grip II: Anticipatory control of isometric forces targeted for object's weight. *Experimenal Brain Research, 90*, 393-398.

Gordon, A. M., Forssberg, H., Johansson, R. S., & Westling, G. (1991a). The integration of haptically acquired size information in the programming of precision grip. *Experimental Brain Research, 83*, 483-488.

Gordon, A. M., Forssberg, H., Johansson, R. S., & Westling, G. (1991b). Integration of sensory information during the programming of precision grip: Comments on the contribution of size cues. *Experimental Brain Research, 85*, 226-229.

Gordon, A. M., Forssberg, H., Johansson, R. S., & Westling, G. (1991c). Visual size cues in the programming of manipulative forces during precision grip. *Experimental Brain Research, 83*, 477-482.

Gordon, A. M., Westling, G., Cole, K. J., & Johansson, R. S. (1993). Memory representations underlying motor commands used during manipulation of common and novel objects. *Journal of Neurophysiology, 69*(6), 1789-1796.

Grandy, M. S., & Westwood, D. A. (2006). Opposite perceptual and sensorimotor responses to a size-weight illusion. *Journal of Neurophysiology, 95*(6), 3887-3892.

Greer, K. L. (1989). Gravitational and inertial effects of mass on the perceived heaviness of objects. *Bulletin of the Psychonomic Society, 27*(1), 18-20.

Harshfield, S. P., & DeHardt, D. C. (1970). Weight judgment as a function of apparent density of objects. *Psychonomic Science, 20*(6), 365-366.

Jakobson, L. S., & Goodale, M. A. (1991). Factors affecting higher-order movement planning: A kinematic analysis of human prehension. *Experimental Brain Research, 86*, 199-208.

Johansson, R. S. (1984). Roles of glabrous skin receptors and sensorimotor memory in automatic control of precision grip when lifting rougher or more slippery surfaces. *Experimental Brain Research, 56*, 550-564.

Johansson, R. S., Hager, C., & Backstrom, L. (1992). Somatosensory control of precision grip during unpredictable pulling loads III: Impairments during digital anesthesia. *Experimental Brain Research, 89*, 204-213.

Johansson, R. S., Hager, C., & Riso, R. (1992). Somatosensory control of precision grip during unpredictable pulling loads II: Changes in load force rate. *Experimental Brain Research, 89*(192-203)

Johansson, R. S., & Westling, G. (1987). Signals in tactile afferents from the fingers eliciting adaptive motor responses during precision grip. *Experimental Brain Research, 66*, 141-154.

Johansson, R. S., & Westling, G. (1988a). Coordinated isometric muscle commands adequately and erroneously programmed for the weight during lifting task with precision grip. *Experimental Brain Research, 71*, 59-71.

Johansson, R. S., & Westling, G. (1988b). Programmed and triggered actions to rapid load changes during precision grip. *Experimental Brain Research, 71*, 72-86.

Jones, L. A., & Hunter, I. W. (1983). Perceived force in fatiguing isometric contractions. *Perception & Psychophysics, 33*(4), 369-374.

Jordan, M. I., & Rumelhart, D. E. (1992). Forward models: Supervised learning with a distal teacher. *Cognitive Science, 16*, 307-354.

Kawai, S., Summers, V. A., MacKenzie, C. L., Ivens, C. J., & Yamamoto, T. (2002). Grasping an augmented object to analyze manipulative force control. *Ergonomics, 45*(15), 1091-1102.

Kawai, S. (2003a). Heaviness perception III. Weight/Aperture in the discernment of heaviness in cubes haptically perceived by thumb-index finger grasp. *Experimental Brain Research, 153*, 289-296.

Kawai, S. (2003b). Heaviness perception IV. weight x aperture^{-1} as a heaviness model in finger-grasp perception. *Experimental Brain Research, 153*, 297-301.

Kawai, S., Henigman, F., MacKenzie, C.L., Kuang, A.B., & Faust, P.H. (2007). A reexamination of the size weight illusion induced by visual size cues. *Experimental Brain Research, 179,* 443-456.

Kawato, M. (1999). Internal models for motor control and trajectory planning. *Current Opinion in Neurobiology, 9*, 718-727.

Kingma, I., Savelsbergh, G. J. P., & Toussaint, H. M. (1999). Object size effects on initial lifting forces under microgravity conditions. *Experimental Brain Research, 124*, 422-428.

Kingma, I., Van Dieen, J. H., & Toussaint, H. M. (2005). Scaling of lifting forces in relation to object size in whole body lifting. *Ergonomics, 48*(8), 1020-1030.

Koseleff, P. (1957). Studies in the perception of heaviness. *Acta Psychologica, 13*, 242-252.

Masin, S. C., & Crestoni, L. (1988). Experimental demonstration of the sensory basis of the size-weight illusion. *Perception & Psychophysics, 44*(4), 309-312.

Miall, R. C., & Wolpert, D. M. (1996). Forward models for physiological motor control. *Neural Networks, 9*(8), 1265-1279.

Milner, A. D., & Goodale, M. A. (2006). In D'Esposito M., Driver J., Robbins T., Schacter D., Treisman A. and Weiskrantz L. (Eds.), *The visual brain in action* (2nd ed.). Oxford: Oxford University Press.

Mon-Williams, M., & Murray, A. H. (2000). The size of the visual size cue used for programming manipulative forces during precision grip. *Experimental Brain Research, 135*, 405-410.

Morioka, S., Matsuo, A., & Yagi, F. (2006). The influence of size perception and internal modeling on the control process while lifting. *Journal of Physical Anthropology, 25*(2), 163-169.

Murray, D. J., Ellis, R. R., & Bandomir, C. A. (1999). Charpentier (1891) on the size-weight illusion. *Perception & Psychophysics, 61*(8), 1681-1685.

Nowak, D. A., Glasauer, S., & Hermsdorfer, J. (2004). How predictive is grip force control in the complete absence of somatosensory feedback. *Brain, 127*, 182-192.

Nowak, D. A., Hermsdorfer, J., Glasauer, S., Philipp, J., Meyer, L., & Mai, N. (2001). Short communication: The effects of digital anesthesia on predictive grip force adjustments during vertical lifting movements of a grasped object. *European Journal of Neuroscience, 14*, 756-762.

Payne, M. C. (1958). Apparent weight as a function of color. *American Journal of Psychology, 71*, 725-730.

Payne, M. C. (1961). Apparent weight as a function of hue. *American Journal of Psychology, 74*, 104-105.

Pick, H. L.,Jr, & Pick, A. D. (1967). A developmental and analytic study of the size-weight illusion. *Journal of Experimental Child Psychology, 5*(3), 362-371. doi:0022-0965(67)90064-1 [pii]

Pinkerton, E., & Humphrey, N. K. (1974). The apparent heaviness of colours. *Nature, 250*, 164-165.

Robinson, H. B. (1964). An experimental examination of the size-weight illusion in young children. *Child Development, 35*, 91-107.

Ross, H. E. (1966). Sensory information necessary for the size-weight illusion. *Nature, 212*, 650.

Ross, H. E. (1969). When is a weight not illusory? *The Quarterly Journal of Experimental Psychology, 21*(4), 346-355.

Ross, J., & DiLollo, V. (1970). Differences in heaviness in relation to density and weight. *Perception & Psychophysics, 7*(3), 161-162.

Ross, H. E., & Gregory, R. L. (1970). Weight illusions and weight discrimination-a revised hypothesis. *The Quarterly Journal of Experimental Psychology, 22*(2), 318-328.

Schmitz, C., Jenmalm, P., Ehrsson, H. H., & Forssberg, H. (2005). Brain activity during predictable and unpredictable weight changes when lifting objects. *Journal of Neurophysiology, 93*, 1498-1509.

Scripture, E. W. (1897). The law of size-weight suggestion. *Science, 5*(110), 227.

Sekuler, R. W., Hartings, M. F., & Bauer, J. A. J. (1974). 'Jiggling' a lifted object does not aid judgment of its perceived weight. *American Journal of Psychology, 87*(1/2), 255-259.

Stevens, J. C., & Cain, W. S. (1970). Effort in isometric muscular contractions related to force level and duration. *Perception & Psychophysics, 8*(4), 240-244.

Taylor, C. D. (1930). Visual perception versus visual plus kinesthetic perception in judging colored weights. *Journal of General Psychology, 4*, 229-245.

Warden, C. J., & Flynn, E. L. (1926). The effect of color on apparent size and weight. *American Journal of Psychology, 37*(3), 398-401.

Westling, G., & Johansson, R. S. (1984). Factors influencing the force control during precision grip. *Experimental Brain Research, 53*, 277-284.

Westwood, D. A., & Goodale, M. A. (2003). A haptic size-contrast illusion affects size perception but not grasping. *Experimenal Brain Research, 153*(2), 253-259.

White, J. A., & Westwood, D. A. (2009). *A pound of bricks or a pound of feathers? effects of learning on the size-weight illusion.* Unpublished manuscript.

Wolfe, H. K. (1898). Some effects of size on judgements of weight. *Psychological Review, 5*, 25-54.

Wolpert, D. M., & Flanagan, J. R. (2001). Motor prediction. *Current Biology, 11*(18), 729-732.

Wolpert, D. M., Ghahramani, Z., & Jordan, M. I. (1995). An internal model for sensorimotor integration. *Science, 269*(5232), 1880-1882.

Wolpert, D. M., & Kawato, M. (1998). Multiple paired foward and inverse models for motor control. *Neural Networks, 11*, 1317-1329.

Wolpert, D. M., Miall, R. C., & Kawato, M. (1998). Internal models in the cerebellum. *Trends in Cognitive Sciences, 2*(9), 338-347.

Woodworth, R. S. (1921). *Psychology: A study of mental life*. New York: Holt

APPENDIX A: SCRIPT FOR WORD OF MOUTH RECRUITMENT

Hello,

My name is Justin White and I will be conducting a study entitled "The Influence of Colour on the Size-Weight Illusion: Redefining Expectation".The Goal of my study is to further explore what causes the size-weight illusion and how colour may contribute to you experiencing this illusion.

I am not very picky about who participates in this study, I just ask that you are 18 years old or older, and have no history of neurological, visual or motor disturbances. I will need participants for a maximum of 1 hour. I will be giving you a series of cubes of varying sizes and weights which you will pick up. These cubes will weigh a maximum of 200 g. I will measure how much force you produce to pick up the cubes. You will then be asked to compare the weight of the cubes by assigning them a weight value on a 1-10 scale, 1 being light and 10 being heavy.

There is minimal risk involved in this study. You will be asked to lift cubes of varying sizes and weights a number of times. Because this task is repetitive, you may experience upper body fatigue. If this fatigue becomes uncomfortable you may take a break or cease testing if necessary. The work station that you will occupy will be ergonomically assessed for your safety.

It is also important for me to say that, unfortunately, there is no compensation for participating in this study. However, if you are taking a psychology class, look for my study, it is again entitled "The Influence of Colour on the Size-Weight Illusion" on the Psychology Subject Pool and you will receive 1 bonus point for participating. Please see the study for more details. The psychology subject pool website is located at http://dalpsyc.sona-systems.com, all you need to do is register for an account and sign up through the pool. If you would like to participate or would like more information, send me an email at Justin.White@dal.ca or give me a call in the lab at 494-2066.

Thank you for your time,

Justin

Appendix B: Participants Contact Form

Research Participant Contact Form

Academic Year 2009/2010

Code Number: **2009-2047**

Date Approved: TBA

Staff Member Responsible: Dr. David Westwood
Telephone No. 494-2066

Experimenter(s): Mr. Justin White
Contact E.mail: Justin.White@dal.ca

Duration of Experiment: a maximum of 1, 1 hour session.

Description of the research project

Study Title

The Influence of Colour on the Size-Weight Illusion: Redefining Expectation

Purpose of the research project

To further explore the mechanisms responsible for the size-weight illusion and how colour may contribute to perception of this illusion.

Who can participate

Males and females, over the age of 18, with no history of neurological, visual or motor disturbances (experimenter will carry out screening).

What you will be asked to do

You will be asked to volunteer a maximum of 1 hour of your time. You will be given a series of cubes of varying sizes and weights which you will pick up. These cubes will weigh a maximum of 200g. We will measure how much force you produce to pick up the cubes. You will then be asked to compare the weight of the cubes by assigning them a weight value.

Possible risks and discomforts

The risks for this study are minimal. You will be asked to lift cubes of varying sizes and weights a number of times. Due to the repetitive nature of this task you may experience *upper body fatigue. If this fatigue becomes uncomfortable you may take a break or cease testing if necessary. The work station has been ergonomically assessed to ensure safe lifting loads.*

Compensation

There is no compensation beyond the bonus participation points (one hour session = 1 credit point).

APPENDIX C: SCREENING QUESTIONNAIRE

DALHOUSIE
University

SCHOOL OF HEALTH AND
HUMAN PERFORMANCE
6230 South Street
Halifax, Nova Scotia
Canada B3H 3J5
Tel (902) 494-2152
Fax (902) 494-5120
hahp@dal.ca
www.dal.ca/hahp

<u>If the answer to any of the following questions is "YES", you may not participate in this study. It is not necessary for you to tell us which of the following questions applies to you</u>

1. Have you ever been diagnosed with any form of neurological illness or abnormality? (This includes but is not limited to the following: stroke, cerebral palsy, encephalitis, hydrocephalus, epilepsy, seizures, meningitis, vestibular disorder, Tourette's syndrome, Parkinson's disease, learning disability).

2. Have you ever been diagnosed with any form of visual disorder? (This includes but is not limited to the following: **uncorrected** near- or far-sightedness, astigmatism, loss of an eye, extended period of monocular deprivation, colour blindness, glaucoma, amblyopia, strabismus).

3. Have you ever been diagnosed with any form of movement disorder? (This includes but is not limited to the following: Huntington's disease, Parkinson's disease, peripheral neuropathy, progressive supranuclear palsy, amyotrophic lateral sclerosis, multiple sclerosis, myasthenia gravis, muscular dystrophy, hemiplegia, hemiparesis)?

If you are not sure what any of the above disorders are, please ask. Further discussions can be had on any specific symptoms you may be experiencing. After this we will have the opportunity to rule out any of the above disorders that would exclude you from the study.

APPENDIX D: CONSENT FORM FOR PSYCHOLOGY SUBJECT POOL

Department of Psychology
INFORMED CONSENT FORM

Study Title: The Influence of Colour on the Size-Weight Illusion: Redefining Expectation

Principal Investigator
Justin White (B.Sc. Kinesiology [honours])
Masters Student
School of Health and Human Performance
494-2066
email: Justin.White@dal.ca

> *Feel free to address any questions you may have about the study to the Principal Investigator/Contact Person either now, or after you have participated.*

Psychology Department Code Number **TBA**

1) To All Participants

You are invited to take part in the research project that is described below. This document is intended to:

(1) Inform you of the purpose of the research project and any attendant inconvenience, risk, or benefits.
(2) Explain to you the character of the task.
(3) Make you aware that participation is voluntary and that you may decline to continue at any point during the course of the research project, without loss of expected compensation. Your performance evaluation in any Dalhousie courses will not be influenced by your decision to participate or not.
(4) Assure you that all information assembled is confidential.

2) Purpose of the Study

The purpose of this project is to explore the role of colour on size-weight illusion perception.

3) Study Design

You will be asked to lift a set of small cubes and compare their weight. The amount of force you produce for each trial will be measured.

4) Who can Participate in the Study

You are eligible to participate in this study if you have no history of neurological illness and if you have normal or corrected-to-normal vision. You will be asked to complete a participant screening form before agreeing to participate in this study, to make sure that these requirements are satisfied.

5) Who will be conducting the Research

Mr. Justin White, a MSc Kinesiology student, will be conducting the study. Dr. David Westwood, a faculty member of the School of Health and Human Performance at Dalhousie University, will be supervising.

6) What you will be asked to do

You will be asked to volunteer for a maximum time of one, 1 hour session (30 minute testing period + review of consent and debriefing forms). The experiment will be held at the Action: Motor Control Lab in Dalplex room 217 and you will be expected to find your own way there. You will be given a series of cubes of varying sizes and weights which you will pick up via an instrument that measures fingertip forces. This instrument measures how much force you produce to pick up the cubes. You will then be asked to compare the weight of the cubes by assigning them a weight value.

7) Possible Risks and Discomforts

The risks for this study are minimal. You will be asked to lift cubes of varying sizes and weights a number of times. Due to the repetitive nature of this task you may experience upper body fatigue. If this fatigue becomes uncomfortable you may take a break or cease testing if necessary. The work station has been ergonomically assessed to ensure safe lifting loads.

8) Possible Benefits

There are no benefits to you for your participation.

9) Compensation / Expense Reimbursement

You will receive one credit-point towards your course grade. No additional compensation or reimbursement will be provided.

10) Confidentiality & Anonymity

You will be assigned a participant number after completing this form, so your name will not be included beside any information from this experiment. Your identity will not be revealed when the data from the study are reported in papers and presentations. All data from the study will be kept in a locked cabinet in Dr. David Westwood's faculty office in Dalplex 215F for 5 years after the publication of the results from the study, at which point all physical and electronic data from this study will be destroyed. No one will have direct access to your data except Mr. Justin White.

11) Questions

Feel free to address any questions you may have about the study to the Principal Investigator either now, or after you have participated. If you wish to have the results of the study, contact the Principal Investigator following the experiment.

12) Summary

For a maximum of 60 minutes you will be asked to perform various weight comparisons and lifting tasks. We will measure the amount of force you produce to lift each cube via a force transducer. There is no serious risk of injury or discomfort (refer to above for potential risks) and you will not receive any compensation beyond the course points.

13) Problems or Concerns

In the event that you have difficulties with, or wish to voice concern about, any aspect of your participation in this study, you may contact Patricia Lindley, Director, Dalhousie University's Office of Human Research Ethics Administration, Tel: 494.1462, email patricia.lindley@dal.ca, or contact a member of the Human Research Participants & Ethics Committee of the Department of Psychology, Tel: 494.1580, email beatrice@dal.ca.

SIGNATURE PAGE

Feel free to address any questions you may have about the study to the Principal Investigator either now, or after you have participated.

> **Study Title** The Influence of Colour on the Size-Weight Illusion: Redefining Expectation
> **Name of Principal Investigator** Justin White
> **University Address** Dalplex 217
> **University Telephone** 494-2066
> **Email** Justin.White@dal.ca

14) Psychology Department Participant Pool Policy

Individuals with specific ethical concerns should contact either the Research Supervisor or a member of the Human Research Participants & Ethics Committee of the Department of Psychology, Tel: 494.1580, email beatrice@dal.ca. Individuals may also voice their concerns to Patricia Lindley, Director, Dalhousie University's Office of Human Research Ethics Administration, Tel: 494.1462, email patricia.lindley@dal.ca

Please sign below to confirm that you have had your questions answered to your satisfaction, that you are aware that all records are entirely confidential and that you may discontinue participation at any point in the study.

If you anticipate receiving educational credit points for assisting in this research, you may choose to do so as either a research participant or as an observer. Your performance evaluation as a student will not be influenced by your decision to participate or not in this research study.

If you choose to be a research **Participant**, the researcher will **keep your data** and use it in the research project.

If you choose to be an **Observer**, the researcher will **destroy any data** that you may have provided, after you complete the study.

Please check one box below to indicate whether you choose to be a research participant or an observer.

☐ **Research Participant (Use my data)** ☐ **Observer (Destroy my data)**

Participant's Signature: Date:
Principal Investigator's Signature: Date:

APPENDIX E: CONSENT FORM FOR THOSE RECRUITED BY WORD OF MOUTH

DALHOUSIE UNIVERSITY
Inspiring Minds

School of Health and Human Performance
INFORMED CONSENT FORM

Study Title: The Influence of Colour on the Size-Weight Illusion: Redefining Expectation

Principal Investigator

Justin White (B.Sc. Kinesiology [honours])
Masters Student
School of Health and Human Performance
494-2066
email: Justin.White@dal.ca

Feel free to address any questions you may have about the study to the Principal Investigator/Contact Person either now, or after you have participated.

Psychology Department Code Number TBA

1) To All Participants

You are invited to take part in the research project that is described below. This document is intended to:

(1) Inform you of the purpose of the research project and any attendant inconvenience, risk, or benefits.
(2) Explain to you the character of the task.
(3) Make you aware that participation is voluntary and that you may decline to continue at any point during the course of the research project, without loss of expected compensation. Your performance evaluation in any Dalhousie courses will not be influenced by your decision to participate or not.
(5) Assure you that all information assembled is confidential.

2) Purpose of the Study

The purpose of this project is to explore the role of colour on size-weight illusion perception.

3) Study Design

You will be asked to lift a set of small cubes and compare their weight. The amount of force you produce for each trial will be measured.

5) Who can Participate in the Study

You are eligible to participate in this study if you have no history of neurological illness and if you have normal or corrected-to-normal vision. You will be asked to complete a participant screening form before agreeing to participate in this study, to make sure that these requirements are satisfied.

5) Who will be conducting the Research

Mr. Justin White, a MSc Kinesiology student, will be conducting the study. Dr. David Westwood, a faculty member of the School of Health and Human Performance at Dalhousie University, will be supervising.

6) What you will be asked to do

You will be asked to volunteer for a maximum time of one, 1 hour session (30 minute testing period + review of consent and debriefing forms). The experiment will be held at the Action: Motor Control Lab in Dalplex room 217 and you will be expected to find your own way there. You will be given a series of cubes of varying sizes and weights which you will pick up via an instrument that measures fingertip forces. This instrument measures how much force you produce to pick up the cubes. You will then be asked to compare the weight of the cubes by assigning them a weight value.

7) Possible Risks and Discomforts

The risks for this study are minimal. You will be asked to lift cubes of varying sizes and weights a number of times. Due to the repetitive nature of this task you may experience upper body fatigue. If this fatigue becomes uncomfortable you may take a break or cease testing if necessary. The work station has been ergonomically assessed to ensure safe lifting loads.

8) Possible Benefits

There are no benefits to you for your participation.

9) Compensation / Expense Reimbursement

You will receive no compensation or reimbursement for participating in this study

10) Confidentiality & Anonymity

You will be assigned a participant number after completing this form, so your name will not be included beside any information from this experiment. Your identity will not be revealed when the data from the study are reported in papers and presentations. All data from the study will be kept in a locked cabinet in Dr. David Westwood's faculty office in Dalplex 215F for 5 years after the publication of the results from the study, at which point all physical and electronic data from this study will be destroyed. No one will have direct access to your data except Mr. Justin White.

11) Questions

Feel free to address any questions you may have about the study to the Principal Investigator either now, or after you have participated. If you wish to have the results of the study, contact the Principal Investigator following the experiment.

12) Summary

For a maximum of 60 minutes you will be asked to perform various weight comparisons and lifting tasks. We will measure the amount of force you produce to lift each cube via a force transducer. There is no serious risk of injury or discomfort (refer to above for potential risks) and you will not receive any compensation beyond the course points.

13) Problems or Concerns

In the event that you have difficulties with, or wish to voice concern about, any aspect of your participation in this study, you may contact Patricia Lindley, Director, Dalhousie University's Office of Human Research Ethics Administration, Tel: 494.1462, email patricia.lindley@dal.ca, or contact a member of the Human Research Participants & Ethics Committee of the Department of Psychology, Tel: 494.1580, email beatrice@dal.ca.

SIGNATURE PAGE

Feel free to address any questions you may have about the study to the Principal Investigator either now, or after you have participated.

Study Title The Influence of Colour on the Size-Weight Illusion: Redefining Expectation
Name of Principal Investigator Justin White
University Address Dalplex 215
University Telephone 494-1164
Email Justin.White@dal.ca or david.westwood@dal.ca

Participant's Signature: Date:

Principal Investigator's Signature: Date:

APPENDIX F: ETHICS APPROVAL NOTICE

Date: Fri, 31 Jul 2009 14:20:11 -0300

From: Sharon Gomes <Sharon.Gomes@dal.ca>

Reply-To: Sharon.Gomes@dal.ca

Subject: Ethics Approval # 2009-2047 (White)

To: Justin.White@dal.ca

Please be advised your project entitled " The Influence of Colour on the Size-Weight Illusion: Redefining Expectation" has been approved by the Social Sciences and Humanities Human Research Ethics Board effective July 31,2009.

An official approval letter stating the terms and duration of the approval will be forwarded to your attention in the School of Health and Human Performance in due course.

Please read this letter carefully as it stipulates your ongoing responsibilities with respect to the ethical conduct of the study.

NOTE: For future correspondence concerning this project, we would ask that the assigned file number (2009-2047) is referenced.

Funding: NSERC

Award: 250235-07

Trusting this information is satisfactory.

Sharon Gomes

Research Ethics

Sharon Gomes

Research Ethics Clerk

APPENDIX G: TABLES OF MEANS

Perceptual data

Colour Groups

					95% Confidence Interval	
Group	Object	lift	Mean	Std. Error	Lower Bound	Upper Bound
Different	Small	1	3.314	.275	2.765	3.864
		2	5.143	.337	4.470	5.816
		3	5.429	.313	4.803	6.054
		4	5.629	.315	4.999	6.258
		5	5.743	.341	5.063	6.423
		6	5.486	.330	4.827	6.144
		7	5.943	.330	5.284	6.602
		8	5.857	.307	5.244	6.470
		9	6.143	.327	5.489	6.796
		10	5.943	.309	5.327	6.559
		11	6.000	.357	5.288	6.712
		12	6.200	.373	5.456	6.944
		13	6.257	.377	5.504	7.010
		14	6.086	.357	5.374	6.797
		15	6.086	.386	5.315	6.857
	Large	1	3.257	.250	2.759	3.755
		2	3.771	.311	3.151	4.392
		3	3.457	.242	2.975	3.939
		4	3.600	.253	3.094	4.106
		5	3.943	.290	3.364	4.522
		6	3.971	.293	3.387	4.556
		7	3.971	.269	3.434	4.509
		8	4.086	.308	3.470	4.701
		9	3.857	.291	3.276	4.438
		10	4.343	.332	3.680	5.006
		11	3.914	.329	3.257	4.571
		12	3.943	.331	3.283	4.603
		13	4.086	.299	3.488	4.683
		14	4.057	.359	3.341	4.773
		15	3.914	.356	3.204	4.624
Same	Small	1	3.171	.275	2.622	3.721
		2	4.600	.337	3.927	5.273
		3	5.286	.313	4.660	5.911
		4	5.400	.315	4.771	6.029
		5	5.343	.341	4.663	6.023
		6	5.571	.330	4.913	6.230
		7	5.686	.330	5.027	6.345
		8	5.857	.307	5.244	6.470
		9	5.829	.327	5.175	6.482

		10	5.914	.309	5.299	6.530
		11	6.029	.357	5.317	6.741
		12	6.171	.373	5.428	6.915
		13	6.143	.377	5.390	6.896
		14	6.343	.357	5.631	7.054
		15	6.543	.386	5.772	7.314
	Large	1	2.800	.250	2.302	3.298
		2	3.371	.311	2.751	3.992
		3	3.629	.242	3.147	4.111
		4	3.600	.253	3.094	4.106
		5	3.743	.290	3.164	4.322
		6	3.829	.293	3.244	4.413
		7	3.800	.269	3.263	4.337
		8	3.886	.308	3.270	4.501
		9	4.114	.291	3.533	4.695
		10	4.029	.332	3.365	4.692
		11	4.286	.329	3.629	4.943
		12	4.429	.331	3.768	5.089
		13	4.457	.299	3.860	5.055
		14	4.486	.359	3.769	5.202
		15	4.457	.356	3.747	5.167

Colour Subgroups

					95% Confidence Interval	
Colour	Object	lift	Mean	Std. Error	Lower Bound	Upper Bound
Red	1	1	3.389	.387	2.617	4.161
		2	4.722	.477	3.770	5.674
		3	5.333	.443	4.448	6.218
		4	5.389	.446	4.498	6.280
		5	5.333	.482	4.370	6.297
		6	5.389	.464	4.463	6.315
		7	5.611	.466	4.680	6.542
		8	5.944	.434	5.078	6.810
		9	6.056	.461	5.136	6.975
		10	5.667	.434	4.799	6.534
		11	6.222	.504	5.216	7.228
		12	6.111	.527	5.059	7.164
		13	6.389	.532	5.326	7.452
		14	6.444	.504	5.439	7.450
		15	6.556	.547	5.464	7.648
	2	1	2.889	.345	2.200	3.578
		2	3.278	.440	2.399	4.156
		3	3.722	.334	3.055	4.389
		4	3.556	.358	2.840	4.271
		5	3.833	.410	3.014	4.653
		6	3.833	.404	3.027	4.639
		7	3.944	.375	3.196	4.693

		8	4.111	.426	3.260	4.963
		9	4.278	.405	3.470	5.086
		10	3.889	.469	2.952	4.826
		11	4.389	.461	3.468	5.310
		12	4.444	.462	3.523	5.366
		13	4.667	.412	3.845	5.489
		14	4.556	.500	3.557	5.554
		15	4.500	.503	3.495	5.505
RedS	1	1	3.500	.387	2.728	4.272
		2	5.111	.477	4.159	6.063
		3	5.500	.443	4.615	6.385
		4	5.611	.446	4.720	6.502
		5	5.722	.482	4.759	6.686
		6	5.222	.464	4.296	6.148
		7	5.778	.466	4.847	6.709
		8	6.000	.434	5.134	6.866
		9	6.333	.461	5.414	7.253
		10	5.889	.434	5.021	6.756
		11	5.944	.504	4.939	6.950
		12	6.111	.527	5.059	7.164
		13	6.222	.532	5.159	7.285
		14	5.944	.504	4.939	6.950
		15	6.056	.547	4.964	7.148
	2	1	2.833	.345	2.145	3.522
		2	3.778	.440	2.899	4.656
		3	3.056	.334	2.389	3.722
		4	3.556	.358	2.840	4.271
		5	4.000	.410	3.180	4.820
		6	3.444	.404	2.638	4.251
		7	3.611	.375	2.863	4.360
		8	3.611	.426	2.760	4.463
		9	3.444	.405	2.637	4.252
		10	4.222	.469	3.285	5.159
		11	3.556	.461	2.635	4.476
		12	3.500	.462	2.578	4.422
		13	3.556	.412	2.734	4.378
		14	3.556	.500	2.557	4.554
		15	3.833	.503	2.828	4.839
Yellow	1	1	2.941	.398	2.147	3.735
		2	4.471	.491	3.491	5.450
		3	5.235	.456	4.325	6.146
		4	5.412	.459	4.495	6.329
		5	5.353	.496	4.362	6.344
		6	5.765	.477	4.812	6.717
		7	5.765	.480	4.807	6.723
		8	5.765	.446	4.874	6.656
		9	5.588	.474	4.642	6.534

		10	6.176	.447	5.284	7.069
		11	5.824	.518	4.789	6.858
		12	6.235	.542	5.152	7.318
		13	5.882	.548	4.789	6.976
		14	6.235	.518	5.200	7.270
		15	6.529	.563	5.406	7.653
	2	1	2.706	.355	1.997	3.415
		2	3.471	.453	2.567	4.375
		3	3.529	.344	2.843	4.216
		4	3.647	.369	2.911	4.384
		5	3.647	.422	2.804	4.490
		6	3.824	.415	2.994	4.653
		7	3.647	.386	2.877	4.417
		8	3.647	.439	2.771	4.523
		9	3.941	.416	3.110	4.773
		10	4.176	.483	3.212	5.141
		11	4.176	.475	3.229	5.124
		12	4.412	.475	3.463	5.360
		13	4.235	.424	3.389	5.081
		14	4.412	.515	3.384	5.439
		15	4.412	.518	3.377	5.446
YellowS	1	1	3.118	.398	2.324	3.912
		2	5.176	.491	4.197	6.156
		3	5.353	.456	4.442	6.264
		4	5.647	.459	4.730	6.564
		5	5.765	.496	4.773	6.756
		6	5.765	.477	4.812	6.717
		7	6.118	.480	5.160	7.075
		8	5.706	.446	4.815	6.597
		9	5.941	.474	4.995	6.887
		10	6.000	.447	5.107	6.893
		11	6.059	.518	5.024	7.094
		12	6.294	.542	5.211	7.377
		13	6.294	.548	5.200	7.388
		14	6.235	.518	5.200	7.270
		15	6.118	.563	4.994	7.241
	2	1	3.706	.355	2.997	4.415
		2	3.765	.453	2.861	4.669
		3	3.882	.344	3.196	4.569
		4	3.647	.369	2.911	4.384
		5	3.882	.422	3.039	4.726
		6	4.529	.415	3.700	5.359
		7	4.353	.386	3.583	5.123
		8	4.588	.439	3.712	5.464
		9	4.294	.416	3.463	5.125
		10	4.471	.483	3.507	5.435
		11	4.294	.475	3.347	5.242

		12	4.412	.475	3.463	5.360
		13	4.647	.424	3.801	5.493
		14	4.588	.515	3.561	5.616
		15	4.000	.518	2.966	5.034

Lifting Force Data

Colour Groups

PLF

					95% Confidence Interval	
Group	object	lift	Mean	Std. Error	Lower Bound	Upper Bound
Different	Small	1	4.024	.329	3.365	4.683
		2	4.292	.331	3.629	4.956
		3	4.364	.291	3.782	4.946
		4	4.302	.312	3.677	4.928
		5	4.527	.304	3.919	5.135
		6	4.502	.256	3.989	5.015
		7	4.464	.307	3.849	5.080
		8	4.519	.314	3.890	5.148
		9	4.332	.326	3.679	4.985
		10	4.131	.307	3.517	4.745
		11	4.206	.269	3.668	4.745
		12	4.307	.254	3.798	4.817
		13	4.071	.281	3.507	4.634
		14	4.224	.301	3.621	4.827
		15	4.215	.289	3.636	4.794
	Large	1	3.991	.341	3.307	4.674
		2	4.593	.325	3.942	5.245
		3	4.369	.314	3.740	4.998
		4	4.647	.329	3.989	5.306
		5	4.367	.315	3.736	4.999
		6	3.874	.257	3.360	4.388
		7	4.350	.268	3.813	4.886
		8	4.499	.320	3.858	5.140
		9	4.460	.353	3.753	5.167
		10	4.243	.319	3.603	4.882
		11	4.417	.301	3.814	5.020
		12	4.122	.277	3.568	4.676
		13	4.485	.283	3.918	5.053
		14	4.384	.261	3.861	4.907
		15	4.448	.304	3.839	5.057
Same	Small	1	4.487	.335	3.817	5.158
		2	4.623	.337	3.949	5.298
		3	4.637	.296	4.045	5.229
		4	4.723	.318	4.086	5.359

		5	4.711	.309	4.093	5.329
		6	4.321	.261	3.799	4.843
		7	5.024	.312	4.399	5.650
		8	5.075	.320	4.435	5.715
		9	4.785	.332	4.121	5.449
		10	5.032	.312	4.407	5.656
		11	4.704	.274	4.156	5.251
		12	4.618	.259	4.100	5.137
		13	4.932	.286	4.358	5.505
		14	4.713	.306	4.100	5.327
		15	4.754	.294	4.166	5.343
	Large	1	4.967	.347	4.272	5.662
		2	4.608	.331	3.946	5.270
		3	4.689	.319	4.050	5.329
		4	4.563	.334	3.893	5.232
		5	4.677	.321	4.035	5.319
		6	4.484	.261	3.961	5.007
		7	4.777	.272	4.232	5.323
		8	5.332	.326	4.680	5.984
		9	4.665	.359	3.946	5.384
		10	4.411	.325	3.760	5.061
		11	4.906	.306	4.293	5.519
		12	4.776	.281	4.213	5.339
		13	4.635	.288	4.058	5.212
		14	4.961	.266	4.429	5.494
		15	5.063	.309	4.444	5.683

PLFR

					95% Confidence Interval	
Group	object	lift	Mean	Std. Error	Lower Bound	Upper Bound
Different	Small	1	49.308	8.130	33.028	65.587
		2	47.903	6.207	35.474	60.333
		3	51.718	5.269	41.166	62.269
		4	50.511	5.971	38.555	62.466
		5	48.689	4.633	39.411	57.967
		6	50.461	4.670	41.111	59.812
		7	51.463	5.879	39.691	63.234
		8	48.083	6.020	36.028	60.139
		9	48.526	5.639	37.234	59.818
		10	39.328	5.007	29.302	49.355
		11	46.297	4.636	37.013	55.581
		12	44.128	3.981	36.156	52.100
		13	42.463	4.402	33.648	51.277
		14	48.314	5.976	36.348	60.281
		15	42.057	5.540	30.963	53.150
	Large	1	52.756	5.665	41.412	64.100
		2	51.736	6.043	39.635	63.836

		3	51.183	5.575	40.020	62.347
		4	51.326	6.659	37.990	64.661
		5	50.617	5.442	39.720	61.514
		6	45.190	5.209	34.760	55.621
		7	51.054	5.333	40.374	61.733
		8	48.856	4.634	39.577	58.134
		9	47.080	5.309	36.449	57.711
		10	49.039	4.957	39.114	58.964
		11	49.059	4.883	39.281	58.836
		12	44.251	4.349	35.542	52.960
		13	48.338	4.811	38.703	57.972
		14	48.732	4.277	40.167	57.297
		15	50.635	6.471	37.678	63.593
Same	Small	1	72.659	8.269	56.102	89.217
		2	60.116	6.313	47.474	72.758
		3	59.501	5.359	48.769	70.232
		4	58.292	6.073	46.132	70.452
		5	56.106	4.712	46.670	65.543
		6	50.046	4.749	40.535	59.556
		7	64.184	5.979	52.212	76.157
		8	65.730	6.123	53.468	77.991
		9	58.049	5.736	46.564	69.534
		10	59.385	5.093	49.187	69.583
		11	54.572	4.715	45.130	64.015
		12	54.770	4.049	46.662	62.878
		13	49.523	4.477	40.558	58.488
		14	54.941	6.078	42.770	67.112
		15	59.742	5.635	48.458	71.025
	Large	1	63.057	5.762	51.519	74.595
		2	63.707	6.146	51.399	76.014
		3	61.997	5.670	50.642	73.351
		4	65.005	6.773	51.441	78.568
		5	57.091	5.535	46.008	68.174
		6	56.343	5.298	45.734	66.952
		7	55.563	5.424	44.701	66.426
		8	58.060	4.713	48.623	67.497
		9	58.522	5.400	47.710	69.335
		10	54.790	5.041	44.695	64.885
		11	56.744	4.966	46.799	66.689
		12	55.825	4.423	46.967	64.683
		13	55.863	4.894	46.063	65.662
		14	57.999	4.350	49.287	66.710
		15	59.606	6.581	46.427	72.785

PGF

Group	object	lift	Mean	Std. Error	95% Confidence Interval	
					Lower Bound	Upper Bound

Different	Small	1	15.384	1.533	12.314	18.453
		2	12.324	1.582	9.156	15.491
		3	12.943	1.441	10.056	15.829
		4	11.987	1.496	8.991	14.982
		5	10.688	1.274	8.136	13.239
		6	10.895	1.537	7.818	13.972
		7	10.388	1.194	7.996	12.779
		8	10.369	1.368	7.629	13.108
		9	11.952	1.585	8.778	15.126
		10	9.422	1.215	6.990	11.855
		11	10.341	1.274	7.789	12.893
		12	10.161	1.374	7.409	12.913
		13	9.738	1.046	7.644	11.831
		14	9.804	1.328	7.144	12.465
		15	9.224	1.381	6.459	11.990
	Large	1	15.433	1.690	12.049	18.816
		2	12.245	1.584	9.072	15.417
		3	12.649	1.557	9.531	15.767
		4	11.988	1.675	8.634	15.341
		5	11.667	1.800	8.063	15.272
		6	11.814	1.278	9.254	14.373
		7	11.330	1.445	8.437	14.223
		8	10.609	1.227	8.151	13.066
		9	10.782	1.318	8.142	13.422
		10	11.162	1.413	8.333	13.991
		11	10.468	1.104	8.257	12.679
		12	10.160	1.218	7.721	12.599
		13	10.585	1.207	8.168	13.002
		14	10.708	1.260	8.185	13.230
		15	9.844	1.106	7.629	12.058
Same	Small	1	16.853	1.559	13.731	19.975
		2	15.327	1.609	12.106	18.549
		3	12.738	1.466	9.803	15.674
		4	12.715	1.522	9.668	15.762
		5	11.642	1.296	9.047	14.237
		6	11.833	1.563	8.703	14.963
		7	10.771	1.215	8.339	13.204
		8	10.530	1.391	7.744	13.316
		9	10.970	1.612	7.742	14.199
		10	10.656	1.236	8.181	13.130
		11	10.725	1.296	8.130	13.321
		12	10.874	1.398	8.075	13.674
		13	9.308	1.063	7.179	11.438
		14	10.461	1.351	7.755	13.166
		15	11.079	1.405	8.267	13.892
	Large	1	18.482	1.719	15.040	21.923
		2	16.704	1.611	13.477	19.930

		3	14.010	1.584	10.839	17.182
		4	14.939	1.703	11.529	18.350
		5	13.501	1.831	9.835	17.167
		6	10.708	1.300	8.105	13.312
		7	11.281	1.470	8.339	14.224
		8	11.181	1.248	8.682	13.681
		9	10.734	1.341	8.049	13.419
		10	12.216	1.437	9.339	15.093
		11	10.618	1.123	8.369	12.867
		12	10.347	1.239	7.867	12.828
		13	10.209	1.228	7.751	12.667
		14	10.459	1.281	7.893	13.024
		15	9.295	1.125	7.043	11.548

PGFR

					95% Confidence Interval	
Group	object	lift	Mean	Std. Error	Lower Bound	Upper Bound
Different	Small	1	72.785	9.154	54.454	91.116
		2	68.619	10.787	47.018	90.220
		3	73.212	12.267	48.647	97.776
		4	77.395	11.511	54.345	100.444
		5	69.212	9.324	50.541	87.883
		6	69.322	11.663	45.967	92.678
		7	68.317	11.725	44.839	91.795
		8	72.951	11.780	49.361	96.541
		9	78.320	11.236	55.820	100.820
		10	58.501	8.923	40.634	76.369
		11	62.047	9.311	43.401	80.693
		12	63.494	11.177	41.113	85.876
		13	61.042	6.436	48.154	73.929
		14	62.296	9.814	42.644	81.948
		15	56.015	10.220	35.549	76.480
	Large	1	82.321	12.618	57.053	107.589
		2	71.941	12.710	46.489	97.393
		3	81.177	12.160	56.826	105.528
		4	74.639	13.239	48.127	101.150
		5	71.700	10.942	49.789	93.612
		6	66.420	8.831	48.736	84.103
		7	73.926	13.735	46.422	101.430
		8	69.562	8.519	52.503	86.622
		9	68.814	9.256	50.279	87.349
		10	70.316	10.646	48.998	91.633
		11	64.682	8.472	47.717	81.647
		12	63.323	8.869	45.564	81.083
		13	66.399	7.763	50.854	81.944
		14	66.764	9.282	48.176	85.352
		15	66.307	9.264	47.755	84.859

Same	Small	1	85.609	9.311	66.964	104.253
		2	94.364	10.972	72.394	116.334
		3	88.554	12.477	63.569	113.539
		4	88.670	11.707	65.226	112.113
		5	75.183	9.483	56.193	94.173
		6	79.183	11.863	55.429	102.938
		7	87.563	11.925	63.683	111.442
		8	82.298	11.982	58.305	106.292
		9	74.932	11.428	52.047	97.816
		10	74.303	9.075	56.130	92.475
		11	79.315	9.471	60.350	98.279
		12	84.361	11.368	61.597	107.125
		13	61.753	6.546	48.646	74.861
		14	74.319	9.982	54.330	94.307
		15	80.697	10.395	59.881	101.512
	Large	1	115.186	12.834	89.486	140.886
		2	108.480	12.928	82.593	134.368
		3	95.778	12.368	71.011	120.546
		4	101.167	13.466	74.202	128.131
		5	89.575	11.129	67.289	111.861
		6	77.602	8.982	59.616	95.588
		7	81.532	13.970	53.558	109.506
		8	72.159	8.665	54.808	89.510
		9	72.236	9.414	53.384	91.088
		10	86.419	10.828	64.737	108.101
		11	75.261	8.617	58.006	92.516
		12	75.363	9.021	57.300	93.427
		13	68.583	7.896	52.772	84.394
		14	76.397	9.441	57.491	95.302
		15	71.280	9.423	52.411	90.149

Colour Subgroups

PLF

					95% Confidence Interval	
Colour	object	lift	Mean	Std. Error	Lower Bound	Upper Bound
Red	Small	1	4.232	.470	3.289	5.174
		2	4.923	.466	3.988	5.857
		3	5.245	.402	4.441	6.050
		4	4.943	.448	4.046	5.840
		5	5.009	.432	4.143	5.875
		6	5.014	.343	4.327	5.701
		7	5.226	.438	4.348	6.104
		8	4.894	.451	3.990	5.798
		9	5.031	.459	4.111	5.951
		10	5.054	.436	4.180	5.928

		11	4.842	.386	4.069	5.615
		12	4.735	.361	4.013	5.458
		13	5.123	.398	4.325	5.922
		14	4.910	.432	4.044	5.775
		15	5.005	.412	4.180	5.831
	Large	1	4.796	.487	3.821	5.771
		2	4.945	.463	4.017	5.872
		3	4.891	.450	3.988	5.793
		4	4.954	.465	4.022	5.886
		5	4.763	.454	3.854	5.672
		6	4.460	.365	3.728	5.192
		7	4.733	.385	3.961	5.505
		8	5.249	.461	4.326	6.172
		9	5.005	.499	4.004	6.005
		10	5.196	.433	4.328	6.064
		11	5.377	.424	4.528	6.226
		12	4.924	.391	4.141	5.708
		13	4.986	.402	4.180	5.791
		14	5.307	.368	4.570	6.044
		15	5.417	.432	4.551	6.284
RedS	Small	1	3.862	.470	2.919	4.804
		2	4.723	.466	3.789	5.658
		3	4.378	.402	3.574	5.183
		4	4.247	.448	3.350	5.144
		5	4.696	.432	3.830	5.562
		6	4.629	.343	3.942	5.316
		7	4.694	.438	3.816	5.572
		8	4.548	.451	3.644	5.451
		9	4.776	.459	3.856	5.696
		10	4.496	.436	3.622	5.370
		11	4.318	.386	3.545	5.091
		12	4.627	.361	3.904	5.349
		13	4.405	.398	3.607	5.203
		14	4.288	.432	3.422	5.153
		15	4.369	.412	3.543	5.194
	Large	1	4.299	.487	3.324	5.274
		2	4.459	.463	3.531	5.386
		3	4.424	.450	3.521	5.326
		4	4.417	.465	3.485	5.350
		5	4.342	.454	3.433	5.252
		6	4.173	.365	3.441	4.905
		7	4.455	.385	3.684	5.227
		8	4.537	.461	3.614	5.460
		9	4.831	.499	3.831	5.831
		10	4.373	.433	3.505	5.241
		11	4.428	.424	3.579	5.277
		12	4.486	.391	3.703	5.270

		13	4.431	.402	3.625	5.236
		14	4.168	.368	3.431	4.905
		15	4.394	.432	3.527	5.261
Yellow	Small	1	4.761	.487	3.786	5.737
		2	4.303	.483	3.336	5.270
		3	3.985	.416	3.152	4.818
		4	4.486	.463	3.558	5.415
		5	4.392	.447	3.495	5.288
		6	3.578	.355	2.867	4.289
		7	4.808	.454	3.899	5.717
		8	5.269	.467	4.333	6.204
		9	4.522	.475	3.570	5.475
		10	5.007	.451	4.103	5.912
		11	4.556	.399	3.756	5.356
		12	4.493	.373	3.745	5.241
		13	4.726	.412	3.900	5.552
		14	4.503	.447	3.607	5.399
		15	4.485	.427	3.630	5.340
	Large	1	5.150	.504	4.140	6.159
		2	4.247	.479	3.287	5.207
		3	4.474	.466	3.540	5.408
		4	4.144	.481	3.179	5.108
		5	4.585	.470	3.644	5.526
		6	4.511	.378	3.753	5.268
		7	4.824	.399	4.026	5.623
		8	5.422	.477	4.466	6.377
		9	4.301	.517	3.266	5.336
		10	3.569	.448	2.671	4.468
		11	4.401	.438	3.522	5.279
		12	4.617	.405	3.806	5.428
		13	4.259	.416	3.426	5.093
		14	4.591	.381	3.828	5.354
		15	4.684	.448	3.787	5.581
YellowS	Small	1	4.187	.470	3.245	5.129
		2	3.861	.466	2.927	4.796
		3	4.349	.402	3.545	5.154
		4	4.358	.448	3.461	5.255
		5	4.358	.432	3.492	5.224
		6	4.375	.343	3.688	5.062
		7	4.235	.438	3.357	5.113
		8	4.490	.451	3.586	5.394
		9	3.888	.459	2.968	4.808
		10	3.767	.436	2.893	4.640
		11	4.095	.386	3.322	4.868
		12	3.988	.361	3.265	4.710
		13	3.737	.398	2.938	4.535
		14	4.160	.432	3.295	5.026

		15	4.061	.412	3.235	4.887
	Large	1	3.682	.487	2.707	4.658
		2	4.728	.463	3.800	5.656
		3	4.315	.450	3.412	5.218
		4	4.877	.465	3.945	5.809
		5	4.392	.454	3.483	5.301
		6	3.575	.365	2.843	4.307
		7	4.244	.385	3.472	5.016
		8	4.461	.461	3.538	5.384
		9	4.090	.499	3.090	5.090
		10	4.112	.433	3.244	4.980
		11	4.405	.424	3.556	5.254
		12	3.757	.391	2.974	4.541
		13	4.540	.402	3.734	5.346
		14	4.600	.368	3.863	5.337
		15	4.502	.432	3.635	5.369

PLFR

Colour	object	lift	Mean	Std. Error	95% Confidence Interval	
					Lower Bound	Upper Bound
Red	Small	1	64.278	11.573	41.085	87.471
		2	58.600	8.931	40.701	76.499
		3	60.402	7.578	45.216	75.589
		4	58.845	8.594	41.621	76.069
		5	58.248	6.655	44.910	71.586
		6	50.780	6.717	37.319	64.241
		7	64.991	8.459	48.038	81.944
		8	60.167	8.599	42.933	77.401
		9	61.525	8.090	45.312	77.739
		10	60.761	7.188	46.355	75.167
		11	56.172	6.645	42.855	69.488
		12	49.654	5.609	38.414	60.895
		13	50.873	6.268	38.311	63.435
		14	57.908	8.574	40.725	75.090
		15	62.275	7.957	46.329	78.221
	Large	1	61.745	8.149	45.414	78.075
		2	63.812	8.611	46.554	81.069
		3	62.145	8.015	46.083	78.208
		4	66.910	9.574	47.724	86.097
		5	56.724	7.825	41.043	72.406
		6	49.420	7.373	34.644	64.197
		7	53.127	7.649	37.798	68.456
		8	62.585	6.613	49.333	75.838
		9	61.562	7.601	46.330	76.793
		10	61.488	7.008	47.443	75.532
		11	59.690	6.999	45.662	73.717
		12	54.293	6.181	41.906	66.681

		13	55.182	6.920	41.313	69.051
		14	57.362	6.118	45.102	69.623
		15	63.423	9.209	44.969	81.877
RedS	Small	1	45.949	11.573	22.756	69.142
		2	48.256	8.931	30.358	66.155
		3	53.322	7.578	38.136	68.509
		4	51.072	8.594	33.848	68.296
		5	47.798	6.655	34.460	61.135
		6	49.236	6.717	35.774	62.697
		7	50.329	8.459	33.376	67.281
		8	48.566	8.599	31.332	65.799
		9	48.823	8.090	32.610	65.036
		10	36.856	7.188	22.450	51.261
		11	49.177	6.645	35.860	62.493
		12	47.462	5.609	36.221	58.703
		13	47.158	6.268	34.596	59.720
		14	46.124	8.574	28.942	63.307
		15	40.808	7.957	24.862	56.754
	Large	1	51.605	8.149	35.274	67.935
		2	45.252	8.611	27.995	62.510
		3	48.974	8.015	32.912	65.036
		4	53.183	9.574	33.996	72.369
		5	48.635	7.825	32.954	64.317
		6	46.556	7.373	31.780	61.333
		7	53.551	7.649	38.222	68.880
		8	48.816	6.613	35.563	62.068
		9	49.958	7.601	34.727	65.190
		10	47.228	7.008	33.183	61.272
		11	50.720	6.999	36.693	64.748
		12	49.246	6.181	36.858	61.633
		13	46.946	6.920	33.077	60.815
		14	45.102	6.118	32.842	57.362
		15	44.345	9.209	25.890	62.799
Yellow	Small	1	81.639	11.979	57.632	105.646
		2	61.741	9.245	43.214	80.267
		3	58.534	7.844	42.815	74.254
		4	57.699	8.896	39.871	75.528
		5	53.811	6.889	40.005	67.617
		6	49.259	6.953	35.325	63.193
		7	63.320	8.756	45.773	80.868
		8	71.690	8.901	53.852	89.529
		9	54.324	8.374	37.541	71.107
		10	57.911	7.441	43.000	72.823
		11	52.858	6.878	39.075	66.642
		12	60.251	5.806	48.616	71.886
		13	48.076	6.488	35.074	61.079
		14	51.763	8.875	33.977	69.548

		15	57.027	8.236	40.521	73.533
	Large	1	64.463	8.435	47.559	81.367
		2	63.594	8.914	45.731	81.458
		3	61.837	8.296	45.211	78.463
		4	62.963	9.910	43.103	82.823
		5	57.484	8.100	41.252	73.716
		6	63.761	7.632	48.466	79.056
		7	58.174	7.917	42.307	74.041
		8	53.212	6.845	39.495	66.930
		9	55.266	7.867	39.499	71.032
		10	47.614	7.254	33.077	62.152
		11	53.588	7.245	39.069	68.108
		12	57.466	6.398	44.644	70.289
		13	56.592	7.163	42.236	70.947
		14	58.680	6.332	45.990	71.371
		15	55.516	9.532	36.414	74.618
YellowS	Small	1	52.666	11.573	29.473	75.859
		2	47.550	8.931	29.652	65.449
		3	50.113	7.578	34.927	65.300
		4	49.949	8.594	32.726	67.173
		5	49.580	6.655	36.242	62.917
		6	51.687	6.717	38.225	65.148
		7	52.597	8.459	35.644	69.549
		8	47.601	8.599	30.367	64.835
		9	48.230	8.090	32.016	64.443
		10	41.801	7.188	27.395	56.207
		11	43.417	6.645	30.100	56.733
		12	40.793	5.609	29.552	52.034
		13	37.767	6.268	25.206	50.329
		14	50.504	8.574	33.322	67.687
		15	43.306	7.957	27.359	59.252
	Large	1	53.907	8.149	37.577	70.238
		2	58.219	8.611	40.961	75.477
		3	53.392	8.015	37.330	69.455
		4	49.468	9.574	30.282	68.655
		5	52.599	7.825	36.917	68.280
		6	43.825	7.373	29.048	58.601
		7	48.556	7.649	33.227	63.885
		8	48.896	6.613	35.644	62.148
		9	44.201	7.601	28.970	59.433
		10	50.850	7.008	36.806	64.894
		11	47.397	6.999	33.369	61.424
		12	39.257	6.181	26.869	51.645
		13	49.730	6.920	35.861	63.598
		14	52.362	6.118	40.102	64.622
		15	56.926	9.209	38.472	75.380

PGF

Colour	object	lift	Mean	Std. Error	95% Confidence Interval Lower Bound	Upper Bound
Red	Small	1	17.735	2.200	13.326	22.144
		2	14.594	2.263	10.060	19.129
		3	10.784	2.026	6.723	14.844
		4	10.044	2.077	5.881	14.206
		5	10.123	1.802	6.511	13.735
		6	10.431	2.194	6.035	14.828
		7	9.874	1.708	6.451	13.298
		8	8.932	1.945	5.034	12.829
		9	9.404	2.256	4.882	13.926
		10	8.259	1.684	4.883	11.634
		11	8.151	1.764	4.615	11.687
		12	9.100	1.946	5.200	12.999
		13	7.536	1.462	4.607	10.465
		14	9.018	1.889	5.233	12.804
		15	9.145	1.952	5.232	13.058
	Large	1	19.264	2.427	14.400	24.128
		2	14.660	2.245	10.161	19.159
		3	11.858	2.201	7.447	16.268
		4	13.856	2.400	9.046	18.665
		5	13.440	2.589	8.251	18.630
		6	9.669	1.824	6.015	13.324
		7	10.682	2.076	6.520	14.843
		8	9.110	1.720	5.663	12.557
		9	8.773	1.856	5.054	12.492
		10	9.724	1.971	5.773	13.674
		11	8.561	1.538	5.477	11.644
		12	8.456	1.705	5.040	11.872
		13	9.327	1.728	5.864	12.791
		14	8.655	1.764	5.120	12.191
		15	7.838	1.563	4.707	10.970
RedS	Small	1	15.236	2.200	10.827	19.645
		2	13.434	2.263	8.899	17.969
		3	14.201	2.026	10.140	18.261
		4	13.220	2.077	9.058	17.383
		5	11.585	1.802	7.973	15.197
		6	11.387	2.194	6.990	15.783
		7	10.850	1.708	7.427	14.274
		8	10.509	1.945	6.612	14.407
		9	12.766	2.256	8.245	17.288
		10	9.801	1.684	6.426	13.177
		11	10.624	1.764	7.088	14.160
		12	10.706	1.946	6.807	14.606
		13	10.294	1.462	7.365	13.223
		14	10.371	1.889	6.586	14.157

		15	9.172	1.952	5.259	13.085
	Large	1	15.083	2.427	10.219	19.947
		2	11.898	2.245	7.399	16.397
		3	12.218	2.201	7.808	16.629
		4	12.506	2.400	7.697	17.315
		5	12.226	2.589	7.037	17.415
		6	12.561	1.824	8.906	16.215
		7	11.118	2.076	6.957	15.280
		8	10.372	1.720	6.925	13.820
		9	11.393	1.856	7.674	15.111
		10	11.839	1.971	7.888	15.789
		11	10.623	1.538	7.540	13.706
		12	11.130	1.705	7.714	14.547
		13	10.289	1.728	6.826	13.753
		14	9.489	1.764	5.953	13.024
		15	9.242	1.563	6.111	12.374
Yellow	Small	1	15.909	2.277	11.345	20.473
		2	16.112	2.342	11.418	20.806
		3	14.833	2.097	10.630	19.036
		4	15.578	2.150	11.269	19.886
		5	13.269	1.866	9.530	17.008
		6	13.335	2.271	8.785	17.886
		7	11.732	1.768	8.188	15.276
		8	12.242	2.013	8.208	16.277
		9	12.649	2.335	7.968	17.329
		10	13.224	1.743	9.730	16.718
		11	13.484	1.826	9.824	17.144
		12	12.776	2.014	8.740	16.812
		13	11.208	1.513	8.176	14.240
		14	12.006	1.955	8.087	15.924
		15	13.152	2.021	9.102	17.202
	Large	1	17.644	2.512	12.609	22.678
		2	18.894	2.324	14.237	23.551
		3	16.317	2.278	11.751	20.882
		4	16.100	2.484	11.122	21.078
		5	13.566	2.680	8.194	18.937
		6	11.822	1.888	8.039	15.605
		7	11.924	2.149	7.617	16.231
		8	13.400	1.780	9.832	16.968
		9	12.835	1.921	8.985	16.684
		10	14.887	2.040	10.798	18.976
		11	12.822	1.592	9.631	16.014
		12	12.374	1.765	8.838	15.910
		13	11.153	1.789	7.568	14.738
		14	12.391	1.826	8.731	16.050
		15	10.856	1.617	7.615	14.098
YellowS	Small	1	15.531	2.200	11.122	19.941

		2	11.213	2.263	6.678	15.748
		3	11.685	2.026	7.625	15.745
		4	10.753	2.077	6.591	14.916
		5	9.790	1.802	6.178	13.402
		6	10.403	2.194	6.007	14.800
		7	9.925	1.708	6.501	13.348
		8	10.228	1.945	6.331	14.126
		9	11.137	2.256	6.615	15.659
		10	9.043	1.684	5.668	12.419
		11	10.058	1.764	6.522	13.594
		12	9.616	1.946	5.716	13.515
		13	9.181	1.462	6.252	12.110
		14	9.238	1.889	5.452	13.023
		15	9.276	1.952	5.364	13.189
	Large	1	15.783	2.427	10.918	20.647
		2	12.591	2.245	8.092	17.090
		3	13.079	2.201	8.668	17.489
		4	11.469	2.400	6.660	16.279
		5	11.109	2.589	5.920	16.298
		6	11.067	1.824	7.412	14.721
		7	11.541	2.076	7.380	15.703
		8	10.845	1.720	7.398	14.292
		9	10.171	1.856	6.452	13.890
		10	10.485	1.971	6.535	14.435
		11	10.313	1.538	7.230	13.396
		12	9.190	1.705	5.774	12.606
		13	10.880	1.728	7.417	14.344
		14	11.926	1.764	8.391	15.462
		15	10.445	1.563	7.314	13.577

PGFR

					95% Confidence Interval	
Colour	object	lift	Mean	Std. Error	Lower Bound	Upper Bound
Red	Small	1	82.826	13.142	56.489	109.163
		2	80.668	15.250	50.106	111.230
		3	67.048	17.122	32.735	101.361
		4	73.059	16.117	40.761	105.357
		5	67.984	13.273	41.385	94.584
		6	71.867	16.670	38.460	105.273
		7	85.180	16.814	51.484	118.877
		8	69.264	16.714	35.770	102.759
		9	67.137	16.080	34.912	99.363
		10	63.257	12.595	38.015	88.499
		11	64.607	13.056	38.443	90.772
		12	74.421	15.958	42.440	106.402
		13	55.497	9.042	37.377	73.617
		14	61.131	13.853	33.369	88.894

		15	70.117	14.522	41.014	99.221
	Large	1	107.256	18.101	70.981	143.531
		2	88.489	17.877	52.662	124.315
		3	78.872	17.196	44.410	113.335
		4	96.741	18.967	58.730	134.752
		5	81.225	15.572	50.018	112.432
		6	71.127	12.390	46.296	95.958
		7	78.120	19.758	38.523	117.716
		8	64.824	12.164	40.447	89.202
		9	69.192	13.220	42.699	95.685
		10	77.072	15.208	46.594	107.550
		11	67.047	12.070	42.858	91.236
		12	66.592	12.589	41.362	91.821
		13	62.333	11.096	40.095	84.571
		14	59.784	12.949	33.834	85.735
		15	66.219	13.302	39.562	92.875
RedS	Small	1	68.406	13.142	42.070	94.743
		2	75.154	15.250	44.591	105.716
		3	79.270	17.122	44.957	113.583
		4	89.915	16.117	57.617	122.213
		5	76.765	13.273	50.165	103.364
		6	76.860	16.670	43.454	110.267
		7	75.725	16.814	42.029	109.422
		8	80.205	16.714	46.711	113.700
		9	83.071	16.080	50.846	115.297
		10	65.498	12.595	40.256	90.739
		11	67.568	13.056	41.403	93.733
		12	67.363	15.958	35.382	99.345
		13	69.541	9.042	51.421	87.660
		14	67.973	13.853	40.210	95.735
		15	62.196	14.522	33.092	91.299
	Large	1	81.687	18.101	45.412	117.962
		2	74.363	17.877	38.536	110.190
		3	80.324	17.196	45.862	114.786
		4	83.439	18.967	45.428	121.450
		5	80.887	15.572	49.680	112.094
		6	79.826	12.390	54.995	104.657
		7	71.612	19.758	32.016	111.209
		8	73.040	12.164	48.662	97.418
		9	77.066	13.220	50.573	103.559
		10	73.291	15.208	42.814	103.769
		11	68.542	12.070	44.353	92.731
		12	70.056	12.589	44.826	95.285
		13	69.331	11.096	47.094	91.569
		14	62.980	12.949	37.029	88.930
		15	65.803	13.302	39.146	92.460
Yellow	Small	1	88.590	13.603	61.329	115.851

		2	109.038	15.786	77.403	140.673
		3	111.596	17.723	76.079	147.113
		4	105.396	16.682	71.964	138.828
		5	82.896	13.739	55.363	110.429
		6	87.023	17.255	52.443	121.602
		7	90.115	17.404	55.236	124.995
		8	96.264	17.300	61.593	130.934
		9	83.283	16.645	49.927	116.640
		10	86.137	13.037	60.010	112.265
		11	95.073	13.514	67.990	122.156
		12	95.011	16.519	61.908	128.115
		13	68.456	9.359	49.700	87.212
		14	88.448	14.340	59.711	117.185
		15	92.032	15.032	61.907	122.156
	Large	1	123.682	18.736	86.134	161.231
		2	129.900	18.505	92.816	166.984
		3	113.892	17.800	78.220	149.564
		4	105.908	19.633	66.563	145.253
		5	98.521	16.118	66.219	130.823
		6	84.540	12.825	58.838	110.243
		7	85.188	20.452	44.201	126.174
		8	80.018	12.591	54.784	105.251
		9	75.497	13.684	48.075	102.920
		10	96.433	15.742	64.886	127.981
		11	84.062	12.494	59.023	109.100
		12	84.761	13.031	58.646	110.876
		13	75.279	11.486	52.261	98.297
		14	94.195	13.404	67.334	121.057
		15	76.703	13.768	49.110	104.295
YellowS	Small	1	77.164	13.142	50.827	103.501
		2	62.084	15.250	31.522	92.646
		3	67.153	17.122	32.840	101.466
		4	64.875	16.117	32.576	97.173
		5	61.660	13.273	35.060	88.259
		6	61.784	16.670	28.378	95.191
		7	60.909	16.814	27.212	94.605
		8	65.697	16.714	32.202	99.191
		9	73.569	16.080	41.343	105.794
		10	51.505	12.595	26.264	76.747
		11	56.527	13.056	30.362	82.692
		12	59.625	15.958	27.644	91.607
		13	52.543	9.042	34.423	70.663
		14	56.619	13.853	28.856	84.382
		15	49.834	14.522	20.730	78.937
	Large	1	82.955	18.101	46.680	119.230
		2	69.519	17.877	33.692	105.346
		3	82.030	17.196	47.567	116.492

4	65.838	18.967	27.827	103.849
5	62.514	15.572	31.307	93.721
6	53.013	12.390	28.182	77.844
7	76.240	19.758	36.644	115.837
8	66.085	12.164	41.707	90.462
9	60.563	13.220	34.070	87.055
10	67.340	15.208	36.862	97.818
11	60.823	12.070	36.634	85.012
12	56.591	12.589	31.361	81.820
13	63.467	11.096	41.229	85.704
14	70.549	12.949	44.598	96.499
15	66.811	13.302	40.154	93.467