GENERALIZATION OF LEARNING IN ADOLESCENTS AND ADULTS WITH AUTISM SPECTRUM DISORDER

by

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Abstract

Autism Spectrum Disorder (ASD), a neurodevelopmental disorder, is defined by impairments in reciprocal social interaction, communication, and by the presence of restricted and repetitive patterns of behavior, interests, and activities. Although not made explicit in lists of diagnostic criteria, ASD is associated with atypical cognitive processes. Learning represents one aspect of cognition that is atypical in ASD, and atypical learning processes in ASD probably contribute to well-established abnormalities in language and social skill development, and to poor adult outcomes. Of particular interest for the current research is generalization of explicit learning processes, and several prominent theories of cognition and perception in ASD predict that individuals with ASD will have difficulty with generalization. Mixed evidence has been found for both implicit and explicit learning deficits among individuals with ASD. Several studies have provided some evidence of poor generalization in this population, but few have explicitly measured generalization ability in ASD. A novel computerized card task was developed for the purpose of examining learning and generalization. This task required participants to select sets of three cards by applying a complex explicitly defined rule. After demonstration of ability to apply the rule, the stimulus set was switched and participants were required to apply the rule to the new stimuli. Three stimulus switches were made during the task. Twenty-eight participants with ASD and 32 control participants were recruited for the study. All were asked to complete measures of intelligence and executive function in addition to the generalization measure, and a measure of adaptive skills was included for the ASD group. Challenging the conventional assumption that generalization is a weakness for individuals with ASD, no between-group differences in initial ability to learn or ability to generalize the rule were found. The ASD group demonstrated an inferior rate of improvement in performance following one of the stimulus switches, but did not demonstrate generalization impairment. Correlations between learning and generalization measures, IQ, executive functioning, and adaptive skills are considered. Results are interpreted within the context of the literature on learning in ASD, and the potential impact of task complexity and social learning demands are discussed.

List Of Abbreviations Used

ABAS-II – Adaptive Behavior Assessment System – II

ADOS – Autism Diagnostic Observation Schedule

ANOVA – Analysis of Variance

ANCOVA – Analysis of Covariance

ASD – Autism Spectrum Disorder

BD – Wechsler Block Design task

DSM-V – Diagnostic and Statistical Manual of Mental Disorders - Fifth Edition

EFT – Embedded Figures Test

EPF – Enhanced Perceptual Functioning

fMRI – Functional Magnetic Resonance Imaging

Gen1 – Generalization One from the Set Task

Gen2 – Generalization Two from the Set Task

Gen3 – Generalization Three from the Set Task

NVIQ – Nonverbal Intelligence Quotient (or Perceptual Reasoning Quotient)

IQ – Intelligence Quotient

RT – Reaction time

VIQ – Verbal Intelligence Quotient

WAIS-IV – Wechsler Adult Intelligence Scale-IV

WASI – Wechsler Abbreviated Intelligence Scale

WCST – Wisconsin Card Sorting Test

WISC – IV - Wechsler Intelligence Scale for Children-IV

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Chapter 1: Introduction

1.1 Overview

Autism Spectrum Disorder (ASD) is a neurodevelopmental disorder that is present from early childhood. It is defined by impairments in reciprocal social interaction, communication, and by the presence of restricted and repetitive patterns of behavior, interests, and activities (*Diagnostic and Statistical Manual of Mental Disorders - Fifth Edition*; DSM-V; American Psychiatric Association, 2013). The degree of impairment in these domains that is associated with ASD is quite variable, as highlighted by the inclusion of severity ratings in the DSM-V. Although not made explicit in lists of diagnostic criteria, ASD is associated with atypical cognitive processes, including exceptional abilities in some domains (e.g., memory and visual search; Dawson, Mottron, & Gernsbacher, 2008; O'Riordan, Plaisted, Driver, & Baron-Cohen, 2001) and deficits in other domains (e.g., executive function; Hill, 2004a, 2004b). Learning represents one aspect of cognition that is atypical in ASD, and atypical learning processes in ASD are made evident by well-established abnormalities in language development (Kjelgaard & Tager-Flusberg, 2001), social skill development (Carter, Davis, Klin, & Volkmar, 2005; Williams White, Koenig, & Scahill, 2007), and poor adult outcomes (Szatmari, Bartolucci, Bremner, Bond, & Rich, 1989; Howlin, Goode, Hutton, & Rutter, 2004). As a result of skill deficits that are associated with ASD, considerable resources have been devoted to the development of intervention programs aimed at impacting constructs such as early language and cognitive development (review: Warren et al., 2011), social skills (reviews: Bellini & Peters, 2008; Bellini, Peters, Benner, Hopf, 2007; Williams White, Koenig, Scahill, 2007), life skills (e.g. TEACCH, addressing life skills and other domains; Virues-Ortega, Julio, Pastor-Barriuso, 2013), and various mental health problems (e.g., anxiety; Reaven, Blakeley-Smith, Culhane-Shelburne, & Hepburn, 2012). Although an understanding of learning and generalization of skills among people with ASD could inform the development of these intervention programs, the literature on these topics in ASD is characterized by a lack of consensus (for a review, see Dawson, Mottron, & Gernsbacher, 2008). The goal of the current research is to add to our understanding of learning and generalization in ASD, and in doing so inform the development and implementation of intervention programs for individuals with ASD.

This research was initially motivated by the clinical experiences of the author. Working in a supported independent-living setting with adults with ASD, the author and several other staff noted that a key factor hindering the development of greater independence for some clients was difficulty generalizing information or skills to new contexts or tasks. Colloquially, this difficulty was characterized as a lack of flexibility in the application of skills or knowledge. Importantly, these clinical observations are consistent with portions of the literature in ASD (e.g., Lovaas, Koegel, & Schreibman, 1979; Plaisted, 2001; Brown & Bebko, 2012), yet relatively little research has explicitly examined the ability of individuals with ASD to generalize skills or use knowledge in novel contexts. As a result, a novel task was developed to assess the ability to learn a rule and generalize the use of the rule in several contexts. This task forms the backbone of the current research.

This thesis begins by summarizing several theories that describe perceptual and cognitive processes in ASD, and highlighting the predictions of these theories regarding learning and generalization. This summary is followed by a review of the existing empirical literature examining learning and generalization in people with ASD, focusing on types of learning that are most relevant to the current research. Next, the novel task used to examine learning and generalization in the current study is described, and the method and results of the research based on that task are presented. Finally, the results of this research are discussed and fit into the context of existing literature and theories.

1.2 Perceptual And Cognitive Abnormalities In ASD

Patterns of atypicalities in perceptual and cognitive processing have been robustly demonstrated in people with ASD (e.g., Happé & Frith, 2006; Happé, Booth, Charlton, & Hughes, 2006; Mottron, Dawson, Soulières, Hubert, & Burack, 2006). A variety of theories have been developed in an attempt to explain these cognitive and perceptual atypicalities (e.g. Happé & Frith, 2006; Mottron et al., 2006). Several of these theories make or allow specific predictions regarding learning and generalization abilities in people with ASD, including weak central coherence theory (Frith, 1989; Happé & Frith, 2006), reduced generalization theory (Plaisted, 2001), and the enhanced perceptual functioning theory (Mottron et al., 2006). Each theory is discussed in turn below.

1.2.1 Weak Central Coherence

The weak coherence account of ASD has motivated and guided a considerable amount of research since its first description by Frith (1989; Happé & Frith, 2006). It is now one of the dominant cognitive theories proposed to explain both symptoms and cognitive atypicalities in ASD (Rajendran & Mitchell, 2007). The weak coherence account suggests that humans typically have a drive to find meaning, relation, and structure among as wide a range of contexts and stimuli as possible. This drive results in an information processing approach that focuses on extracting the gist from a situation (e.g., remembering the key points from a message) and largely disregarding the details (e.g., a verbatim version of a message). Frith (1989) describes this drive for meaning as a drive to form "coherence", a drive that attends to details only in a manner that allows them to be interpreted as a cohesive whole. The weak coherence account of ASD suggests that individuals with ASD have a low drive to form coherence, instead focusing preferentially on details and neglecting a more global or cohesive interpretation or understanding.

Initial support for the weak coherence account was provided by research examining the performance of individuals with ASD on the Children's Embedded Figures Test (EFT; Shah & Frith, 1983) and the Wechsler Block Design task (Frith, 1989; Shah & Frith, 1993). A key feature of both of these tasks is that they require examination of a figure that can be mentally segregated into smaller components and require quick processing of these constituent parts. Weak central coherence is suggested to facilitate performance on this type of task by speeding up or eliminating the need for mental segregation. That is, weak central coherence may result in expedient processing of details by reducing the need to spend mental resources on processing the whole.

The EFT asks participants to search line drawings for pre-specified shapes that are embedded components of the larger drawings. Shah and Frith (1983) reported that children with ASD performed more accurately than mental-age-matched typical and intellectually disabled controls, and performed better than would be expected based on normative scores for the test given their mental age. Shah and Frith (1983) also reported that the children with ASD completed the tasks more quickly than controls, indicating that children with ASD more often found the target shape immediately and without the need for a visual search. In the time since this initial research was reported, over 30 studies have been published examining EFT performance in people with ASD (reviews: Horlin, Black, Falkmer, & Falkmer, 2014; Muth, Honekopp, Falter, 2014; Dillen, Steyaeck, Op de Beeck, Boets, 2015). A recent systematic review (Horlin et al., 2014) concluded that there is no clear consensus regarding the superiority of people with ASD on EFTs. A majority of the studies reviewed found no evidence of superior performance on EFTs by people with ASD, while 1/3 of studies found that people with ASD found the embedded figures more quickly than controls. One meta-analysis (Muth et al., 2014) reported a slight advantage on figure disembedding tasks, but noted that this overall advantage disappeared when 4/35 studies were removed from the analysis. Another meta-analysis study has even found evidence of inferior EFT performance by people with ASD (Dillen et al., 2015). It has been suggested that such discrepancies may be a result of procedural differences, diversity in the composition of both ASD and comparison groups, and small sample sizes (Horlin et al., 2014; Dillen et al., 2015). Regardless of whether performance on EFTs provide evidence of weak central coherence in people with ASD, this area of research was seminal in the development of the weak coherence account of ASD and inspired a considerable amount of research.

The Wechsler Block Design (BD) task, another of the original tasks used to support the weak coherence account, requires participants to arrange individual blocks in a specific way to create a larger design, and is a key measure of perceptual reasoning skills on numerous Wechsler intelligence scales (e.g., Wechsler, 2008). It has been suggested that in this task participants benefit from the adoption of a piecemeal approach in which they consider the correct orientation of each individual block and inhibit focus on the larger design (Frith, 1989). A drive for central coherence would be predicted to draw attention to the larger design and away from the orientation of individual blocks. If individuals with ASD have a weak drive for central coherence, they should automatically focus their attention on individual blocks, skipping the task of shifting focus from the whole to the parts (Shah & Frith, 1993). A clever experiment (Shah & Frith, 1993) tested these hypotheses by comparing performance of typical controls and individuals with ASD on whole and pre-segmented BD patterns. Pre-segmented patterns presumably reduce the drive to view the design as a whole, thereby facilitating consideration of individual block orientations. It was demonstrated that typical controls benefitted significantly more from pre-segmentation of designs than did participants with ASD, who performed better than controls only on whole design patterns.[1] Shah and Frith (1993) concluded that these patterns of performance supported the weak coherence account of ASD.

Subsequent research has demonstrated that performance of people with ASD on block design tasks is quite variable across studies (for a non-replication of Shah & Frith, 1993, see de Jonge, Kemner, Naber, & von Engeland, 2009). A meta-analysis of 24 block design studies (combining data from 520 participants with ASD and 518 controls) indicated a small advantage for people with ASD on this task, but noted large heterogeneity in results (Muth et al., 2014). Another meta-analysis has found no difference between participants with ASD and controls (Hallen et al., 2015). While little explanation has been offered for this heterogeneity, it has been suggested that lower functioning individuals with ASD tend to perform unusually well on these tasks and higher functioning individuals perform in a manner more commensurate with expectations based on their other abilities (de Jonge et al., 2009). In addition, some research has suggested that evidence of superior performance on block design can be found among people with ASD even when overall scores do not provide such evidence. For example, de Jonge et al. (2009) reported no evidence of superior performance by people with ASD on block design tasks using typical scores, but found evidence of superior performance when they considered the number of block rotation mistakes made during construction.

[1] Shah and Frith (1993) included two control conditions to ensure that the demonstrated effect was not simply explained by a general superiority in spatial ability of people with ASD. These control conditions (rotated designs & designs containing oblique patterns) increased the difficulty of the task (greater spatial reasoning demand) without changing the role that central coherence may play in performance.

A variety of other methods have been used to examine the weak central coherence theory of ASD in the time since the initial EFT and block design research was reported (see Happé & Frith, 2006, for a review). For example, several studies have examined homograph-reading performance of people with ASD (e.g. Happé, 1997; Joliffe & Baron-Cohen, 1999). As would be expected based on the weak coherence account, these studies have generally indicated that people with ASD are less likely to take the context of the sentence into account when reading homographs.[2] Similarly, Booth & Happé (2010) administered a Sentence Completion task to people with ASD and controls, and found that people with ASD were more likely to produce local completions that did not account for the broader context of the sentence[3]. Others have examined performance of people with ASD on drawing tasks, and reported that people with ASD were more likely to show a detail-focused drawing style (e.g. starting a drawing with a local element rather than a global outline; Booth, Charlton, Hughes, Happé, 2003). Finally, several studies have examined performance of people with ASD on a variety of tasks using Navon hierarchical figures—large letters made up of the same or different smaller letters (e.g. Wang, Mottron, Peng, Berthiaume, & Dawson, 2011). Meta-analyses of Navon figure studies have provided evidence that people with ASD are more likely to spontaneously focus on the local/smaller letters, that typical individuals tend to respond more quickly than people with ASD when it is necessary to focus on the global stimuli and ignore local stimuli, and that people with ASD respond more accurately when it is necessary to attend to local stimuli and ignore the global level (Muth et al., 2014; Hallen et al., 2015).

Recently, several authors have argued for modification to the weak central coherence account of ASD. Happé & Frith (2006) have argued that weak central coherence is more accurately conceptualized as a detail-focused processing style that is not necessarily accompanied by a global processing deficit. They maintain that individuals with ASD tend to have superior local processing skills, but suggest that a global processing deficit, if present, may simply be a secondary effect of enhanced local processing. Additionally, Happé & Booth (2008) have argued that most of the tasks used

[2] Example sentences: "Mary's dress remained spotless, but in Lucy's dress there was a big tear" (Happé, 1997), and "It was lead in the box that made it so heavy." (Joliffe & Baron-Cohen, 1999).

[3] Example stem: "In the sea there are fish and…". An example of a local completion is, "chips", while an example of a correct completion is, "whales" (from Booth & Happé, 2010).

to assess weak central coherence place local and global processing in competition with one another. They suggest that if this is true, superior local processing may create the appearance of impaired global processing when it is actually a methodological artefact. Complicating matters, a recent meta-analysis (Hallen et al., 2015) yielded no evidence of enhanced local visual processing in people with ASD, and no evidence of a global processing deficit. Instead, Hallen et al. (2015) presented evidence that individuals with ASD process global-order visual information more slowly than typical controls, especially when incongruous local-order information is present. Although this meta-analysis examined only visual processing and analyzed some measures differently than did the original studies (e.g. used overall scores from drawing tasks, whereas Booth et al., 2003 created a scoring system for the drawing process), it highlights the uncertainty regarding the nature of the weak coherence account of ASD that remains 25 years after its first description.

Although the accuracy of the weak coherence (or detail-focused processing style) account of ASD continues to be a topic of debate, it remains a prominent cognitive theory of ASD[4] (e.g. Rajendran & Mitchell, 2007; Muth, Hönekopp, Falter, 2014; Hallen et al., 2015). One prediction resulting from this theory is that people with ASD will have difficulty with generalization of skills (Happé & Frith, 2006). In considering this prediction, it is useful to discuss the elements that are necessary for generalization of behavior to occur. In the selection of behavior, it is essential that we are able to discriminate between cues for particular behaviors, responding to each cue we encounter with the appropriate behavior. However, it is also important that we are able to identify similarities between such cues, as sometimes it is best to respond to similar cues in a similar manner. In the dynamic environment in which we exist, it is likely that cues for a given behavior will be variable in nature, sharing some features but not identical to one another. Perception and understanding of the similarities between these variable cues (or situations/stimuli/contexts) should allow us to benefit from our past experience and respond appropriately when a similar, but novel, cue is encountered. That is, if we are able to perceive similarities between behavioral cues, and respond appropriately,

[4] Happé and Frith's (2006) most recent review of the theory was cited 106 times in 2014 according to Web of Science citation reports.

generalization of behavior should occur (Hulse, Deese, & Egeth, 1958; Plaisted, 2001). For individuals with ASD, the weak coherence account predicts that a problem may occur at the point of perceiving similarities between various cues/contexts (Happé & Frith, 2006). If an individual with ASD is particularly detail-focused, he/she may have a reduced tendency to attend to the necessary global-level similarities between situations, and therefore may not realize that a behavior that has served him/her well in the past could do so again (i.e., generalization of that behavior may not occur).

Several other theories make specific predictions regarding learning and generalization of learning in people with ASD. While these theories diverge on many topics, all converge with the weak coherence account by predicting difficulty in generalization of skills. It is to those theories that we now turn.

1.2.2 Enhanced Perceptual Discrimination And Reduced Generalization Theory

The Reduced Generalization theory of ASD was developed as an alternative to the weak central coherence account of ASD (Plaisted, 2001). In developing the rationale for this theory, Plaisted (2001) pointed out that the weak coherence account does not provide a reason why people with ASD preferentially attend to local-level stimuli—it simply describes the behavioral effects. Plaisted (2001) suggested that the mechanism that results in weak-coherence-like results, and in reduced generalization ability, is enhanced perceptual discrimination ability. Enhanced discrimination ability is suggested to reduce generalization ability by enhancing the processing of unique features of stimuli and reducing the processing of commonalities. Furthermore, Plaisted (2001) argued that enhanced discrimination ability can explain results often suggested to support the weak coherence account of ASD. For example, Plaisted (2001) suggested that enhanced discrimination ability could result in superior performance on tasks such as embedded figures and block design because of enhanced processing of unique features of key stimuli and reduced processing of commonalities between the key stimuli and the rest of the stimulus array.

A key study cited in support of the enhanced discrimination ability and reduced generalization theory of ASD asked participants to discriminate between two highly similar designs in a perceptual learning task (Plaisted, O'Riordan, & Baron-Cohen, 1998). In this task participants learned to make difficult discriminations in a training phase, and then completed a test phase with stimuli that were either similar (but not identical) to those from the training phase or entirely novel. Participants with ASD demonstrated enhanced discrimination ability (or perhaps superior perceptual learning ability) in that their performance was superior to that of controls by the end of the training phase, and when presented with novel stimuli in the test phase. However, controls outperformed participants with ASD when presented with test phase stimuli that were similar to those from the training phase. Therefore, although participants with ASD demonstrated superior discrimination ability, control participants demonstrated better ability to generalize their learning from the test phase to the training phase. Participants with ASD, on the other hand, treated each stimulus set as if it were novel (Plaisted et al., 1998).

In other research, evidence of enhanced discrimination ability in people with ASD has been mixed. Considering the visual domain, individuals with ASD have demonstrated enhanced discrimination ability when presented with simple luminance-defined grating stimuli that are processed in primary cortical visual area V1, but reduced discrimination ability when presented with texture-defined grating stimuli that require processing in associative cortical areas (e.g., V2 and V3; Bertone, Mottron, Jelenic, Faubert, 2005). Based on this research, it was suggested that enhancement and reduction of visual discrimination ability in people with ASD may be dependent on the level of complexity of the neural network required to process a given stimulus (Bertone et al., 2005). Using a different methodological approach, several authors have made the argument that the enhanced performance of people with ASD on difficult visual search tasks (O'Riordan, Plaisted, Driver, Baron-Cohen, 2001) is evidence of enhanced discrimination ability (Plaisted, 2001; O'Riordan & Plaisted, 2001). However, this argument proves circular, as the authors argue that individuals with ASD have superior visual search ability because of their enhanced discrimination ability, and point to superior visual search as evidence of this enhanced discrimination ability.

Outside of the visual domain, evidence of enhanced discrimination ability in ASD has also been mixed. Considering the auditory domain, some research has suggested enhanced discrimination of the pitch of simple pure tones among people with Autism but not Asperger Syndrome (Bonnel et al., 2010). However, this same series of studies failed to find enhanced discrimination ability among people with ASD when considering vocal timbre, non-vocal timbre, and loudness (Bonnel et al., 2010). Other research has suggested enhanced auditory discrimination among people with ASD using pure tones (O'Riordan & Passeti, 2006) and discrimination of change in simple melodies (Mottron, Peretz, Ménard, 2000). Research on tactile discrimination in people with ASD has suggested enhanced tactile discrimination (Blakemore et al., 2006), performance similar to control participants (O'Riordan & Passeti, 2006), and reduced tactile discrimination (Puts, Wodka, Tommerdahl, Mostofsky, Edden, 2014).

In summary, the research evidence for enhanced discrimination ability in people with ASD is more complex and inconsistent than would be expected based on Plaisted's (2001) theory. However, the theory is discussed here because of its relevance to the current research on generalization ability, and clear predictions regarding generalization ability in people with ASD. In addition, although Plaisted's (2001) enhanced discrimination account of ASD was presented as an alternative to the WCC account, for the purpose of the present study it converges with the WCC account in its prediction of reduced generalization ability in people with ASD while proposing a novel mechanism for the phenomenon. The current study will not be able to differentiate whether it is a detail-focused processing style (weak coherence) or enhanced discrimination ability that results in differences in generalization ability, but it will consider whether differences in generalization ability exist.

1.2.3 Enhanced Perceptual Functioning

The Enhanced Perceptual Functioning (EPF; Mottron et al., 2006) model suggests that perception in ASD is characterized by over-functioning of low-level perceptual mechanisms that leads to enhanced extraction of basic sensory information. Accordingly, the EPF model suggests that perceptual areas are more highly activated in people with ASD during a range of visuospatial, language, working memory, and reasoning tasks, with perception playing a more prominent role in supporting complex cognitive operations in this group than in typical controls (Mottron et al., 2006; Kéïta et al., 2014).

In addition to this enhanced bottom-up flow of information influencing cognition, the EPF account proposes an increased independence of cognitive processes from top-down influences (Bouvet et al., 2014), importantly describing higher-order processing as optional but not deficient in people with ASD (Mottron et al., 2006).

While there are commonalities between the EPF theory of ASD and the other theories presented above, some differences exist. The EPF account differs from the enhanced discrimination account (Plaisted, 2001) in that it suggests enhanced discrimination ability is only one aspect of perception that is atypical in people with ASD. The EPF model suggests enhanced discrimination ability is present in people with ASD, but simply as a result of underlying over-functioning of low-level perceptual mechanisms that are suggested to broadly affect cognitive processing (Mottron et al., 2006). The distinction between the EPF and WCC account is subtle, and has become less clear in recent years. Earlier versions of the WCC account (Frith, 1989) suggested that a local processing bias in ASD was coupled with a global processing deficit. The EPF account has never made such a claim, instead suggesting a more locally oriented default setting in ASD coupled with optional but otherwise typical global processing. However, it is notable that more recent updates to the WCC account (Happé & Frith, 2006; Happé & Booth, 2008) have suggested that failure to extract the global form or meaning by people with ASD happens only in some circumstances and is most likely a secondary outcome of enhanced local processing that can be overcome when necessary. Another difference between the EPF and WCC accounts is the specificity of the EPF account regarding the reasons for enhanced local-level processing in ASD. The EPF specifies that people with ASD have an increased reliance on and enhancement of low-level perceptual functioning, while the WCC account simply explains the behavioural effects of a detail-focused processing style and notes its consistency with other theories that may suggest a mechanism (such as the under-connectivity theory of ASD; Just, Keller, Malave, Kana, Varma, 2012).

Although there are differences between the WCC (Happé & Frith, 2006), enhanced discrimination (Plaisted, 2001), and EPF (Mottron et al., 2006) accounts of cognition in ASD, their similarities are most relevant to the current study. The EPF account notes the prominent role of perceptual mechanisms in complex cognitive operations, such as learning and generalization. If perception plays a greater role in supporting such cognitive operations in ASD, it is likely the case that people with ASD will be less able to notice the higher-order or conceptual commonalities between various situations, thereby reducing their ability to generalize skills or knowledge sets. Note that both the WCC and enhanced discrimination accounts of ASD also predict reduced generalization ability as a result of reduced processing of commonalities between situations and stimuli (Happé & Frith, 2006; Plaisted, 2001). The convergence of these three theories of cognition in ASD on the prediction of reduced generalization ability in ASD provides a rationale and a clear hypothesis for the current research. However, prior to further discussion of the present study, the current empirical evidence for reduced generalization ability in people with ASD must be examined.

1.3 Existing Research On Learning And Generalization In ASD

The following section will present the existing research on learning and generalization in ASD that is relevant to the current research. After a description of the types of learning that have been studied in people with ASD, the literature on category learning will be reviewed. The literature on category learning in ASD represents the most extensive literature that provides some information about the generalization ability of people with ASD.

1.3.1 Explicit Learning, Implicit Learning, And Generalization

Learning is generally divided into two categories: implicit and explicit. Implicit learning occurs relatively automatically with practice in a complex, rule-governed environment, and occurs without clear awareness of the knowledge or skill being acquired. As a result, the knowledge or skill acquired through implicit learning is often difficult to verbalize, and sometimes the learner has not even realized that a new knowledge base or skill has been acquired (Reber, Walkenfeld, & Hernstadt, 1991; Klinger, Klinger, & Pohlig, 2007; Brown, Aczel, Jiménez, Kaufman, & Plaisted-Grant, 2010). Alternatively, explicit learning generally occurs through effortful processes, with intentional encoding of rules or knowledge and some ability to verbalize the associated information. Accordingly, explicit memory would involve intentional recollection of previous learning, while implicit memory would result in enhancement of performance without deliberate recollection of previous learning (Graf & Schacter, 1985). Importantly, explicit memory is highly correlated with intelligence, while implicit memory has been found to be both uncorrelated with intelligence and robust in cases of neurological injury (e.g., patients with amnesia; Graf & Schacter, 1985; Reber et al., 1991).

As described above, various authors have suggested that learning in ASD is atypical (e.g., Lovaas, et al., 1979; Klinger et al., 2007, Tomasello, Carpenter, Call, Behne, Moll, 2005), but there is little consensus regarding the nature of this atypicality (for a review, see Dawson et al., 2008). Formal testing of implicit learning ability in ASD has provided mixed results. A recent meta-analysis (Foti, De Crescenzo, Vivanti, Menghini, Vicari, 2015) provided no evidence of implicit learning deficits in ASD. However, the category learning literature, described in more detail below, provides some evidence that implicit learning may occur more slowly among individuals with ASD, even though they eventually reach a similar level of categorization performance (e.g., Church et al., 2015, Schipul & Just, 2016). The research on explicit learning (and memory) in ASD has also provided mixed results. Formal assessment of explicit learning using immediate recall measures in word-learning tasks (e.g., the California Verbal Learning Test) has demonstrated that people with ASD perform at a level similar to control participants, even though some atypical patterns in responding emerge among individuals with ASD (e.g., Minshew, Goldstein, & Siegel, 1997; Bowler, Limoges, & Mottron, 2009; Brown et al., 2010; Phelan, Filliter, & Johnson, 2011). However, there is evidence in ASD that deficits in explicit learning and memory emerge when the complexity of the task increases (Minshew et al., 1997; Williams, Goldstein & Minshew, 2006). For example, control participants have been found to perform better than children and adults with ASD on more complex assessments of learning and memory (e.g., recalling a story after a 30 min delay, recalling a complex figure, recalling differences between two pictures; Minshew et al., 1997; Williams et al., 2006) and on tasks that require complex rule learning (Minshew, Meyer, & Goldstein, 2002). While some of the tasks used in this research do not provide pure measures of explicit learning ability, the variety of complex learning or memory tasks on which people with ASD have demonstrated atypical performance suggests that some atypicality in explicit learning is likely present for individuals with ASD.

Although generalization of learning has been identified as an important consideration for effective treatment involving individuals with ASD (e.g., Rhea, 2008), only a small number of studies have explicitly examined generalization ability in ASD (Plaisted et al., 1998, described above, was one example). One recent study analyzed the ability of individuals with ASD to generalize a strategy from one task to a novel context (de Marchena, Eigsti, & Yerys, 2015). In the teaching phase of this study, an experimenter presented a participant with two novel objects and taught the participant to identify one of the objects using either a nonword label or a fact about the object. Following this information, participants were asked to give the experimenter the object associated with a second (unfamiliar) nonword label or fact. The correct response in either condition would be the object that was not identified in the teaching phase, indicating that mutually exclusive labels or facts identified the objects. Critically, all participants completed both the label and fact condition, and the order of completion was counterbalanced. For typical individuals, completing the label condition first conferred a substantial advantage, as they were able to generalize the strategy learned in the label condition to the fact condition. For individuals with ASD, completing the label condition first did not confer a significant advantage, indicating that individuals with ASD did not readily generalize the strategy learned in that condition.

The intervention literature also provides the opportunity for consideration of generalization ability in ASD. This literature has often suggested that deficits in generalization exist for individuals with ASD based on a lack of transfer of trained skills from the training environment to everyday settings (e.g., Koegel & Rincover, 1977; Bellini et al., 2007; Fletcher-Watson, McConnell, Manola, McConachie, 2014), and that special effort must be focused on enhancement of generalization for this population (Vismara & Rogers, 2010; Koegel, Kuriakose, Singh, & Koegel, 2012). It has been suggested that there are potential reasons aside from generalization ability that poor generalization may be observed in treatment settings for people with ASD (Dawson et al., 2008), but it remains the case that generalization ability has been a topic of significant concern and discussion for those designing and implementing ASD-specific interventions.

Although several studies have been reviewed here, research on implicit and explicit learning in ASD has not typically examined the ability to generalize that learning. However, the category learning literature uses tasks that require generalization, and thereby provide some assessment of generalization in ASD. It is to that literature that we now turn.

1.3.2 Category Learning In People With ASD

Learning of categories that require integration of multidimensional information is assumed to occur through implicit processes, while learning of simple categories defined by single dimensional rules is assumed to occur through explicit processes (Ashby & Maddox, 2005; Smith et al., 2014). Research on category learning in people with ASD has provided useful insights regarding learning and generalization abilities in this group (e.g., Church et al., 2015). The majority of this research has examined whether people with ASD demonstrate typical prototype effects using category-learning tasks that require integration of multidimensional information, and presumably rely on implicit learning processes. In such tasks, artificial categories are created by generating a prototype stimulus (e.g., a random dot pattern or a schematic animal-like stimulus), and randomly varying features of the stimulus in order to create other category exemplars (e.g., Posner & Keele, 1968; Molesworth, Bowler, & Hampton, 2005; Church et al., 2015). Participants in these studies complete a training phase that requires them to learn to discriminate categories using only category exemplars and no category prototype. During a subsequent test phase, participants are asked to categorize exemplars seen during training, new category exemplars, and the not-previously-seen prototype stimulus. Typically, the prototype stimulus, which has never been seen before, is categorized with accuracy similar to that of the stimuli presented in the training phase, and superior to that of new exemplars (e.g., Posner & Keele, 1968). This pattern of performance, referred to as a prototype effect, suggests that categories can be mentally represented by a prototype (Ashby & Maddox, 2005). Importantly for the current study, the ability to form a mental representation of a prototype from category exemplars requires generalization of learning (Church et al., 2015). As a result, research on prototype formation in people with ASD may provide important information about generalization in people with ASD.

A relatively small number of studies have provided evidence of deficits in the acquisition of prototypes among people with ASD (Klinger & Dawson, 2001; Church et al., 2010; Gastgeb et al., 2011). In these studies, participants with ASD were better able to categorize familiar non-prototype items than the unfamiliar prototype, while typical controls were better able to categorize prototypes. This pattern of performance suggests that individuals with ASD were less able to gain an understanding of family resemblance within a category, and relied more heavily on familiarity with the specific items presented during the training phase. Such an interpretation is consistent with the WCC account of ASD (Happé & Frith, 2006) and the other theories described above.

Importantly, a greater number of studies have shown that people with ASD demonstrate an intact prototype effect (Molesworth, Bowler, & Hampton, 2005) even if it takes longer for them to learn the associated categories (Bott, Brock, Brockdorff, Boucher, Lamberts, 2006; Vladusich, Olu-Lafe, Kim, Tager-Flusberg, Grossberg, 2010; Soulières, Mottron, Giguère, Larochelle, 2011; Schipul & Just, 2016), or if aspects of their categorization task performance are poorer than controls (Gastgeb, Dundas, Minshew, Strauss, 2012; Froelich et al., 2012). Additionally, some studies have demonstrated heterogeneity in the prototype effect within a sample of individuals with ASD (Molesworth, Bowler, and Hampton, 2008; Church et al., 2010; Church et al., 2015), with some individuals with ASD demonstrating an intact prototype effect and others demonstrating a deficient prototype effect.

Several recent studies (Dovgopoly & Mercado, 2013; Church et al., 2015; Schipul & Just, 2016) provide some explanation of the inconsistency present in the ASD literature on prototype effects and categorization task performance. Simulations using artificial neural networks have successfully modeled the prototype and category learning performance of people with ASD (Dovgopoly & Mercado, 2013). Notably, these simulations produced models consistent with the heterogeneity observed among individuals with ASD in behavioural studies (Church et al., 2010, and Vladusich et al., 2010), where some participants with ASD show learning impairments and others perform similarly to typical controls. These artificial neural network models (Dovgolpoly & Mercado, 2013) suggested that abnormalities in neural plasticity might be responsible for prototype and category learning impairments observed in some people with ASD. Importantly, this modeling study also made the counterintuitive prediction that atypical learners with ASD would perform optimally when presented with repeated exposures of prototypical exemplars, while typical learners with ASD would perform better when presented with multiple variable examples of a category.

A recent behavioural study (Church et al., 2015) confirmed this prediction. Testing only children with ASD, Church et al. found that a subgroup of relatively high performers benefitted more from training involving multiple distortions of category prototypes, while relatively poor performers benefitted more from training involving repeated exposures of the category prototypes. They interpret this pattern of results as evidence that atypical category learning performance among some children with ASD can be explained by a deficit in neural plasticity.

Complementing this interpretation, results of fMRI research (Schipul & Just, 2016) provide evidence of atypical neural processes underlying category learning, even when behavioural performance appears typical. This study asked adult participants with ASD and typical controls to learn categories of random dot pattern stimuli (similar to those used by Church et al., 2015, and other studies cited above). Behavioural results were similar to many previous studies (e.g. Vladusich et al., 2010), with the ASD group learning the categories more slowly than controls but performing similarly in the test phase once the categories were learned. However, fMRI analyses indicated that while typical controls experienced decreasing brain activation during learning, ASD participants tended to show sustained or increasing activation throughout learning. Additionally, participants with ASD showed lower functional connectivity (synchronization) between frontal and posterior regions compared to controls, and this synchronization did not increase over time for ASD participants in the same way that it did for controls. Variability in brain activity within the group of participants with ASD was also noted, as degree of decrease in brain activation was correlated with a measure of ASD symptom severity. Consistent with the conclusions of Church et al. (2015), these results are interpreted as evidence of decreased neural adaptation during implicit learning in people with ASD.

Although Schipul and Just (2016) did not identify a subgroup of participants with ASD who demonstrated atypical post-learning test performance, they demonstrated that performance within their ASD group was correlated with symptomatology. Given that they tested a much smaller sample than Church et al. (2015), the lack of identification of subgroups is not surprising. Regardless of this difference, it may be the case that the lack of neural adaptation identified by Schipul and Just (2016) is fMRI evidence of the deficit in neural plasticity identified by Church et al. (2015). Taken together, these studies indicate that abnormalities in category learning are likely to be present for individuals with ASD, even if they are not made evident behaviourally by the standard methodology used in category learning studies. Additionally, it should be expected that the degree of abnormality in category learning is variable within groups of people with ASD.

For the purposes of the current research, some information can be gleaned from this category learning literature. First, to the extent that the typical prototype effect involves generalization of learning from the exemplars in order to form a mental representation of the prototype, the research described above suggests that abnormalities in this generalization process are present for many people with ASD. Although there is evidence of abnormalities in this process, it is not clear that these abnormalities are universally detectable through behavioural research. It has been suggested that individuals with ASD may adopt a strategy for performing category-learning tasks (e.g., using explicit processes) that is different from that of control participants but allows similar behavioural performance once the categories are learned (Schipul & Just, 2016). It seems possible that this pattern of similar behavioural performance using different processes may be relevant in other domains of learning and generalization. Second, one category learning study suggests that evidence of impaired generalization in ASD can be found in the presence of an intact prototype effect. Froelich et al. (2012) found that participants with ASD who demonstrated an intact prototype effect had disproportionate difficulty relative to controls in generalizing this mental representation to high-distortion novel stimuli presented in the test phase. Although the size of the sample in this study and the statistical methods used allow for only tentative conclusions, its unique methodology provides some evidence of atypical generalization in ASD. Third, in addition to providing information regarding generalization in Autism, the category learning literature provides some insight into the proficiency of the learning process in people with ASD. The conclusion that appears to result from the current literature is that the category learning process can be slower for people with ASD (Bott et al., 2006; Vladusich et al., 2010; Soulières et al., 2011; Schipul & Just, 2016). However, it seems clear from this research that similar levels of category learning performance can be obtained by people with ASD if given enough time to learn the categories (Vladusich et al., 2010, Church et al., 2015, Schipul & Just, 2016).

The conclusions regarding learning and generalization made from the literature on category learning in people with ASD may require some consideration of the type of learning that is occurring during the completion of such tasks. Category learning research among typical individuals suggests that implicit and/or explicit learning processes can be recruited while learning complex categories that require integration of multidimensional information (e.g., Posner-style random dot patterns; Reber, Gitelman, Parrish, Mesulam, 2003; Gureckis, James, Nosofsky, 2011). The complexity of these tasks suggests that implicit processes are likely to be used in the absence of specific instructions that encourage explicit learning (Ashby & Maddox, 2005). However, some research has suggested that individuals with ASD may preferentially use explicit learning on tasks that typically encourage implicit learning (Klinger, Klinger, & Pohlig, 2007). In addition, some category learning studies using Posner-style dot patterns observed a correlation between IQ and performance for the ASD group but not the control group (Vladusich et al., 2010; Gastgeb et al., 2012). Given that IQ is correlated with explicit, but not implicit, learning ability (Reber, Walkenfeld, Hernstadt, 1991), this result suggests that people with ASD may sometimes be using explicit processes to perform complex category learning tasks. Therefore, the conclusion that category learning is less efficient and may demonstrate abnormalities in generalization among individuals with ASD should not be interpreted only as evidence of atypical implicit learning in ASD. Instead, it may demonstrate abnormalities in the efficiency and generalization of implicit and/or explicit learning in ASD.

1.4 Current Research

The current study expands upon the literature on learning and generalization by using a novel task to examine explicit learning and rule generalization. This examination of generalization of learning in ASD represents one of the first attempts to measure generalization ability in this population outside of the context of intervention or category learning research. Although attempts to consider generalization of skills within the context of ASD intervention research are important and practical, these assessments may not accurately represent generalization ability in ASD because they focus on domains that are atypical enough to require intervention (Dawson, 2007). Consideration of generalization ability based on the category learning literature is also problematic because of its indirect assessment of generalization and lack of clarity regarding the type of learning involved. The current study examines generalization ability directly, and in a manner that is somewhat representative of that required in real-life settings. Specifically, in this study participants were required to learn to use a complex rule that is explicitly defined and to apply that rule to stimuli different from those with which the rule was learned.

The task the current study used to examine learning and generalization, developed specifically for this purpose, was an adapted version of the commercially available card game *Set*. The cards in this game have symbols that vary in three dimensions—color, shape, and shading. For example, a card could have a purple oval with vertical lines on the inside, a red diamond with solid color inside, etc. (see Figure 1). This Set task required participants to make "sets" of three cards using a multidimensional rule—the three cards making up a set must be either all the same or all different on each of three stimulus dimensions (color, shape, shading; see Figure 1). In the training portion of the task, participants were taught to create valid sets of cards using this rule with the original *Set* game stimuli. In each trial, participants were presented with a partially completed set of two cards, and asked to pick one of two additional cards that would complete a proper set (a two-alternative-forced-choice design). Training consisted of two phases. In phase one, participants were told that a rule existed that could be applied to complete the task accurately, and that they should focus on figuring out the rule. Phase one was completed in this manner so that it would provide an assessment of the ability of people with ASD to discover the rule using only feedback on their performance. In phase two, participants were explicitly presented with the rule, and were required to demonstrate that they could use it successfully by meeting a 90% criterion within a block of 10 trials. Following training, phase three represented the first generalization phase, as the stimuli appearing on the cards changed to an alternate type (different shapes, colors, and shadings; see Figure 1b). Participants were not given additional instructions at this point, except that the rule could still be applied, so that this required them to adapt their previous understanding of the Set rule to the new stimuli. The change in performance (reaction time and accuracy) following this stimulus switch represents a critical measure of generalization ability for this task. After the completion of 50 trials with the alternate stimuli, a switch to another novel stimulus set was made (phase four). Phase four stimuli were composed of schematic animal-like creatures that vary in three dimensions—color of head, shape of body, and shading of body (Figure 1c). Again, participants were required to apply the same rule to a new set of stimuli for 50 trials without instruction on how to do so. Two more switches of stimulus set were made in the task (phases five and six). Phase five presented the schematic animal-like stimuli again, but inverted, in order to present a requirement to apply the rule with stimuli that were only superficially different from the previous set. Finally, phase six presented the same stimuli as the training phases (one and two), to ensure that the participants had retained the original rule. Both reaction time and accuracy were recorded throughout the task, providing multiple measures of performance. One learning score (from phase one), three generalization scores (following the shift of each stimulus set), and one retention score result from the task for each performance measure (see Table 2 for a representation of each phase of the task).

In addition to the *Set* task, all participants completed the Wisconsin Card Sorting Test (WCST) and an intelligence measure. The WCST is a widely used neuropsychological assessment tool that requires explicit rule learning and flexible shifting between rules. It is a measure of executive function that assesses set shifting, abstract thinking, and perseveration (Heaton, Chelune, Talley, Kay, Curtiss, 1993). Although there is inconsistency in the literature, a recent meta-analysis provided evidence that individuals with ASD demonstrate impairment on all of the most commonly used measures of WCST performance (perseverative errors, number of categories, failure to maintain set, non-perseverative errors; Landry & Al-Taie, 2015). During the WCST, participants are asked to sort cards into piles under several key cards. Participants are told that the task is unusual because they will not be told how to sort the cards. Instead, they will only be told whether they are sorting correctly or incorrectly. Participants must use the correct/incorrect feedback provided by the examiner to determine the correct card-sorting rule. Critically, the examiner changes the rule several times throughout the task without notifying the participant. Participants are expected to notice that a rule change has occurred and adapt their responses accordingly. Like the *Set* task, the WCST requires rule learning. However, instead of requiring a generalization of the rule learned, it requires switching between rules. Therefore, it appears that where the *Set* task measures generalization, the WCST measures set shifting. However, some degree of set shifting may be required for the *Set* task, as the stimuli presented change in each phase of the task. The inclusion of the WCST in this experiment will allow examination of the relationship between performances on the two tasks. If the *Set* task does depend on set shifting skill to some degree, a correlation between performance on the WCST and the *Set* task would be expected. In the presence of such a relationship, the inclusion of the WCST would allow examination of learning and generalization results while statistically controlling for the effect of set shifting demands.

In addition to these measures, the ASD group was asked to participate in an assessment of adaptive skills. Adaptive skills are the skills that are necessary in day-to-day life, and measures of adaptive skills typically assess domains such as community use, home living, self-care, social functioning, functional academics, occupational skills, etc. In the current study, adaptive skills were assessed in order to provide a means of assessing the relationship between learning, generalization, and a measure of level of functioning in real-life settings. If learning and generalization are skills that impact daily functioning for individuals with ASD, and if the *Set* task measures these skills in a reliable and valid manner, then a relationship between learning and/or generalization and adaptive skills would be expected.

1.5 Hypotheses

It is expected that individuals with ASD will demonstrate less efficient learning in phase one of the *Set* task, according to measures of reaction time and accuracy. Previous research on explicit rule learning has suggested that individuals with ASD learn less efficiently than typical control participants when the rules being learned are complex (Minshew, Meyer, & Goldstein, 2002). In the current study, the rule being learned requires consideration of three variables (shape, shading color), and may therefore be considered a complex rule. In addition, individuals with ASD demonstrated less efficient learning in several category-learning studies (Bott et al., 2006; Vladusich et al., 2010; Soulières et al., 2011; Schipul & Just, 2016). Although category learning tasks are traditionally assumed to measure implicit learning, it is argued above that these tasks may involve some explicit learning processes in individuals with ASD, and therefore may offer some information that informs the hypothesis of the current study regarding efficiency of learning.

It is expected that individuals with ASD will demonstrate less efficient generalization than typical controls on measures of generalization that result from the *Set* task. The *Set* task will produce three measures of generalization, resulting from the three switches of stimulus set (see Table 1). The shift between phases three and four is expected to represent the most challenging generalization, and therefore may provide the most sensitive measure of generalization ability. It is expected that individuals with ASD will demonstrate poorer generalization than controls on this shift in stimulus set (marked Generalization 2 on Table 1). It seems possible that people with ASD will demonstrate inefficiency on the shifts in stimulus set that are anticipated to be easier (Generalizations 1 and 3 on Table 1), but it is expected that effects on these generalizations will be smaller. Broadly, the literature supports the prediction that individuals with ASD will demonstrate less efficient generalization. As reviewed above, this prediction is supported by theories of cognition in ASD (Plaisted, 2001; Happé & Frith, 2006; Mottron et al., 2006), and a variety of empirical research (e.g., perceptual learning task: Plaisted et al., 1998; category learning tasks: Froelich et al., 2012; intervention research: Bellini et al., 2007; Lovaas et al., 1979).

Regression analyses will be conducted to examine the correlations between the generalization measures, initial learning slopes, intelligence scores, WCST performance measures, and adaptive skills (the latter for the ASD group only). Given that the Set task and WCST both require learning of explicit rules, and that both may involve some degree of set shifting, it is likely that small to moderate correlations between performance on the WCST and *Set* measures of learning and generalization will emerge. However, it is expected that the constructs assessed by the WCST and *Set* task are sufficiently different that WCST performance will not statistically explain between-group differences on measures of learning and generalization. Therefore, it is expected that between-group effects on measures of learning and generalization will remain following the consideration of WCST performance as a covariate. Additionally, given that the Set task is measuring explicit learning and generalization ability, and that explicit learning efficiency has been demonstrated to be correlated with intelligence (Reber et al., 1991), it is expected that Set task performance measures will be correlated with intelligence scores.

Regression analyses will be conducted to examine the relationship between adaptive skills and learning, generalization, and WCST performance in the ASD group. It is expected that all three measures will have some relationship with adaptive skills. It is expected that explicit learning is important for the development of the life skills measured by an adaptive skills assessment, and that generalization supports the flexible use of these skills in a variety of situations. Also, WCST performance has been observed to be correlated with adult level of functioning in individuals with ASD (Szatmari et al., 1989).

Chapter 2: Method

2.1 Participants

Thirty-five participants were recruited for the ASD group, and 32 for the typical control group. Participants in the ASD group were asked to provide confirmation of diagnosis (a copy of a diagnostic report) whenever possible. If a diagnostic report was not available, the Autism Diagnostic Observation Schedule (ADOS) was administered in order to confirm diagnosis. In some instances, S. Bryson (Clinical Psychologist with extensive experience diagnosing ASD) confirmed diagnosis for individuals with whom she was familiar. Four participants recruited for the ASD group were excluded from the study because a diagnosis of ASD could not be confirmed (i.e., the ADOS assessment did not indicate ASD and the participants could not provide evidence of a diagnosis). Three additional participants from the ASD group were excluded because they could not complete the learning and generalization measure. As a result, the final sample size for the ASD group was 28. Typical control participants were recruited to match the ASD group as closely as possible on age, gender, and IQ. All 32 control participants recruited were able to complete the learning and generalization task.

No participants reported a history of psychosis of any form, or developmental disability aside from ASD. None of the participants in the control group reported a history of ASD. No participants reported that they were currently taking antipsychotic medications, or any other medication known to slow reaction time. All participants completed an intelligence assessment, provided an assessment report describing a recently conducted intelligence assessment, or had previously participated in research at Dalhousie and provided consent for the use of a past intelligence assessment. Intelligence data were collected using the Wechsler Adult Intelligence Scale-IV (WAIS-IV), the Wechsler Abbreviated Intelligence Scale (WASI), or the Wechsler Intelligence Scale for Children-IV (WISC-IV). When the WAIS-IV or WISC-IV was administered, only verbal comprehension and perceptual reasoning indices were administered (full scale IQ was not collected). See Table 2 for a summary of information describing the two participant groups.

2.2 Measures

2.2.1 Set Learning And Generalization Measure

The *Set* learning and generalization measure was developed for the purpose of the current study (see Table 1 for a quick reference to the task). For the *Set* task, all participants were seated in front of a 13.3" Samsung Series 9 laptop computer monitor. During this task, participants responded using the laptop keyboard, so had to sit within arm's reach of the keyboard. Participants were asked to keep their fingers over the response keys at all times in order to provide a consistent viewing distance, and so that they were prepared to respond as quickly as possible after making a decision.

Some of the stimuli for the learning and generalization task were taken from the commercially available card game *Set*, and some were developed for this project. Samples of the stimuli are presented in Figures 1 and 2. All stimulus sets varied on three stimulus characteristics: color, shape, and shading. The sample stimuli presented in Figure 1 provide examples of each color, shape, and shading variation within each stimulus set. Each stimulus set was presented in at least one phase of the learning and generalization task. The stimulus set in Figure 1C was presented twice—once as depicted and once inverted.

This task required participants to learn to create sets of three cards according to the following rule: "A *Set* consists of 3 cards in which each of the cards' features, looked at one-by-one, are the same on each card, or, are different on each card. All features must separately satisfy this rule." Once participants had learned to apply this rule using one stimulus set, they were asked to figure out how to apply the rule to other stimulus sets. Participants were provided with feedback on their performance (correct/incorrect) following each trial throughout the task. The task was divided into several phases, described below. Completion of all six phases typically required approximately 45 minutes.

In each trial, participants were presented with four cards on the screen. See Figure 2 for a sample display of a single trial (with stimuli from phase one, 2, or 6 of the task).

The two upper cards were part of the set under consideration, and participants were asked to select one of the two lower cards to complete the set according to the *Set* rule.

Phase one, figuring it out. In this phase, participants were asked to proceed without being presented with the rule, and learn through trial-and-error. Instructions prior to starting this phase were:

"In this part of the experiment you will play a card game. This game is unusual in that you will not get much instruction on how to play the game. Instead, you will need to figure out how to play the game by trial and error. After you make each response in this game you will find out whether you were correct or incorrect. Use this information to learn how to play the game.

In this game you will be creating sets of three cards. On each screen you will see two cards near the top. These two cards will always be part of the correct set of three cards. Two cards will also appear at the bottom of the screen. In order to complete the set, you need to pick one of the two bottom cards by clicking a button on the keyboard.

To select the card on the left, press the 'C' key.
To select the card on the right, press the 'M' key.

After you make a selection you will find out whether you responded correctly. Try to use this feedback to learn how to play the game better.

Please do your best to figure out how to play the game. Please respond as quickly and accurately as possible."

After reading the instructions, participants were given extra instruction from the experimenter during the first two trials of the task to make sure that the demands of the task were understood. However, the rule for making sets correctly was not presented at this point. Participants were told that a rule could be used to make correct sets, but they would have to try to figure it out using feedback from the task. Participants completed 50 trials before proceeding to the next phase.

Phase two, reaching criterion. In this phase, participants were explicitly taught the Set rule, and asked to complete more trials like those in Phase One (with stimuli depicted in Figure 1A). Participants completed a variable number of trials in this phase, because they were required to attain 70% accuracy on a block of 24 trials before moving on to Phase three. Participants were required to complete at least 48 trials in this phase, but were permitted to complete up to 141 trials. The instructions that preceded this phase were:

"Great job! Now the experimenter is going to go through a few trials with you, just to make sure that you know how to do the task correctly before moving on.

The rule for making sets: A set consists of three cards in which each of the cards' features, looked at one-by-one, are the same on each card, or are different on each card. All of the features must separately satisfy this rule. In other words: shape must be either the same on all 3 cards, or different on the 3 cards; color must be either the same on all 3 cards, or different on each of the 3, etc.

[Example correct and incorrect sets were displayed]"

After the instructions, the experimenter taught the rule during the first couple of trials, as needed. Feedback following each trial during this phase was more detailed than during any other phase. Participants were told why responses were correct or incorrect following each trial by listing each stimulus variable (color, shape, and shading), and indicating whether the response followed the Set rule for that stimulus variable.

Phase three, first generalization. In this phase, participants were asked to apply the rule that had just been learned to a new set of stimuli. The stimuli presented in this phase are depicted in Figure 1B. Fifty trials were completed. The instructions presented prior to this phase were:

"Great job! You've learned how to apply the rule quite well. Now you're going to be asked to make correct sets of three cards using a new group of cards. You can still apply the same rule using these new cards.

Please continue to respond as accurately and quickly as possible.

There will be an opportunity for you to take a quick break in the middle of this block of trials."

Phases four & five, generalizations two and three. In these phases participants were asked to continue applying the original rule to new sets of stimuli. 50 trials were completed in each phase. In Phase Four, schematic animal stimuli (Figure 1C) were presented. In Phase Five, inverted versions of these stimuli were presented (Figure 1C, inverted). Instructions presented prior to these phases were:

"Great job! Now you are going to be asked to make correct sets of cards with another set of cards. These cards are different from the last cards, but you can still apply the same rule as before. You will get feedback on your answers so you know whether you are answering correctly."

Phase six, retention. In this phase, participants were asked to complete 50 trials using the stimuli that were originally presented in Phases One and Two (Figure 1A). This phase was included in order to examine whether the rule, as originally learned, was retained.

2.2.2 Wisconsin Card Sorting Test

The Wisconsin Card Sorting Test (WCST) is a widely-used neuropsychological assessment tool considered to be a measure of executive function (specifically, set-shifting), abstract thinking, and perseveration (Heaton, Chelune, Talley, Kay, Curtiss, 1993). In this task, participants are asked to sort cards into piles under several key cards. Participants are told that the task is unusual because they will not be told how to sort the cards. Instead, they will only be told whether they are sorting correctly or incorrectly. Participants must use the correct/incorrect feedback provided by the examiner to determine the correct card-sorting rule. Critically, the examiner changes the rule several times throughout the task without notifying the participant. Participants are expected to notice that a rule change has occurred and adapt their responses accordingly. For this experiment, the 128-card non-computerized version of the WCST was used. Completion of the WCST required 10-30 minutes.

2.2.3 Adaptive Behavior Assessment System - 2

The Adaptive Behavior Assessment System - 2 (ABAS-2) is a questionnaire-style assessment of adaptive behaviour and skills that can be used for individuals of any age up to 89 years old. This tool allows assessment of a variety of domains, including Conceptual, Practical, Community Use, Home Living, Self-Care, Social, Functional Academics, Social, Community, Leisure, Health and Safety, Self-Direction, and Work. It provides scores for three composite domains (Conceptual, Social, and Practical), and a Global Adaptive Composite score. For individuals below age 18, someone who knows the participant well, such as a parent, must complete the questionnaire. For individuals 18 and older, the questionnaire can be completed by the participant (describing him/herself) or can be completed by someone who knows the participant well. Separate normative scores are used for these two scenarios. In this study, only participants in the ASD group were asked to complete the questionnaire. Participants were encouraged to have a parent or someone who knows them well (e.g., a support worker for clients in supported living) complete the questionnaire. Several participants chose to self-report.

2.3 Procedure

Participants were tested individually in a quiet room. Room set-up varied between participants, as several testing locations were used. Following the consent process, participants first complete either the learning and generalization measure, or the WCST. The order of these two tasks was counterbalanced across participants. Participants completed the intelligence assessment following these two tasks, when it was required (see *Participants* section). A majority of participants in the ASD group completed the ABAS-2 at a separate time (or had a parent/caregiver complete it), and returned it at a later date. The ADOS was typically completed last, but was completed first for two participants who were subsequently excluded from the ASD group (because they scored below the ASD cut-offs on the ADOS).

2.4 Statistical Analyses

The statistical analyses described below mirror the specific aims of this research, described in the introduction. The *Set* learning and generalization measure allows examination of rate of learning, generalization performance, and retention of the rule across the task. Dependent measures are both reaction time (RT) and accuracy. Learning performance can be analyzed by comparing the RT and accuracy means and slopes within phase one of the task (the initial learning of the rule). Generalization performance can be analyzed at 3 points during the task, when quantified as the cost in performance associated with switching to phases three, four, and five. In addition, the RT slopes characterizing improvement in performance following a switch in stimulus set will also be examined as measures of learning or skill development following generalization. Retention of the original rule can be analyzed by considering the difference in performance between phases two and six. Group comparisons on measures of generalization will be conducted using 2 (phase) x 2 (group) split-plot ANOVAs. Group comparisons on measures of phase one learning (slope and mean scores), phases three to five RT slopes characterizing skill development following generalization, WCST performance, and intelligence will be conducted using independent-samples t-tests.

In addition to these group comparisons, bivariate regression analyses will be used to examine the relationships between measures resulting from the learning and generalization task, WCST performance, intelligence and adaptive skills. Based on these results, additional multiple regression analyses may be conducted to examine the predictions made in the introduction.

Chapter 3: Results

3.1 Participant Characteristics

Participant characteristics (age, VIQ, and NVIQ) were compared using independent samples t-tests, and no evidence of differences between the groups on any variables was found (see Table 2). In addition, no statistically significant correlations between age and either IQ measure was found for either group, or for the two groups combined.

3.2 Set Task

Between-group differences in overall *Set* task RT and accuracy were examined using independent-samples t-tests. While the overall RT of the ASD group (M=2693.2 ms, sd=786.5) was numerically greater than that of the control group (M=2514.0 ms, sd=601.0), this difference was non-significant (t(58)=1.00, p=.32, d=.26). The overall proportion correct of the ASD group (M=0.927, sd=0.059) was numerically greater than that of the control group (M=0.898, sd=0.068), but this difference was also non-significant (t(58)=1.80, p=.08, d=.47). [5]

3.2.1 Set Task: Initial Learning Phases

Phases one and two of the Set task assessed participants' ability to learn the Set rule and apply it efficiently. Neither RT nor accuracy differed significantly between the groups in either phase one or two (phase one RT: t(58)=0.961, p=.34; phase one accuracy: t(58)=1.260, p=.21; phase two RT: t(58)=0.654, p=.52; phase two accuracy: t(58)=1.721, p=.09). Learning in phase one was also examined by considering the slope that characterized the relationship between trial number and reaction time. This slope was generally negative, as RTs typically decreased as trial number increased. No significant

[5] Given that performance-based subgroups of individuals with ASD have been discovered in the catgorization literature (Church et al., 2015), it may be expected that similar subgroups would be found on various measures of *Set* task performance. However, distributions and boxplots were examined for all *Set* task measures, and no performance-based subgroups were apparent.

difference in this learning slope was observed between the ASD (M=-19.75, sd=24.01) and control groups (M=-18.12, sd=22.95; t(58)=-0.267, p=.79). In summary, these analyses provide no evidence of between-group differences in performance during the initial learning phases of the *Set* task (see Figures 3 and 4 for graphical depictions of the *Set* task data).

3.2.2 Set Task: Generalization One

The switch in stimulus set in phase three represented the first point in the task that required participants to generalize the application of the *Set* rule (Gen1). A 2(group) x 2 (phase) split-plot ANOVA was conducted for each of the dependent variables (RT and accuracy), comparing performance of the two groups between phases two and three. Considering RT, a significant main effect of phase was observed (F(1, 58)=11.88, p=.001, $\eta^2_{\textbf{partial}}$=.17), but the main effect of group and critical phase x group interaction were non-significant (both F<1). Examination of Figures 3 and 4 reveals that the significant effect of phase was a result of a slower RT in phase three than in phase two. Considering accuracy, a significant effect of group was observed (F(1, 58)=4.76, p=.033, $\eta^2_{\textbf{partial}}$=.08), but the main effect of phase and the phase x group interaction were non-significant (both F<1). Examination of Figures 3 and 4 reveals that the significant effect of group was a result of greater accuracy in the ASD group than in the control group in both phases two and three. The slope resulting from the relationship between trial number and RT in phase three may be considered as a measure of efficiency of learning or skill development following generalization. No significant difference between the ASD (M=-10.37, sd=15.8) and control group (M=-9.13, sd=14.98) was observed using this slope calculation (t(58)= -0.310, p=.76). In summary, no evidence of between group differences in generalization or subsequent skill development resulted from the above analyses.

3.2.3 Set Task: Generalization Two

The second generalization (Gen2) demand was associated with the switch in stimulus set beginning in phase four. Similar to above, a 2(group) x 2 (phase) split-plot ANOVA was conducted for each of the dependent variables (RT and accuracy), comparing performance of the two groups between phases three and four. Considering RT, a significant main effect of phase ($F(1, 58)=71.69$, $p<.001$, $\eta^2_{\mathbf{partial}}=.55$) was observed, but the main effect of group ($F(1, 58)=1.16$, $p=.29$, $\eta^2_{\mathbf{partial}}=.02$) and interaction between phase and group ($F(1, 58)=3.25$, $p=.078$, $\eta^2_{\mathbf{partial}}=.05$) were non-significant. Examination of Figures 3 and 4 indicates that the main effect of phase was a result of slower RT in both groups in phase four as compared to phase three. Considering accuracy, no significant main effects of phase ($F(1, 58)=3.35$, $p=.07$, $\eta^2_{\mathbf{partial}}=.06$) or group ($F(1, 58)=3.15$, $p=.08$, $\eta^2_{\mathbf{partial}}=.05$) were observed, and the phase x group interaction ($F<1$) was non-significant. Importantly, the slope resulting from the relationship between trial number and RT in phase four differed significantly between the groups ($t(58)=2.689$, $p=.009$, $d=.70$), with the control group slope ($M=-26.57$, $sd=19.33$) being significantly steeper than the ASD group slope ($M=-13.95$, $sd=16.66$). The pattern of results above, combined with examination of Figure 3, suggests that ASD group performance (as measured by RT) did not improve as quickly as did control group performance in phase four.

3.2.4 Set Task: Generalization Three

The third generalization (Gen3) demand was associated with the switch in stimulus set beginning in phase five. Similar to above, a 2(group) x 2 (phase) split-plot ANOVA was conducted for each of the dependent variables (RT and accuracy), comparing performance of the two groups between phases four and five. Considering RT, a significant main effect of phase ($F(1, 58)=51.52$, $p<.001$, $\eta^2_{\mathbf{partial}}=.47$) was observed, but the main effect of group ($F(1, 58)= 1.84$, $p=.18$, $\eta^2_{\mathbf{partial}}=.03$) and the phase x group interaction ($F<1$) were non-significant. Considering accuracy, no significant effects were observed (main effect of phase: $F<1$; main effect of group: $F(1, 58)=1.68$, $p=.19$,

$\eta^2_{partial}$=.03; group x phase interaction: F<1). The slope resulting from the relationship between trial number and RT in phase five did not differ significantly between the ASD (M=-6.59, sd=21.30) and control (M=-4.34, sd=15.28) groups (t(58)=-0.472, p=.638). Overall, it appears that RT was reduced for both groups following the stimulus switch in phase five, and no evidence of between group differences in generalization or skill development was observed.

3.2.5 Set Task: Retention Of The Rule

A comparison of phase two and phase six performance was conducted in order to consider retention of the *Set* rule across the task. A 2(group) x 2 (phase) split-plot ANOVA was conducted for each of the dependent variables (RT and accuracy) in order to compare performance in these two phases. Considering RT, there was a significant main effect of phase (F(1, 58)=49.04, p<.001, $\eta^2_{partial}$=.46), but no main effect of group (F<1), and no phase x group interaction (F<1). Considering accuracy, there was a significant main effect of phase (F(1, 58)=4.16, p=.05, $\eta^2_{partial}$=.07), but no main effect of group (F(1, 58)=2.76, p=.10, $\eta^2_{partial}$=.05) and no phase x group interaction (F<1). In summary, both participant groups applied the *Set* rule more efficiently in phase six than they did in phase two.

3.2.6 Set Task: Analyses Of Half Phases

It was expected that evidence of atypical generalization should have been apparent immediately following a stimulus shift. That is, poor generalization should have been more apparent in the first half of the phase following a stimulus shift than in the second half of the phase. As a result, generalization effects were re-analyzed using repeated measures ANOVAs comparing RT and accuracy using half-phases of data to increase sensitivity to generalization effects. For example, Gen1 was analyzed by comparing RT and accuracy in the latter half of phase two to the first half of phase three. Gen 1, Gen2, and Gen3 were analyzed using both RT and accuracy, and none of the critical phase x group interactions were significant in this set of analyses.

3.3 Wisconsin Card Sorting Task

The WCST produces a variety of indices of performance, and statistical examination of all indices would be likely to produce type 1 errors. As a result, four indices of WCST performance were chosen, based on a recent review of WCST performance among individuals with ASD (Landry & Al-Taie, 2015). These indices were: Perseverative Errors (standardized score), Nonperseverative Errors (standardized score), Categories Completed, and Failure to Maintain Set. One participant in the ASD group declined to complete the WCST, leaving 27 participants in the ASD group for these measures. Independent-samples t-tests were used to examine the differences between groups on these measures of WCST, and no significant differences between groups were found on any of the measures (see Table 3 for a summary of WCST results).

3.4 Adaptive Behavior Assessment System 2

Only the ASD group completed the ABAS-2. As a result, only summary scores for the group can be presented (no group comparisons; see Table 4). All mean ABAS-2 scores fell in the "Below Average" range, according to the ABAS-2 manual.

3.5 Regression Analyses

For the purpose of regression analyses, *Set* task learning slopes, generalization effects, mean RT, and mean accuracy were calculated for each individual. Also considered were two measures of WCST performance: perseverative errors and nonperseverative errors. The other two measures of WCST performance were not included in these analyses because of their categorical nature. Finally, measures of VIQ and NVIQ and the ABAS-2 General Adaptive Composite (ABAS-2 for the ASD group only) were included in regression analyses. Given that the *Set* task produces eight scores for each individual, examination of the relationship between all Set scores, WCST, and ABAS variables would be likely to produce Type 1 errors. As a result, the only measures considered in regression analyses from the Set task were the Gen2RT score, the learning slope resulting from phases 1 and 4, and the overall RT and accuracy scores. These variables were chosen because they represent the most sensitive measures of generalization (in the case of Gen2RT and phase four slope), a key measure of initial learning (phase one slope), and measures of overall performance on the task (Mean RT and accuracy). Correlation matrices are presented for both groups together (Table 5), the ASD group (Table 6), and the control group (Table 7). Relevant discrepancies in patterns of correlations between the groups are discussed below.

The Gen2RT effect was initially correlated with NVIQ in the unexpected direction (higher IQ associated with poorer generalization; r=.261, p=.04). However, examination of the relevant scatterplot revealed that two participants were disproportionately influencing the correlation value, and removal of these participants from the correlation analysis rendered the same correlation non-significant (r=.047, p=.73). Gen2RT was not correlated with any ABAS-2 or WCST indices.

Phase one slope, a measure of learning efficiency in phase one, was not significantly correlated with any variables considered. Phase four slope, a measure of learning efficiency following the second (most difficult) stimulus switch, was significantly correlated only with WCST perseverative errors (r=-.275, p=.035). This correlation suggests that those who demonstrated more efficient improvement in phase four tended to make fewer perseverative errors on the WCST.

The existence of a correlation between phase four slope and WCST perseverative errors suggests the between-group phase four slope effect should be reconsidered with WCST perseverative errors as a covariate. A one-way ANCOVA was conducted with phase four slope as the dependent variable, group (ASD vs. Control) as the independent variable, and WCST perseverative errors as the covariate. The significant main effect of group in phase four slope remained after controlling for the effect of WCST perseverative errors ($F(1, 56)=6.46$, $p=.014$, $\eta^2_{\textbf{partial}}=.10$). In this model the covariate, WCST perseverative errors, was marginally significantly related to phase four slope (F(1, 56)=3.96, p=.051, $\eta^2_{partial}$=.07).[6] In order to further examine the relationship between phase four slope and WCST perseverative errors, bivariate correlations were calculated between these two variables separately for the two groups. Phase four slope and WCST perseverative errors (standardized) were significantly correlated in the ASD group (r=-.398, p=.04), but not for the control group (r=-.142, p=.439). This negative correlation indicates that individuals with ASD who tended to make fewer perseverative errors on the WCST also tended to improve their performance more quickly in phase four.

Group differences in Phase four slope suggest that individuals with ASD may be using different cognitive processes than controls to support skill development in phase four. For example, some authors have suggested that individuals with ASD tend to use explicit processes on tasks that controls typically complete using implicit processes (Klinger et al., 2007). If Phase four skill development were supported by explicit learning processes for the ASD group and implicit processes for the control group, a correlation between NVIQ and Phase four slope would be expected for the ASD group but not the control group. Indeed, the correlation between NVIQ and Phase four slope was significant for the ASD group (r= -.376, p=.048) and non-significant for the control group (r= .014, p=.938).

Set task overall mean RT was significantly correlated with WCST perseverative errors (r=-.275, p=.035) and WCST nonperseverative errors (r=-.262, p=.045). These correlations suggest that those who responded more quickly on the *Set* task (across phases) tended to make fewer perseverative and nonperseverative errors on the WCST. Overall mean RT was not significantly correlated with any other variables considered. *Set* Task overall mean accuracy was also significantly correlated with WCST perseverative errors (r=.348, p=.007) and WCST nonperseverative errors (r=.409, p=.001), indicating that those with higher overall accuracy scores on the Set task tended to make fewer perseverative and nonperseverative errors on the WCST. In addition, overall mean accuracy was correlated with VIQ (r=.362, p=.005) and NVIQ (r=.687, p<.001). In order to explore the relationship between overall mean accuracy, VIQ, NVIQ, and WCST

[6] The homogeneity of regression assumption was tested using an additional ANCOVA model that included the group x WCST perseverative errors interaction term. This interaction term was not significantly related to phase four slope (F<1), indicating that the assumption of homogeneity of regression was not violated.

performance, a multiple regression was conducted. This stepwise multiple regression calculated the ability of NVIQ, VIQ, WCST perseverative errors, and WCST nonperseverative errors to predict Set overall mean accuracy. The resulting prediction model contained only one of the four predictors (NVIQ; β=.686, t=7.056, p<.001), and was reached in a single step. None of the other predictors approached significance. The model was statistically significant (F(1, 56)=49.8, p<.001) and accounted for approximately 47% of the variance in *Set* task overall mean accuracy (R^2=.471). These results indicate that NVIQ was a strong predictor of *Set* task overall mean accuracy, and that the relationship between overall mean accuracy and WCST performance became non-significant once NVIQ had been taken into account.

No correlations were found between the ABAS-2 composite score and either WCST score, or between the ABAS-2 and either IQ score. However, both WCST perseverative errors (r=.446, p<.001) and WCST nonperseverative errors (r=.510, p<.001) were correlated with NVIQ, and WCST nonperseverative errors was correlated with VIQ (r=.263, p=.046).

Chapter 4: Discussion

4.1 Summary Of Results

The current study used a novel task to examine explicit rule learning and generalization in individuals with ASD. Based on theoretical models of cognition in ASD and previous studies, it was expected that individuals with ASD would demonstrate less efficient rule learning and poorer generalization of learning than typical controls. In the novel Set task used in the current study, participants were first required to "figure out" a rule, then were taught the rule explicitly, and then were required to generalize the rule to three different stimulus sets. Comparison of initial learning performance using several measures provided no evidence of differences in learning efficiency between the ASD and control group. In addition, comparison of the initial learning phase and the final phase of the task, which shared the same stimulus set, provided a means of examining retention of the rule and degree of improvement in performance during the task. Once again, no between-group differences were found in ability to retain the rule and improve performance when applying the rule to the stimuli from the learning phase.

Participants were required to generalize the rule to a novel stimulus set on three occasions during the *Set* task. The first generalization (Gen1) involved a change in the types of shapes, shadings, and colors presented. The second (Gen2) involved a change to schematic animal-like stimuli (that varied, in shape, color, and shading). The third (Gen3) stimulus set was the same as the second, except all stimuli were inverted. Generalization effects were calculated by comparing performance in phase N to that in phase N-1. No between-group differences were found in generalization on Gen1, Gen2, or Gen3.

The slope characterizing the improvement in RT following each stimulus shift was calculated as a measure of learning or skill development following generalization. These measures are differentiated from phase one slope because they capture performance when the rule had already been learned and skill was being developed in its application to a new stimulus set. No between-group differences in RT slope were noted following Gen1 or Gen3. Between-group RT slope differences were found following Gen2, with control participants improving performance more quickly than participants with ASD (medium effect size). No differences in performance were apparent immediately following the Gen 2 stimulus shift, but the difference in phase four RT slope emerged over the course of the phase. It is noteworthy that this difference in rate of improvement emerged following the most difficult stimulus shift. It may be the case that the increased difficulty associated with the phase four stimuli resulted in increased sensitivity to between group differences in skill development.

It was expected that generalization performance would be correlated with adaptive skills, WCST performance, and IQ. Although the majority of these correlations were not significant, RT slope in phase four was correlated with WCST perserverative errors, indicating that those who improved performance more quickly in phase four also made fewer perseverative errors on the WCST. However, correlation analyses split by group found that this correlation was present for the ASD group but not the control group. Importantly, evidence of superior performance among controls on RT slope in phase four remained following inclusion of WCST perseverations as a covariate. These results suggest that the between group differences in skill development in phase four are not simply a result of difficulty shifting mental set among individuals with ASD.

Measures of overall *Set* task RT and accuracy from the *Set* task were considered as indices of overall performance on the task. No between-group differences on these measures were observed, but overall RT was correlated with WCST performance and overall accuracy was correlated with measures of intelligence and WCST performance. More specifically, those who performed with greater accuracy on the Set task tended to have higher NVIQ and VIQ scores and to make fewer perseverative and nonperseverative errors on the WCST task. The correlation between overall Set task accuracy and NVIQ was large ($r=.687$), and multiple regression revealed that neither VIQ nor WCST performance were predictive of Set overall mean accuracy after NVIQ had been taken into account.

4.2 Learning And Skill Development

It was anticipated that the *Set* task used in the current study would provide a means of examining explicit learning ability. While an absolute dichotomy between implicit and explicit learning may not be realistic in the *Set* task (or in many complex learning tasks; Ashby, Alfonso-Reese, Turken, & Waldron, 1998), both the method and the results of the current study suggest that the learning process assessed can be characterized primarily as explicit learning. Explicit learning is said to occur when individuals are required to figure out a rule or set of rules, and then use such rules in an intentional manner to guide and improve performance (Klinger et al., 2007). In the *Set* task, participants were required to figure out the critical rule, then were explicitly taught the rule, and then were required to attain a high level of performance in application of the rule. Therefore, the method used encouraged explicit learning processes, at least in the early phases of the task. The proposal that the current study examined explicit learning is further supported by the robust relationship between task performance (as defined by overall task accuracy) and nonverbal intelligence. Explicit learning ability, unlike implicit learning, is typically correlated with intelligence (Reber et al., 1991).

Multiple measures of ability to initially learn the rule during phases one and two of the task were used, and none provided evidence of atypical explicit rule learning among individuals with ASD. This result is consistent with previous research demonstrating that individuals with ASD have intact explicit learning ability for a variety of tasks (verbal learning tests, Phelan et al., 2011; rule-based category learning, Klinger & Dawson, 2011; paired associates learning, Minshew et al., 1997). However, other research has indicated that individuals with ASD perform poorly relative to controls on complex explicit learning tasks (Minshew et al., 1997), and tasks that involve learning of complex rules (Minshew et al., 2002). It was expected that the *Set* rule was sufficiently complex that between-group differences in performance would be observed during the initial phases of the task, but the results indicate that this was not the case. However, it is noteworthy that the *Set* rule requires consideration of two to three aspects of a stimulus in order to be applied correctly, thereby involving more complexity than the task used in a previous study that failed to find evidence of atypical rule learning in ASD (Klinger & Dawson, 2001).

It is noteworthy that when stimulus complexity increased in phase four, differences in learning or skill development emerged (in phase four RT slope). At this point participants had clearly demonstrated knowledge of the rule in earlier phases, so that the slope characterizing the decrease in RT is more likely to provide a measure of skill development in a novel context, and is less likely to be confounded with rule learning than performance measures from earlier phases in the task. Supporting this assertion, no between-group differences were apparent in phase four immediately following the stimulus shift. This suggests that both groups initially understood how to apply the rule in a similar manner. Therefore, it is proposed that the between-group difference in phase four RT slope provides evidence that individuals with ASD demonstrated reduced efficiency in developing skill in the application of the *Set* rule on a complex novel stimulus. Consistent with previous research (Minshew et al., 1997, 2002), it is also proposed that this between group difference in skill development emerged in phase four rather than phases one to three because the increased stimulus complexity provided a measure more sensitive to learning differences associated with ASD.

While it is possible that this reduced efficiency in skill development was a result of atypical application of purely explicit learning processes among individuals with ASD, it also seems possible that this reduced efficiency effect was a result of atypical implicit learning processes. The COVIS model of category learning (Ashby et al., 1998) assumes that two categorization systems are in competition with one another during the development of categorization skill—a verbal system that consciously applies explicit rules, and a nonverbal implicit system that uses procedural learning. Claims are that the verbal explicit system initially dominates decision-making, and that it is gradually superseded by the implicit system with training and experience (Ashby et al., 1998). Although the *Set* task is not strictly a categorization task, it shares similarities with rule-based category learning tasks in that it requires that participants apply an easily verbalized rule to choose between multiple options, and it allows improvement in performance with practice (Ashby & Maddox, 2005). In the case of the *Set* task, participants must consider three stimulus cards at once in order to correctly respond, whereas in categorization tasks they more typically have to consider the identity of a single item. However, the Set task ultimately requires participants to consider three cards as a group and make a categorization—correct set or incorrect set. Given these similarities to categorization tasks, it may be the case that the between group differences in skills development can be considered within the framework of the COVIS model.

According to this model, performance in the *Set* task would initially rely on explicit rule-based processes, but gradually shift to implicit processes as expertise develops. If this is the process of skill development in the *Set* task, it is possible that the between group difference in skill development found in phase four of this task is a result of between group differences in implicit, rather than explicit, learning processes.

The notion that participants with ASD may be less efficient than controls in the use of implicit learning processes to support skill development is consistent with the category learning literature reviewed in the introduction. Several category-learning studies that used tasks that rely primarily on implicit processes have demonstrated that individuals with ASD attain proficiency in the tasks more slowly than controls, even if they eventually reach a similar level of performance (as they did in phase five of this task; Bott et al., 2006; Vladusich et al., 2010; Soulières et al., 2011; Schipul & Just, 2016). fMRI research has indicated that this reduced efficiency in development of categorization skill is a result of decreased neural adaptation during implicit learning that may result from lower functional connectivity (synchronization) between frontal and posterior cortical regions (Schipul & Just, 2016). Also supporting the suggestion that individuals with ASD may not improve efficiency through use of implicit learning in a typical manner, it has been suggested by multiple authors that individuals with ASD tend to use explicit processes to complete tasks that are completed by typical controls through implicit processes (e.g., Klinger et al., 2007; Schipul & Just, 2016). The notion that the between group difference in skill development in phase four was a result of the continued used of less-efficient explicit processes by participants with ASD when the typical control participants shifted to implicit processes is consistent with the COVIS model of category learning (Ashby et al., 1998). The COVIS model and category learning research comparing different phases of development (Huang-Pollock, Maddox, Karalunas, 2011) have suggested that the shift from explicit to implicit processes during category learning is associated with an increase in learning efficiency.

4.3 Generalization

The current study represents one of the first attempts to directly characterize generalization ability among individuals with ASD. Both theories of cognition in ASD (e.g., Happé & Frith, 2006) and empirical research (e.g., Plaisted et. al., 1998, Froelich et al., 2012, Fletcher-Watson et al., 2014, de Marchena et al., 2015) have indicated that generalization of skills is an area of difficulty for individuals with ASD. However, the current study does not provide evidence of atypical generalization ability among individuals with ASD. Indeed, generalization performance of the two groups, if conceptualized as the performance cost immediately following a stimulus shift, was quite similar throughout the *Set* task. Since the results of the current study are inconsistent with previous research examining generalization performance of people with ASD, comparison of current and previous methodology may facilitate interpretation of the current results.

One of the major areas of literature that has suggested generalization may be atypical among individuals with ASD is the category learning literature. However, category learning and the formation of prototypes using complex stimuli have largely been assumed to occur through implicit processes in typically developing individuals (on the types of tasks typically used in this research; Ashby & Maddox, 2005). Similarly, another study cited as a key demonstration of atypical generalization among individuals with ASD used a perceptual learning task (Plaisted et al., 1998); perceptual learning is also a process that occurs largely through implicit learning in typical controls. Therefore, while some evidence of atypical generalization of category learning (e.g., Froelich et al., 2012; Church et al., 2015) and perceptual learning (Plaisted et al., 1998) has been found in studies of people with ASD, it may be that the generalization of implicitly learned prototypes relies on a skill that is different from that required for generalization of explicitly learned rules such as those in the *Set* task.

Another major area of literature that has suggested deficits in generalization may exist for individuals with ASD is the intervention literature. Poor generalization of therapeutic gains was noted early in the development of ASD-specific interventions (e.g., Koegel & Rincover, 1977), and has been identified as a particular challenge that needs special consideration in the development of treatments for individuals with ASD (Bellini et al., 2007; Vismara & Rogers, 2010; Koegel et al., 2012). However, while intervention research has developed methods for enhancing generalization (e.g., training in naturalistic settings; Vismara & Rogers, 2010), it has not explicitly assessed whether generalization ability in individuals with ASD is atypical. It is possible that factors other than an ASD-specific generalization deficiency may explain the lack of generalization of skills in treatment settings. For example, it has been suggested that teaching typical behaviours to atypical individuals may be expected to result in a failure to generalize because they are outside of the scope of possible behaviours for some individuals with ASD (Dawson et al., 2008). Although an extreme version of this position is discredited by the effectiveness of some ASD-specific interventions, a weaker version of the assertion may help explain typical generalization performance in domains where learning is largely typical (i.e., the current study), and atypical generalization in domains where learning is atypical (e.g., communication, social skills; Bellini et al., 2007; Vismara & Rogers, 2010). That is, it may be the case that atypical generalization will emerge in areas of atypical learning, but not in areas of typical learning.

Alternatively, given that most ASD interventions involve the teaching of skills by other people, it may be the case that difficulties with generalization of skills taught during intervention are a result of ASD-related deficits in the abilities that support learning from other humans. Indeed, one of the clearest demonstrations of poor generalization ability in ASD (de Marchena et al., 2015) involved the requirement to generalize a strategy that was expected to result from a didactic interaction with the examiner. According to the theory of natural pedagogy (Csibra & Gergely, 2009; 2011), typical individuals are primed to glean generalizable information in such social learning contexts. If it is the case that individuals with ASD are not similarly primed to gather generalizable information, this may explain the lack of generalization following learning from others. In this case, it would also help explain the discrepancy in generalization performance between social learning contexts and the context of the *Set* task. The theory of natural pedagogy is summarized below to facilitate consideration of the possibility that generalization deficits in ASD are more likely in the context of social learning.

The theory of natural pedagogy (Csibra & Gergely, 2009; 2011) is presented as a solution to the induction problem—the question of how humans acquire generalizable knowledge from bits of information gathered during isolated learning episodes. This theory proposes that humans have developed a shortcut for solving this problem that relies on the willingness of a relatively expert teacher to convey generalizable information, and the ability of a relatively novice learner to understand that the teacher is trying to convey generalizable information. It is suggested that three cognitive biases in typically developing humans support natural pedagogy. The first bias is one of sensitivity to ostensive signals. Ostensive signals are nonverbal aspects of communication that indicate to the learner that the teacher is attempting to teach, including direct eye contact and prosody. The second bias is one of referential expectation. This refers to the expectation that ostensive signals will be accompanied by nonverbal behaviors that direct attention to a referent, such as pointing, showing, or shifting of gaze. The third cognitive bias is an interpretation bias for generalizability. This theory assumes that learners expect to gain generalizable information during ostensive-referential communication, rather than something specific to the teacher or the referent. It is suggested that these biases support the efficient transmission of generalizable information through social learning in typical individuals[7].

A relative lack of awareness of or concern for the nonverbal signals associated with ostensive-referential communication is typically observed among individuals with ASD, including a lack of awareness of prosody in others (e.g., Wang & Tsao, 2015) and poor joint attention skills (e.g., Dawson et al., 2004). Therefore, based on the theory of natural pedagogy, it may be expected that individuals with ASD would struggle with social learning because of a failure to notice or interpret the ostensive-referential communication of others as an indication that someone was attempting to teach generalizable information. Whether individuals with ASD may also lack the interpretation bias for generalizability is unknown, but this may not be necessary to create difficulty with generalization, as the natural pedagogy theory assumes that sensitivity to ostensive-referential signals represents a necessary first step in social learning.

[7]Evidence supporting this theory is provided by Csibra & Gergely (2009, 2011). This evidence was not reviewed here, as its presentation would distract from the purpose of the discussion.

Based on the theory of natural pedagogy, it is proposed that the discrepancies regarding generalization ability of individuals with ASD between the current study and intervention literature may be explained by differences in the associated social learning demand. The *Set* task presented no social learning demand, while many ASD-specific interventions present at least some social learning demands, as did the task used in a previous demonstration of poor generalization ability in ASD (de Marchena et al., 2015). This prediction suggests that future research should compare learning and generalization performance in ASD on similar tasks with and without social learning demands that integrate the use of ostensive-referential communication.

A final possible explanation for the failure to find evidence of atypical generalization in participants with ASD in the current study can be found in the conceptualization of ASD as a complex information processing disorder (Minshew et al., 1997; Williams et al., 2006; Williams, Minshew, & Goldstein, 2015). This conceptualization of ASD assumes that impairments associated with ASD are a result of a generalized deficit in the processing of information that requires coordination between distant brain areas, working with a large amount of information, or working with information that lacks inherent organization (Williams et al., 2015). This model and the associated empirical research suggest that individuals with ASD demonstrate deficits in a variety of areas that require the processing of complex information, such as skilled motor behaviors, complex memory tasks, complex language tasks, and in reasoning abilities. Importantly, the model and research also highlight that people with ASD demonstrate intact or superior abilities on simpler tasks that assess these same functional areas (Minshew et al., 1997; Williams et al., 2006). As described above, individuals with ASD demonstrate intact simple verbal learning, but deficits on more complex verbal learning tasks (relative to age- and IQ-matched controls; Minshew et al., 1997; Williams et al., 2006). Although generalization is not specifically addressed, it is expected that this model would predict that individuals with ASD would demonstrate intact generalization in situations with low information processing demand, but deficient generalization in situations with high information processing demand. As a result, it may be the case that the *Set* task did not present a high enough information processing demand to detect abnormality in generalization in this group of individuals with ASD. This assertion could be tested by increasing the complexity of the stimuli involved, increasing the flexibility in thinking required (e.g., by requiring generalization to stimulus characteristics other than shape, shading or color), and by introducing both changes together in one phase of the task.

4.4 Wisconsin Card Sorting Test

The WCST was included to rule out the possibility that any generalization deficits observed were not simply results of the mental set shifting or executive function demand associated with a change in stimuli used. Previous results comparing WCST performance of people with ASD and control participants have been mixed, but recent meta-analyses suggest that individuals with ASD tend to demonstrate poor performance relative to controls on multiple WCST measures (perseverative errors, non-perseverative errors, failure to maintain set, sets completed; Landry & Al-Taie, 2015; Westwood et al., 2016). The current results were inconsistent with the results of these meta-analyses, as no between-group differences in WCST performance were found. However, it is important to note that other authors have highlighted the variability present among individuals with ASD on measures of executive function such as the WCST (Geurts, Sinzig, Booth, Happé, 2014). It is reported by Geurts et al. (2014) that although individuals with ASD often demonstrate executive function deficits when compared as a group to control participants, examination of individual results suggests that only approximately 26% of individuals with ASD demonstrated deficits in the one WCST study considered (Geurts et al., 2004). Similar patterns of results were reported for other measures of executive function (Geurts et al., 2014). In addition, some studies have failed to demonstrate differences in WCST performance at the level of between-group analyses when comparing individuals with ASD and control participants (Ozonoff, 1995; Hill & Bird, 2006; Maes et al., 2011).

The reason for this failure to replicate previous research remains unclear. No obvious reasons for this atypical result, such as mismatched and high IQ in the ASD group or inappropriate ASD diagnoses, are present. It has been suggested that older children or adults with ASD may perform better than younger individuals on the measure of performance typically considered in ASD studies, perseverative errors (Landry & Al-

Taie, 2015). Since the current study included only adolescents and adults, this may provide some explanation for the failure to replicate previous research. However, other studies testing older populations have demonstrated deficits in WCST performance in ASD relative to controls, even though effect sizes were small (e.g., Lopez, Lincoln, Ozonoff, & Lai, 2005; Ambery et al., 2006). Indeed, the discrepancy between the current WCST results and those of previous research may represent a demonstration of the heterogeneity that exists within the autism spectrum (Hus et al., 2007; Jeste & Geschwind, 2014). As highlighted in the examination of the history of the weak central coherence account in the introduction, the ASD literature is replete with examples of discrepant research findings. The current WCST results serve to provide one more example of such a discrepancy.

Although no between-group differences in WCST performance were found, several correlations between WCST measures and other variables were significant. Overall accuracy and RT from the Set task were correlated with perseverative and non-perseverative errors on the WCST. These correlations indicated that those who were faster and more accurate on the Set task tended to make fewer errors on the WCST. These correlations between overall measures of performance on the two tasks may have been expected given that both tasks require application of explicit rules to complex stimuli that vary on similar characteristics (e.g., color & shape). In addition, multiple regression analyses indicated that the relationship between WCST perseverative errors and Set task accuracy, and that between WCST non-perseverative errors and Set task accuracy was fully mediated by NVIQ. This result suggests that the relationships between Set task performance and WCST may be a result of shared measurement of perceptual reasoning ability.

Replicating previous research in typical individuals and those with ASD (Minshew, Meyer, Goldstein, 2002; Salthouse Atkinson, Berish, 2003; Landry & Al-Taie, 2015), WCST perseverative and non-perseverative errors were correlated with NVIQ, and non-perseverative errors were correlated with VIQ as well. These correlations indicated that those who made fewer errors on the WCST tended have higher VIQ and NVIQ, suggesting that the WCST measures some general reasoning ability.

Finally, WCST perseverative errors score was correlated with phase four slope (skill development), indicating that those who made fewer perseverative errors tended to improve performance more quickly during phase four. It has been suggested that the WCST perseverative error score provides some measure of the ability to spontaneously form and evaluate hypotheses, possibly in addition to rule learning and attribute identification (Minshew et al., 2002). Therefore, this result raises the possibility that those who were better able to learn rules and form and evaluate hypotheses on the WCST were also able to use those skills to enhance skill development in phase four of the Set task. Importantly, further analysis identified that this correlation was only significant for the ASD group. This result may reflect between-group differences in processes supporting phase four skill development. Earlier in this discussion it was suggested that individuals with ASD might have continued to use explicit learning processes in phase four when typical individuals shifted towards the use of implicit learning processes, resulting in between-group differences in performance. This result lends some (indirect) support to that hypothesis, as processes such as hypothesis formation and rule learning measured by WCST perseverative errors are explicit learning processes, and were correlated with phase four slope only for the ASD group.

4.5 Adaptive Behavior Assessment Scale

The ABAS-2 was included in order to assess the relationship between ABAS scores and learning, generalization, and WCST performance. It was expected that both Set task and WCST performance would be correlated with adaptive skills, but none of these correlations were significant. On average, the group of individuals with ASD scored in the below average range on the measures of adaptive skills. Deficits in adaptive skills are commonly reported among individuals with ASD, but some studies have previously demonstrated even lower ABAS scores among high functioning individuals with ASD (e.g., Kenworthy et al., 2012). Consistent with the current study, multiple studies have demonstrated that individuals with ASD tend to have lower standardized scores on measures of adaptive skills than on intelligence measures (Klin et al., 2002, 2007;

Kenworthy et al., 2012; Charman, Pickles, Simonoff, Chandler, Loucas, & Baird, 2011, Duncan & Bishop, 2015).

The current study failed to replicate previous research that has demonstrated correlations between adaptive skills and IQ (Klin et al., 2007; Kenworthy et al., 2012; Charman et al., 2011, Duncan & Bishop, 2015) and adaptive skills and WCST performance (Szatmari, Bartolucci, & Bremner, 1989) among individuals with ASD. Correlations between adaptive skills and IQ have been demonstrated primarily using the Vineland Adaptive Behavior Scales (Klin et al., 2007; Charman et al., 2011, Duncan & Bishop, 2015). In addition, no correlation was observed between IQ and the ABAS general adaptive composite (the measure used in the current study) in one study of teens and adults with ASD (Kenworthy et al., 2010). Therefore, the failure to replicate this correlation in the current study may be a result of differences in measurement. Similarly, the previously reported correlation between WCST performance and adaptive skills (Szatmari et al., 1989) was based on assessment of adaptive skills using the Vineland Adaptive Behavior Scales, and may therefore help explain the discrepant results of the current study. Given the differences in patterns of correlations observed between the current study and previous studies, it may be the case that future examinations of the relationship between adaptive skills and learning or generalization performance should assess adaptive skills using the more widely used Vineland Adaptive Behavior Scales.

4.6 Limitations

The sample recruited for the current study cannot be considered a random or representative sample of individuals with ASD. Many participants in the ASD group were drawn from several pre-existing participant pools (at Dalhousie University, University of Guelph, and Woodview Manor in Hamilton, ON). Others were recruited by advertising at a local Autism support centre, and through online classified ads. While the recruitment sources were somewhat diverse in nature, it is likely true that a portion of the population of individuals with ASD with little support from parents/guardians/staff or with little means of transportation would have had great difficulty participating in the current study. In addition, the reasoning skills associated with the *Set* task were considerable, enough that some individuals with ASD were not able to complete the initial phases of the task. Although IQ information is not available for these individuals, it is expected that IQ would have been very low for these individuals, or that assessment of IQ would have been difficult due to behavioral or attentional difficulties. Finally, no individuals currently taking antipsychotic medication or other psychotropic medication known to slow RT were allowed to participate in the study. Several potential participants were excluded based on this criterion. As a result of these sampling biases, it is suggested that the current results can only be generalized to individuals with ASD who do not have intellectual disability, or significant mental health symptoms or aggressive behavior that might require antipsychotic medication. In addition, as a result of the non-random nature of the sample it is suggested that the results be generalized to others with ASD with caution and only following replication.

Another limitation of the current study is the novelty of the *Set* task. The task holds good face validity, and the large correlation between overall *Set* task accuracy and intelligence provides some evidence that the task is assessing explicit learning ability (i.e., convergent validity; Reber et al., 1991). However, the results of the current study only provide evidence that the *Set* task assesses learning ability. The measures of generalization of learning did not correlate with any other variables. Therefore, the current results provide limited means of assessing convergent or discriminant validity of the generalization measures. As a result, it is suggested that any future research using this or similar tasks should include established measures of explicit learning (e.g., verbal and spatial memory tasks, for convergent validity), implicit learning (for divergent validity), and executive function (e.g., the WCST, for divergent validity) in order to better support the examination of task validity. However, as recommended below, future research should modify the Set task in order to maximize the potential for examination of generalization ability.

4.7 Conclusions And Future Research

The current study used a novel task to examine explicit rule learning and generalization ability in individuals with ASD. No evidence was found of between-group differences in the ability to initially learn the Set rule or in generalization ability. Examination of performance following the most difficult stimulus shift provided no evidence of immediate between-group differences in generalization of the *Set* rule, but provided evidence that the control group improved performance more quickly than the ASD group. This difference in learning or skill development is interpreted as evidence that the control and ASD groups used different cognitive processes to support improvement in performance. Additional correlation analysis provided indirect evidence supporting the notion that individuals with ASD may have used explicit learning processes to support skill development in phase four while control participants used implicit learning processes. Unexpectedly, no between-group differences in WCST performance were found, and no correlations between *Set* task performance and adaptive skills or WCST performance and adaptive skills were significant.

The current results provide no evidence that individuals with ASD possess a fundamental deficit in the ability to perceive conceptual similarities between sets of stimuli such as those used in the *Set* task. This perception of similarities between stimuli was hypothesized to be a deficit that may result in poor generalization in ASD, as suggested by the weak coherence account of ASD (Happé & Frith, 2006). The results of the current study suggest that this interpretation of the weak coherence account of ASD should be re-evaluated. In addition, the results of the current study provide no evidence that individuals with ASD possess a fundamental deficit in generalization ability, as suggested by the reduced generalization account of ASD (Plaisted, 2001). Indeed, in the current study the ability of individuals with ASD to apply moderately complex explicit rules to variable stimuli in a non-social learning setting appears comparable to that of controls.

As a result of this failure to detect any deficit in generalization ability among individuals with ASD using this relatively basic explicit learning task, it is suggested that future research investigate the generalization performance of individuals with ASD that results from different types of learning. As described in the discussion, it may be expected that individuals with ASD would struggle to generalize learning resulting from a social learning context that relies upon accurate interpretation of ostensive-referential nonverbal cues (Csibra & Gergely, 2009). Comparison of generalization ability resulting from social learning and non-social learning contexts on tasks of roughly equivalent difficulty may be particularly informative.

Future research might also productively consider the impact of task complexity on both learning and generalization performance. A number of studies have suggested that individuals with ASD may demonstrate typical performance on relatively simple tasks in a variety of cognitive domains, but impaired performance on more complex tasks in those same domains (e.g., Minshew et al., 1997; Williams et al., 2006). Therefore increasing the complexity of both the rules and stimuli used in the *Set* task (or a similar measure) may result in demonstration of atypical learning and generalization in people with ASD.

Table 1. Description of Set Task Phases.

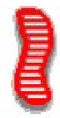
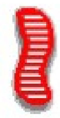
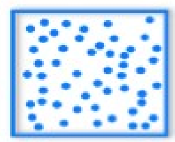
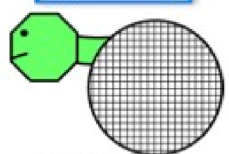
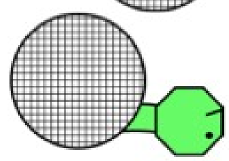
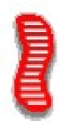
Phase	Task	Stimuli	Description
1	Figure it out		Figure out task using feedback without being taught the rule. Stimuli from Figure 2A.
2	Reaching performance criterion		Reach 70% accuracy on a 24 trial block; minimum 48 trials in this phase
3	Generalization 1		Apply rule to new set of stimuli (Figure 2B)
4	Generalization 2		Apply rule to new set of stimuli (Figure 2C)
5	Generalization 3		Apply rule to new set of stimuli (Figure 2C, inverted)
6	Testing retention of rule		Complete 50 more trials with original stimuli in order to test retention of rule.

Table 2. Participant Characteristics.

	n	Age (years)	Verbal IQ	Performance IQ
Autism Spectrum Disorder	28	24.6	105.4	108.6
range	N/A	13-44	66-142	73-138
Typical Control	31	25.2	109.8	105.8
range	N/A	13-44	81-143	71-148
t-test		t(55.8)=-.25, p=.8	t(51.3)=-.91, p=.36	t(54.3)=.61, p=.54

Table 3. WCST Results.

WCST Measure	Group	N	Mean	T-test
Perseverative Errors (standardized)	ASD	27	97.07	t(57)=-0.6, p=.55
	Control	32	100.41	
Nonperseverative Errors (standardized)	ASD	27	97.89	t(57)=0.35, p=.72
	Control	32	96.38	
Categories Completed	ASD	27	5.11	t(57)=-0.03, p=.97
	Control	32	5.13	
Failure to Maintain Set	ASD	27	0.70	t(57)=-0.56, p=.58
	Control	32	0.56	

Table 4. ABAS-2 Results.

ABAS-2 Index	Mean	Standard Deviation	Range
General Adaptive Composite	82.30	15.10	51-104
Conceptual	86.47	12.63	57-106
Social	80.39	13.86	54-107
Practical	84.39	18.57	46-120

Table 5. Correlation Matrix with data from both groups.

	Gen2RT	Phase 1 RT Slope	Phase 4 RT Slope	Set Task Mean RT	Set Task Mean Accuracy	VIQ	NVIQ	WCST Pers. Errors	WCST Nonpers. Errors
Gen2RT									
Phase 1 RT Slope	r= .018 p= .892 n= 60								
Phase 4 RT Slope	r= -.007 p= .960 n= 60	r= -.009 p= .946 n= 60							
Set Task Mean RT	r= .554 p< .001 n= 60	r= .011 p= .934 n= 60	r= -.087 p= .507 n= 60						
Set Task Mean Accuracy	r= .492 p< .001 n= 60	r= .06 p= .647 n= 60	r=-.256 p=.048 n= 60	r= .217 p= .096 n= 60					
VIQ	r= .120 p= .365 n= 59	r= .12 p= .352 n= 59	r= -.202 p= .125 n= 60	r= .070 p= .599 n= 59	r= .362 p= .005 n= 59				
NVIQ	r= .261 p= .044 n= 60	r= -.131 p= .318 n= 60	r= -.127 p= .335 n= 60	r= .002 p= .989 n= 60	r= .687 p<.001 n= 60	r= .620 p<.001 n=59			
WCST Pers. Errors	r= .010 p= .940 n= 59	r= -.047 p= .724 n= 59	r= -.268 p= .040 n= 59	r= -.275 p= .035 n= 59	r= .348 p= .007 n= 59	r=.203 p=.126 n=58	r= .446 p<.001 n= 59		
WCST Nonpers. Errors	r= .060 p= .653 n= 59	r= .081 p= .542 n= 59	r= -.228 p= .083 n= 59	r= -.262 p=.045 n= 59	r= .409 p=.001 n= 59	r= .263 p= .046 n= 58	r= .510 p<.001 n= 59	r= .864 p<.001 n=59	

Correlation matrix including both groups

Table 6. Correlation Matrix with data from the ASD group only.

	Gen2RT	Phase 1 RT Slope	Phase 4 RT Slope	Set Task Mean RT	Set Task Mean Accuracy	VIQ	NVIQ	ABAS General	WCST Pers. Errors	WCST Nonpers. Errors
Gen2RT										
Phase 1 RT Slope	r= -.250 p= .199 n= 28									
Phase 4 RT Slope	r= .102 p= .604 n= 28	r= .194 p= .321 n= 28								
Set Task Mean RT	r= .749 p< .001 n= 28	r= -.172 p= .383 n= 28	r= .217 p= .268 n= 28							
Set Task Mean Accuracy	r= .478 p< .001 n= 28	r= -.097 p= .624 n= 28	r=-.295 p=.128 n= 28	r= .183 p= .352 n= 28						
VIQ	r= .261 p= .189 n= 27	r= .016 p= .936 n= 27	r= -.340 p= .083 n= 27	r= .193 p= .334 n= 27	r= .456 p= .017 n= 27					
NVIQ	r= .458 p= .014 n= 28	r= -.209 p= .286 n= 28	r= -.376 p= .048 n= 28	r= .247 p= .204 n= 28	r= .738 p<.001 n= 28	r= .739 p<.001 n=27				
ABAS General	r= -.247 p= .256 n= 23	r= .319 p= .137 n= 23	r= .080 p= .717 n= 23	r= -.019 p= .932 n= 23	r= -.156 p= .477 n=23	r= -.108 p=.624 n=23	r= -.057 p=.798 n= 23			
WCST Pers. Errors	r= .026 p= .897 n= 27	r= -.207 p= .300 n= 27	r= -.398 p= .040 n= 27	r= -.265 p= .182 n= 27	r= .505 p= .007 n= 27	r=.423 p=.031 n=26	r= .496 p=.009 n= 27	r= -.222 p=.321 n=22		
WCST Nonpers. Errors	r= -.061 p= .762 n= 27	r= -.182 p= .364 n= 27	r= -.526 p= .005 n= 27	r= -.297 p=.132 n= 27	r= .421 p= .029 n= 27	r= .489 p= .011 n= 26	r= .558 p=.003 n= 27	r= -.182 p= .418 n=22	r= .869 p<.001 n=27	

Correlation matrix including the ASD group only

Table 7. Correlation Matrix with data from the ASD group only.

	Gen2RT	Phase 1 RT Slope	Phase 4 RT Slope	Set Task Mean RT	Set Task Mean Accuracy	VIQ	NVIQ	WCST Pers. Errors	WCST Nonpers. Errors
Gen2RT									
Phase 1 RT Slope	r= .292 p= .105 n= 32								
Phase 4 RT Slope	r= -.244 p= .178 n= 32	r= -.148 p= .420 n= 32							
Set Task Mean RT	r= .303 p=.092 n= 32	r= .239 p= .187 n= 32	r= -.496 p= .004 n= 32						
Set Task Mean Accuracy	r= .456 p=.009 n= 32	r= .203 p= .265 n= 32	r=-.407 p=.021 n= 32	r= .213 p= .242 n= 32					
VIQ	r= .037 p= .839 n= 32	r= .230 p= .205 n= 32	r= -.059 p= .749 n= 32	r= -.055 p= .765 n= 32	r= .368 p= .038 n= 32				
NVIQ	r= .034 p= .852 n= 32	r= -.046 p= .803 n= 32	r= .014 p= .938 n= 32	r= .-.340 p= .057 n= 32	r= .657 p<.001 n= 32	r= .524 p= .002 n=32			
WCST Pers. Errors	r= .035 p= .850 n= 32	r= .110 p= .549 n= 32	r= -.142 p= .439 n= 32	r= -.271 p= .134 n= 32	r= .273 p= .130 n= 32	r= -.055 p= .764 n=32	r= .408 p= .021 n= 32		
WCST Nonpers. Errors	r= .132 p= .473 n= 32	r= .279 p= .122 n= 32	r= -.096 p= .602 n= 32	r= -.264 p=.144 n= 32	r= .403 p=.022 n= 32	r= .113 p= .537 n= 32	r= .483 p= .005 n= 32	r= .895 p<.001 n=32	

Correlation matrix including the control group only

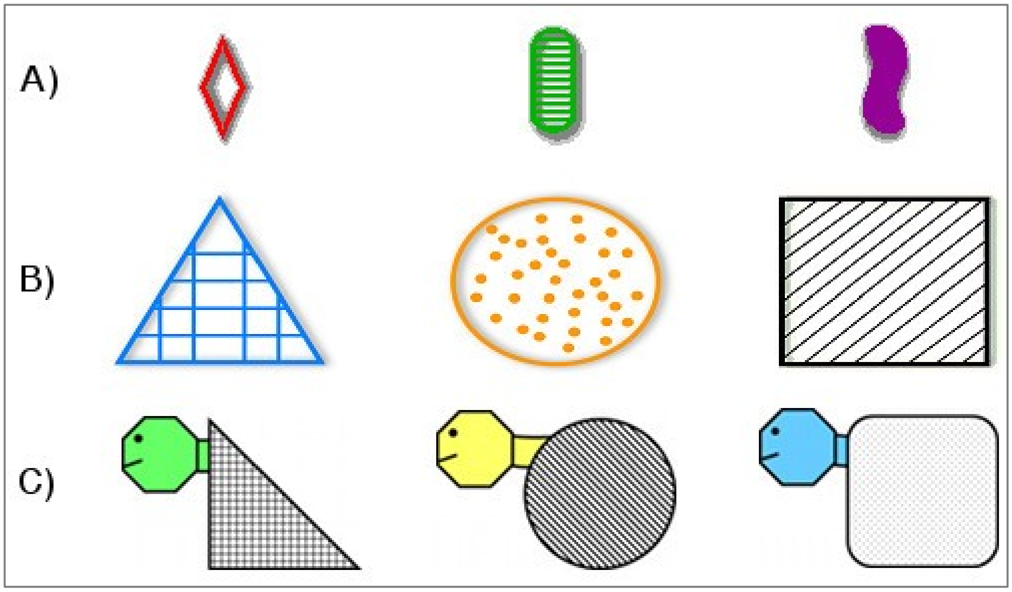


Figure 1. Sample stimuli used the *Set* learning and generalization measure.

The stimuli depicted in this figure are samples of those used in the *Set* learning and generalization measure. Full sets of stimuli were created using each possible combination of the colors, shapes, and shadings within each sample set depicted above. Those in 1A were used in Phases 1, 2, and 6. Those in 1B were used in Phase three. Those in 1C were used in Phase four, and inverted versions of those in 1C were used in Phase five. See Table 1 for a diagram of the phases of the task.

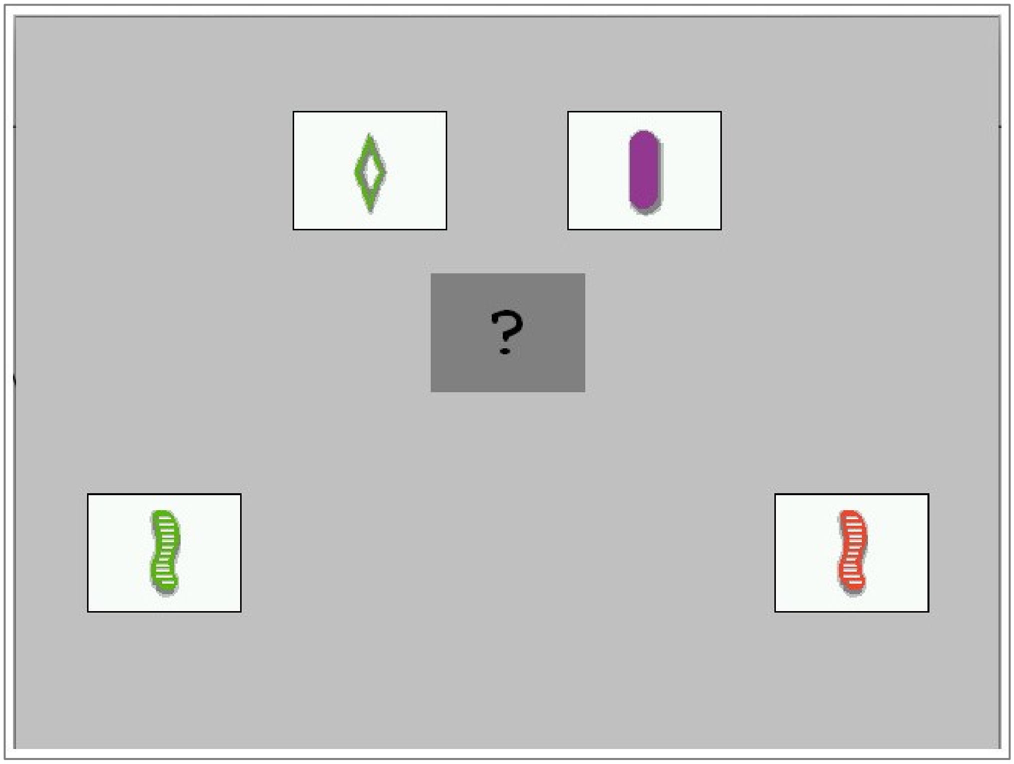


Figure 2. Sample display of a single trial from the learning and generalization task (Phases 1, 2, and 6 used these stimuli).

Participants were told that the two upper cards are always part of the correct set, and their task was to choose one of the two lower cards to complete a set of three. In this example, the card on the lower right is the correct choice.

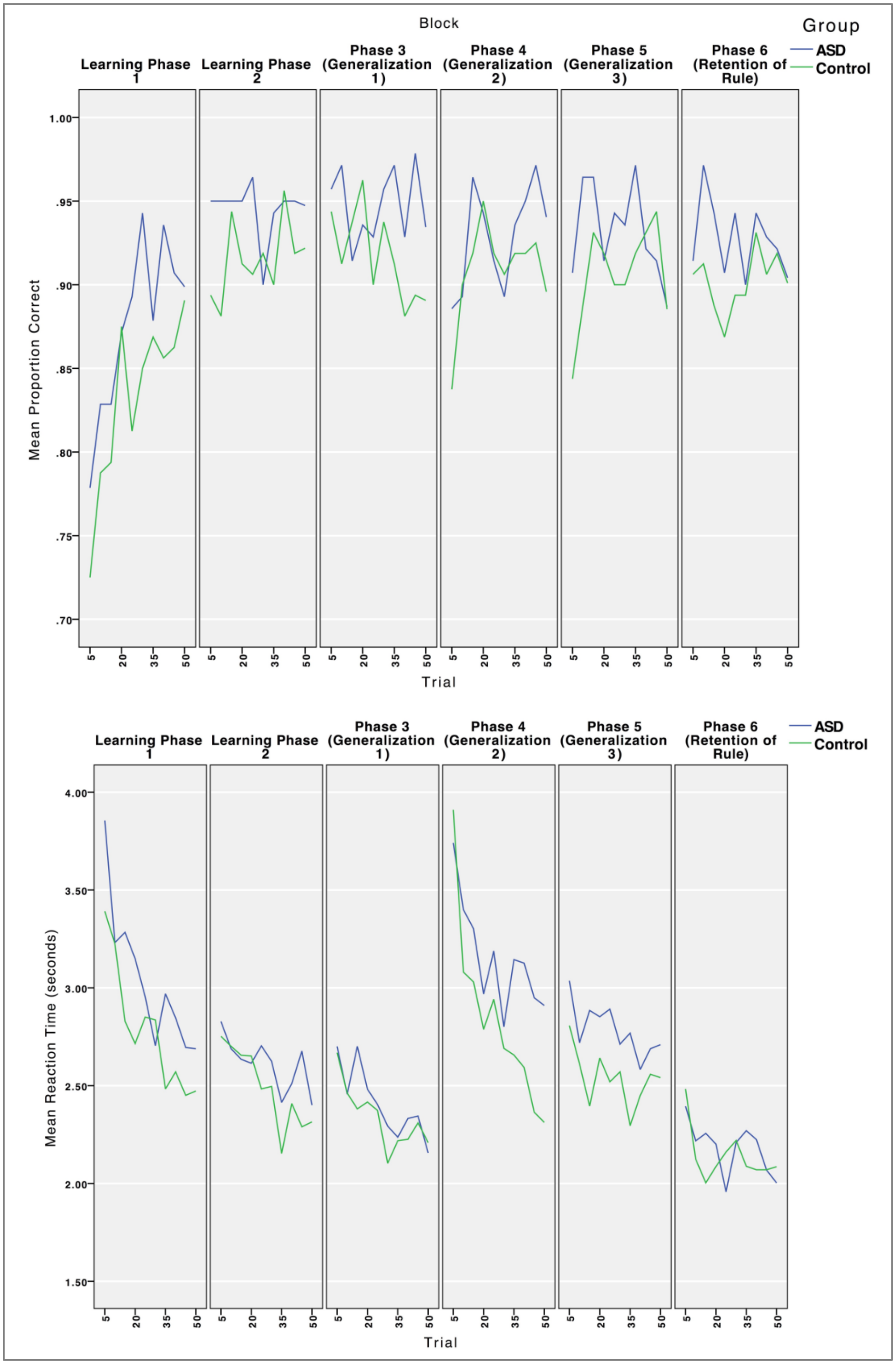


Figure 3. Mean accuracy (proportion correct) and mean reaction time (seconds) data from the *Set* task split by trial, phase, and group.

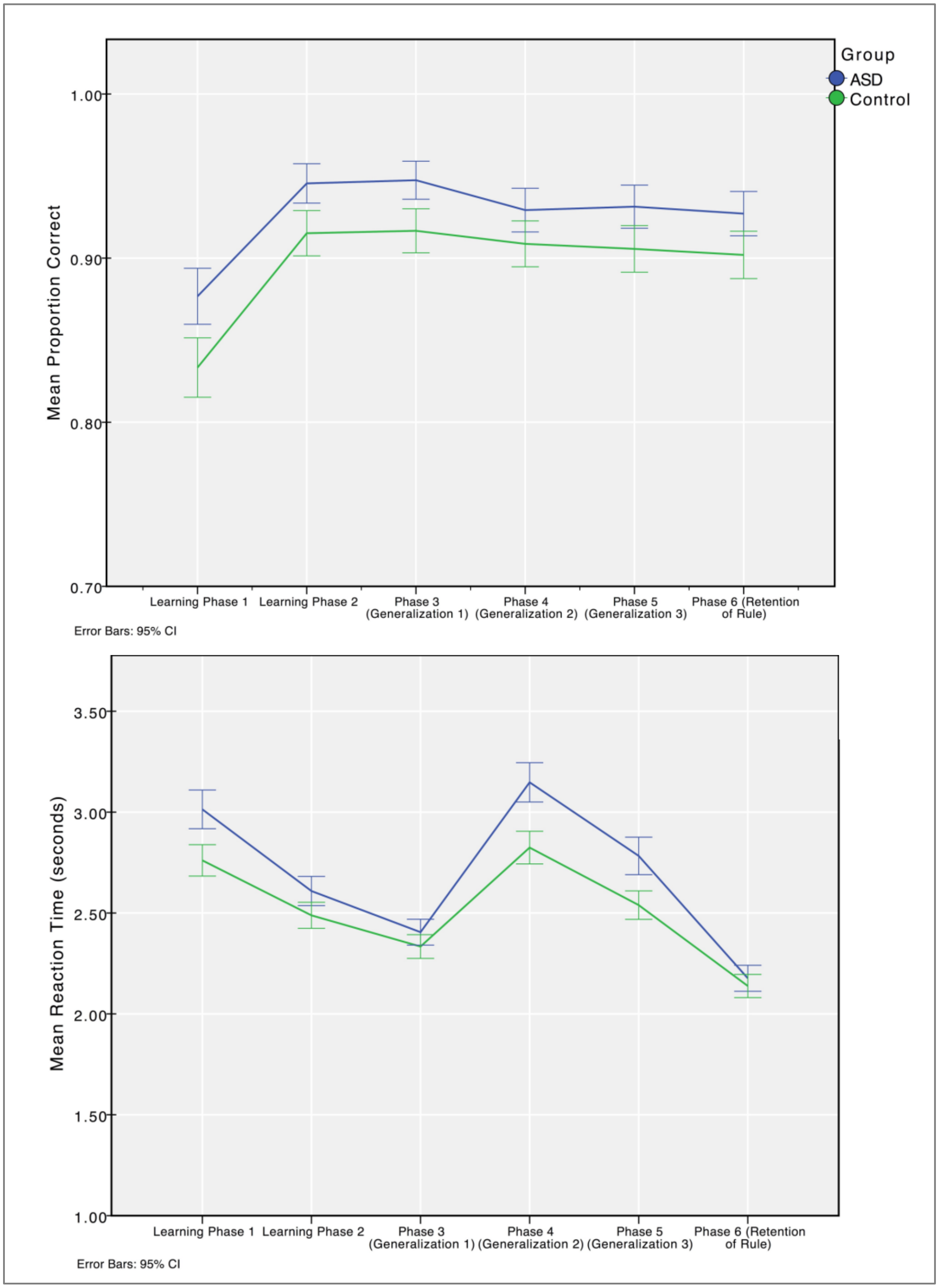


Figure 4. Mean accuracy (proportion correct) and reaction time (seconds) data from the *Set* task split by phase and group.

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Appendix A: IWK Research Ethics Board Approval

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Research

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Approval – Delegated Review
February 20, 2013

Principal Investigator: Dr Susan Bryson
Co-Principal Investigator: Jeff MacLeod
Title: Learning and Generalization Ability in Youth and Adults with Autism Spectrum Disorder
Project #:1012850

On behalf of the IWK Research Ethics Board (IWK-REB) I have reviewed the documents included in this study. I am pleased to confirm the Board's full approval for this research study, effective today. This includes approval for the following study documents:

Document Name	Version Date
Script - Email	2012/11/06
Script - Online Ad	2012/11/06
Form - Consent to Release Psychological Data	2012/11/06
Protocol	2013/02/05
Research Summary	2013/02/05
Information and Consent Form - Pilot Study	2013/02/05
Information and Consent Form - Control Study	2013/02/05
Information and Consent Form - Group with ASD	2013/02/05
Information and Assent Form - ASD Group	2013/02/05
Information and Assent Form - Pilot Study	2013/02/05
Information and Assent Form - Control Study	2013/02/05

The Board's approval for this study will expire one year from the date of this letter (February 20, 2014). To ensure continuing approval, submit a Request for Continuing Review to the Board 2 - 4 weeks prior to the renewal date. If approval is not renewed prior to the anniversary date, the Board will close your file and you must cease all study activities immediately. To reactivate a study, you must submit a new Initial Submission (together with the usual fee, if applicable) to the IWK-REB and await notice of re-approval.

Please be sure to notify the Board of any of the following:
§ Proposed changes to the initial submission (i.e. new or amended study documents)
§ Additional information to be provided to study participants
§ Material designed for advertisement or publication with a view to attracting participants

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§ Serious adverse events experience by local participants
§ Unanticipated problems involving risks to participants or others
§ Sponsor-provided safety information
§ Additional Compensation available to participants
§ Upcoming audits/inspections by a sponsor or regulatory authority
§ Closure of the study (within 90 days of the event)

Approved studies may be subject to internal audit. Should your research be selected for audit, the Board will advise you and indicate any other requests at that time.

Important Instructions and Reminders

Submit all correspondence to Ethics Manager Bev White or Ethics Assistant, Joanne Leonard at the address listed at the top of this letter (do not send your response to the IWK-REB Chair or Co-Chair)

Be sure to reference the Board's assigned file number, 1012850 on all communications.

Highlight all changes on revised documents and remember to update version numbers and version dates, include a clean copy of all revised documents.

Best wishes for a successful study.

Yours truly,

Linda Hamilton
Co-Chair, Research Ethics Board

Research Ethics Board Committee Members		
Robert	Bortolussi	Pediatrics (Clinical Researcher)
Jill	Chorney	Psychology (Clinical Researcher)
Elaine	Cumming	Legal Representative
Eleanor	Fitzpatrick	Nursing (Clinical Researcher)
Margo	Fulmer	Lay Representative
Jane	Gillis	Medical Genetics (Clinical Researcher)
Linda	Hamilton	Obstetrics and Gynecology, Co-Chair
Adam	Huber	Rheumatology (Clinical Researcher), Co-Chair
Faye	Jacobson	Nursing (Research Coordinator)
Sarah	Matheson	Lay Representative
Susan	McKinney	Legal Representative
James	Morrison	Anaesthesia, Executive Chair

Victoria	Price	Hematology/Oncology (Clinical Researcher)
Erna	Snelgrove-Clarke	Nursing (Clinical Researcher)
Valerie	Shaffner	Privacy
Marilyn	Tiller	Pharmacy

* REB members are not in attendance during review of their own proposed research involving human subjects or where there is conflict of interest with the proposed research

This statement is in lieu of Health Canada's Research Ethics Board Attestation: *The Research Ethics Board for the IWK Health Centre operates in accordance with:*
- Food and Drug Regulations, Division 5 "Drugs for Clinical Trials involving Human Subjects"
- The Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans - TCPS(2)
- International Conference on Harmonization - Good Clinical Practice Guidelines - ICH-GCP