Brown, H. M., Oram-Cardy, J., & Johnson, A. (2013). A meta-analysis of the reading comprehension skills of individuals on the autism spectrum. *Journal of Autism and Developmental Disorders*, *43*(4), 932–955. http://doi.org/10.1007/s10803-012-1638-1

The prevalence of autism spectrum disorder (ASD) in children is currently estimated to range between 1:130-180 in Canada, and 1:80-240 in the United States. On average, one child in every 110-155 has ASD (Autism and Developmental Disabilities Monitoring Network, 2009; Fombonne, Zakarian, Bennett, Meng &McLean-Haywood, 2006). In the Canadian province of Ontario, the number of students in publicly funded school systems identified as having a diagnosis of ASD doubled between 1999 and 2006 (Ontario Ministry of Education, 2007). Similarly, there were 258,305 students in the United States identified with ASD who were receiving special education services in 2007, which is 4.7 times more than in 1998 (ADDM Network, 2009b). With increasingly more students with ASD in mainstream educational settings than ever before, teachers may find themselves ill-equipped to meet the complex needs of these learners.

Academic Achievement in Students with ASD

Academic achievement varies widely in students with ASD, ranging from severely impaired to exceptional academic performance (Griswold, Barnhill, Smith-Myles, Hagiwara & Simpson, 2002). Estes, Rivera, Bryan, Cali and Dawson (2011) reported that 90% of the children with ASD in their sample demonstrated a discrepancy between their expected achievement (based on intellectual functioning) and actual achievement in at least one of spelling, word reading or basic number skills. They found that in at least one of these three domains, 60% of students with ASD had lower achievement levels than would be predicted by their intellectual functioning. Surprisingly, however, an equal percentage of children had higher achievement levels in at least one of the three domains than would be predicted by intellectual functioning. Supporting this finding of both academic strengths and weaknesses in students with ASD, Jones, Happé, Golden, Marsden, Tregay et al. (2009) found four largely distinct subgroups of IQ-achievement discrepancies in the math and reading skills of students with ASD that they termed reading peak, reading dip, arithmetic peak and arithmetic dip. That is, there were distinct groups of students who had higher than expected achievement in math and reading as well as students who had lower than expected achievement in these two areas. However, the authors indicated that discrepantly poor reading comprehension was the most prevalent profile in these students. Related to this, Mayes and Calhoun (2006) discovered that the proportion of students with ASD who had academic weaknesses varied by subject. They found that 60% of their participants with ASD had a specific learning disability (LD) in writing, while 23% had an LD in math. In contrast to the findings of Jones et al. (2009), however, only 6% of the participants with ASD in the Mayes and Calhoun (2006) study had an LD in reading. Thus, it seems that there is a large degree of heterogeneity in academic performance of students with ASD.

Reading comprehension is the ultimate goal of reading and one of the most important skills learned in school (Åsberg, Kopp, Berg-Kelly & Gillberg, 2010; Nation, 2005). A number of studies have revealed that individuals with ASD have deficits in reading comprehension that are out of keeping with their intelligence (Åsberg, Dahlgren, & Dahlgren-Sandberg, 2008; Castles, Crichton & Prior, 2010; Flores & Ganz, 2009; Goldstein, Minshew & Siegal, 1994; Huemer & Mann, 2010; Jones, Happé, Golden, Marsden, Tregay et al., 2009; Lindgren, Folstein, Tomblin & Tager-Flusberg, 2009; Minshew, Goldstein, & Siegel, 1995; Nation, Clarke, Wright & Williams, 2006; Newman, Macomber, Naples, Babitz, Volkmar et al., 2007). Despite this relatively robust finding, some researchers have failed to find differences between students with ASD and their non-disabled peers in reading comprehension (Happé, Ehlers, Fletcher, Frith, Johansson et al, 1996; LaPoint-Spear, 2007; Mayes & Calhoun, 2003; 2008; Newman, et al., 2007; Saldaña & Frith, 2007); whereas as others have found that individuals with ASD have reading comprehension strengths (Åsberg, 2010; Åsberg & Dahlgren-Sandberg, 2010; Ashcraft-Bills, 2009, Lindgren, et al., 2009). Moreover, across the studies in which reading comprehension deficits were found, it is noteworthy that the size of the difference in reading comprehension scores between the groups with ASD and controls seemed to vary within two standard deviations. This large variability in the magnitude of reading comprehension deficits in individuals with ASD across studies suggests that there may be factors beyond a diagnosis of ASD that influence the degree of the reading comprehension difficulties in a given sample. The current meta-analysis sought to explore the size and consistency of the differences in reading comprehension skill of individuals with ASD in comparison to those without, with the goal of trying to explain the heterogeneity of reading comprehension deficits across studies. It also sought to identify factors that predict reading comprehension strengths and weaknesses in the ASD population.

What components of reading comprehension fail?

The possibilities for comprehension failure seem endless because reading comprehension covers a large range of complex language processes, any of which can fail (Perfetti, Marron & Foltz, 1996). Comprehension requires readers to build a mental representation of the text (Nation, 2005), that is, a mental model of what is described in the text (Kintsch & Rawson, 2005). When we read, we readily combine previous knowledge with information in the text to create a visual scene (Kintsch & Rawson, 2005; Perfetti, Marron & Foltz, 1996). Readers must make some connection between the words in the text to some piece of knowledge that they have about the world, in order to comprehend what is written (Perfetti, Marron & Foltz, 1996). Building a mental model of the text involves many different processes such as making connections between background knowledge and the textbase. To clarify why there are inconsistencies in the literature on the reading abilities of individuals with ASD, group level differences in some of the processes underlying the development of reading comprehension were examined in the current meta-analysis.

Reading the text: Recognizing words

One of the first processes involved in comprehending a text is the ability to recognize individual words. Reading comprehension deficits are often associated with word level decoding problems (Nation, 2005; Perfetti, Marron & Foltz, 1996). When decoding is slow and effortful, most of the reader's processing resources will be dedicated to decoding and will therefore be unavailable for comprehension (Perfetti, 1985). Indeed, children with poor reading comprehension have been shown to be slower at reading words and pseudowords than their typically developing (TD) peers (Perfetti & Hogaboam, 1975). Reading pseudowords (e.g., gak) and real words is thought to depend in large part on phonological processing, which is the ability to recognize the sound structure of oral language (Lanter & Watson, 2008). Accordingly, there is a high correlation between single word reading and phonological processing abilities (Wagner, Torgesen & Rashotte, 1994).

Word recognition in ASD

Individuals with ASD are often thought to have word recognition strengths. The strong version of this premise is that as a group, students with ASD have weaknesses in reading comprehension despite superior word reading accuracy (Castles et al., 2010; Flores & Ganz, 2009; Goldstein et al., 1994). In accordance with this theory, approximately 5-10% of individuals with ASD are also characterized as "hyperlexic" (Burd & Kerbeshian, 1985) and associations have been found between autism and hyperlexia (Smith & Bryson, 1988). Individuals are categorized as hyperlexic when their ability to decode and sound out individual words is quite high, likely because of exceptional phonological skills, compared to their ability to comprehend those words (Frith & Snowling, 1983; Newman et al., 2007). In contrast, other studies have found that individuals with ASD have typical word reading accuracy (Smith-Gabig, 2010; Nation et al., 2006; Newman et al., 2007), while still other studies have found that this group to have poor word recognition skills (Åsberg, et al., 2008; Huemer & Mann, 2010; Jones et al., 2009). A plausible hypothesis based on these various findings could be that word recognition is normally distributed in people with ASD, and those with hyperlexia simply represent the right hand tail of the distribution. To better understand the distribution of strengths and weaknesses in decoding skill in the ASD population, the current meta-analysis examined the direction and consistency of the size of the difference in decoding skills across studies. As well, the degree to which decoding ability predicted reading comprehension was examined.

Prior Knowledge: Semantic Knowledge and Interpersonal Knowledge

To build an accurate model of the text, individuals must integrate components of the text with prior knowledge (Wahlberg & Magliano, 2004). As such, domain knowledge is crucial to comprehension. To understand the knowledge of a domain means to understand its basic concepts, as well as its goals, rules and principles (Chiesi, Spilich, & Voss, 1979). Examples of domain knowledge would include semantic knowledge; academic subjects such as history or mathematics; procedural knowledge such as how to fix a car; script-like knowledge of familiar events, such as what typically happens at a child's birthday party; and interpersonal knowledge, which "involves such things as knowledge of human needs, motivations, attitudes, emotions, values, behavior, personality traits, and relationships" (Kamhi & Catts, 2005, p. 12). Previous research has shown that individuals who have more highly developed knowledge within a domain tend to have better reading comprehension of texts in that domain (Nation, 2005; Spilich, Vesonder, Chiesi & Voss, 1979). With regards to individuals with ASD, it has been demonstrated that these individuals may have difficulties using domain knowledge to interpret what they read (Wahlberg & Magliano, 2004). In this meta-analysis, two types of prior knowledge, semantic and interpersonal knowledge, were explored as predictors of reading comprehension in ASD.

Semantic knowledge and ASD

Knowledge of word meanings, along with the richness and quality of those representations, is central to comprehension (Nation, 2005; Perfetti, Landi & Oakhill, 2005; Stothers & Oram Cardy, 2012). The reader's ability to access the meaning of a word as it applies in the context of a given text is critical to understanding (Perfetti, Landi & Oakhill, 2005). Research has demonstrated that poor comprehenders have difficulty processing word meanings, such as whether two words mean the same thing, or producing exemplars to a category label (Nation, 2005). It is theorized that the semantic knowledge of poor comprehenders may be restricted in two ways. First, the breadth of their word knowledge could be restricted, in that poor comprehenders have smaller vocabularies than their peers

(Nation, 2005). Second, the depth of the representations may be limited, in that poor comprehenders may have shallow semantic representations, lacking in detail (Stothers & Oram Cardy, 2012).

Individuals with ASD tend to have semantic deficits, but these deficits are not universal (Kjelgaard & Tager-Flusberg, 2001). In one study, the receptive and expressive vocabulary scores of children with ASD ranged from severely impaired to above average, but approximately 25% of the children had essentially normal language skills (Kjelgaard & Tager-Flusberg, 2001). In accordance with the theory that language skills vary in individuals with ASD from impaired to typical, several studies have found that individuals with ASD have poor semantic knowledge (Åsberg, 2010; Brent, Rios, Happé & Charman, 2004; Huemer & Mann, 2010; Naples, 2009; O'Connor & Klein, 2004), while others have found average to above average vocabulary knowledge in participants with ASD (Ashcraft-Bills, 2009; Emerich, Creaghead, Grether, Murray & Grasha, 2003; Griswold et al., 2002; Mayes & Calhoun, 2003; Minshew, Goldstein & Siegel, 1995). This meta-analysis examined the semantic knowledge of individuals with ASD compared to their peers to determine the size and consistency of the differences between the two groups. As well, semantic knowledge was used to predict reading comprehension in individuals with ASD.

Interpersonal Knowledge

One domain that is thought to be critically impaired in individuals with ASD is social cognition. Individuals with ASD tend to lack intuitive knowledge of social behaviour, have difficulties comprehending the social world, and often seem to be unaware of rules that govern social actions (Baron-Cohen, Leslie & Frith, 1985; Bowler, 1992). Further, it has been demonstrated that individuals with ASD struggle to understand mental states (such as beliefs, desires, intentions) as applied both to themselves and to others, a phenomenon often referred to as poor *theory of mind* (ToM; Baron-Cohen, Leslie & Frith, 1985). According to Klin (2000), understanding the social world requires that individuals perceive relevant social elements of a situation, interpret how social elements create the particular social context, and then understand how the social context guides their interpretation of other's behaviours. These same three principals would also be necessary for an individual to build an accurate mental model of a textbase, particularly a text that involved the social world, such as a narrative. Given that individuals with ASD often have limited understanding of interpersonal knowledge, it may follow that their problems with reading comprehension may stem from not having the relevant knowledge to draw upon while reading.

White, Hill, Happé and Frith (2009) investigated the possibility of whether individuals with ASD had problems with reading comprehension generally, or whether their problems with reading comprehension could be the result of limited social knowledge. They gave participants with ASD several different sets of the Strange Stories. Each story set was created to tap (or not to tap) into the participants' thinking about mental states, humans and animate agents. Three of the story sets, termed *mental state stories*, required explicit mentalizing, that is, thinking about humans and animate agents, as well as integrating information across the text in order to create an accurate mental model of the story. In contrast, a fourth story set was designed so that comprehension required only integration of information across the text. They found that children who had ASD and limited ToM knowledge had significant problems with comprehending the text regardless of text type in comparison to the TD controls. In contrast, children with ASD who had greater ToM impairment had significant problems with comprehension compared to their ASD peers with less ToM impairment when the text involved explicit mentalizing along with thinking about humans and/or animate agents, but performed better when the text required only integration of information across text. According to the authors, the relatively poor performance on the mental state stories by participants with ASD was more likely because of a limited knowledge of mental states, rather than a problem with comprehension per se (White et al., 2009). The hypothesis that limited social knowledge impacts reading comprehension in people with ASD was also be explored in the current meta-analysis by examining the reading comprehension skills of individuals with ASD and controls on texts requiring a high degree of social knowledge (i.e. "high social texts") compared to texts requiring limited social knowledge (i.e., "low social texts").

Performance IQ

PIQ has been conceptualized as a set of visual-spatial processes that facilitate organized mental models (Behrmann & Kimchi, 2003; Stothers & Klein, 2010). If the underlying processes thought to be captured when assessing PIQ are indeed involved in creating more organized mental models, then PIQ ought to be related to reading comprehension, since poor comprehenders often construct incomplete mental representations of the text (Cain, Oakhill, Barnes & Bryant, 2001). To investigate this idea, Stothers and Klein (2010) gave a visual perceptual organization task, Gestalt Formation, to participants with non-verbal learning disability (NLD). It is important to note that individuals with NLD have neuropsychological profiles that are "strikingly similar" to Asperger's Syndrome (Rourke, Ahmad, Collins, Hayman-Abello, Sayman-Abello et al., 2002) and NLD is considered by some to be on the "borderlands of autism" (Bishop, 1989; Volden, 2004). Stothers and Klein (2010) found that for individuals with NLD, performance on Gestalt Formation strongly predicted performance on a reading comprehension task. The theory proposed by these researchers, that stronger PIQs allowed some participants to better integrate information and to create more organized mental representations of the text, was indirectly examined in the current analysis by investigating associations between PIQ and reading comprehension.

Aims

In summary, this meta-analysis examined the reading comprehension skills of individuals with ASD and their TD peers by asking the following questions:

1. Did individuals with ASD tend to have difficulties comprehending what they read compared to their TD peers? What were the size, robustness, consistency and directionality of these effects?

2. How can the heterogeneity of effects in reading comprehension be explained? In the studies examined above,

   a. did individuals with ASD tend to have weaker decoding skills than controls?

   b. did individuals with ASD tend to have limited semantic knowledge compared to controls?

   c. did individuals with ASD tend to have weaker PIQs than controls?

      i.) Across analyses a-c, what were the size, robustness, consistency and directionality of these effects?

   d. Do individuals with ASD have greater difficulty with reading comprehension when reading high social texts compared to low social texts? Do age or decoding skill moderate reading comprehension of these two text types?

3. To what extent does decoding skill, semantic knowledge and PIQ predict reading comprehension in the ASD population?

Method

Search Strategy, Inclusion Criteria and Coding System

Four computerized databases (PsycINFO, ERIC, Scopus, and Proquest Theses and Dissertations) were searched for relevant articles using several combinations of the following keywords: reading comprehension, word decoding, academic achievement, inference, literacy, single word reading, word recognition, theory of mind, Strange Stories, homographs, vocabulary, language, hyperlexia, autism, autistic disorder, autism spectrum disorder, Asperger syndrome, and Asperger's Disorder. Additionally, reference lists of retrieved articles were searched along with studies listed in two summary articles: Happé and Frith (2006), and Loukusa and Moilanen (2009). As an additional check, representative journals from January 2008 to December 2011 were selected (i.e., *Journal of Autism and Developmental Disorders*, *International Journal of Language and Communication Disorders*, *Autism Research*,

Research in Autism Spectrum Disorders, and *Writing and Reading*) and hand-searched. No articles were detected that had not been encountered in the initial searches.

The selected articles had to meet the following predetermined criteria. First, a reading comprehension measure was administered to all participants. Reading comprehension was operationally defined as any task that first required the participant to read sentences or a short text and then to use their understanding of what they read to complete some task. It is important to note that a study was included if some of the participants read the text out loud, while others followed along while the experimenter read the text, as long as the text remained in front of the participants throughout the testing session (e.g., Strange Stories in some studies). These studies did not report how many participants read the text themselves and how many followed along while the experimenter read the text. However, in the latter group, we can assume that some of these participants were actually reading, while others were merely listening. Given that likely a significant proportion of the participants were reading (regardless of whether they were reading while the experimenter also read or not), all of the Strange Stories studies were included in the meta-analysis.

Second, the study must have included participants with an ASD. No participants with Pervasive Developmental Disorder – Not Otherwise Specified were included because only one study was found that included these individuals. Unfortunately, it was not possible to break down the data in current meta-analysis by diagnostic categories because many of the studies included did not do so. For those studies that did analyze individuals with ASD by diagnostic subgroup, there was no consistency in the diagnostic categories. For example, diagnostic categories included: autism vs. Asperger's Disorder, ASD with vs. without hyperlexia, and ASD with vs. without language impairment. However, given the large variability of individual traits found in the ASD population, it seemed less useful to study a group of individuals within one homogeneous set of diagnostic labels. By including a full range of individuals with ASD, it is hoped that a more general picture of the reading comprehension skills of these individuals will emerge along with a better understanding of the range of their strengths and needs.

Third, studies included a comparison group of TD individuals, a control group via standardized samples, or (less frequently) individuals with a non-ASD developmental impairment. Fourth, the study was written in English. Fifth, the study reported original empirical data based on direct tests and included means, standard deviations and sample sizes. Four studies could not be included in the meta-analysis because they failed to meet this requirement

(Assouline, Foley Nicpon & Dockery, 2011; Frith & Snowling, 1983; Snowling & Frith, 1986; White, Hill, Happé & Frith, 2009).

A total of 36 studies were included within the meta-analysis. When multiple independent samples were included in one study, they were treated as separate studies (Cronin, 2008; Enoch-Holman, 2004; Goldstein, Minshew & Siegal, 1994; Happé, 1994, 1997; Huemer & Mann, 2010; Jolliffe & Baron-Cohen, 1999a, 1999b, 2000; Lindgren, Folstein, Tomblin & Tager-Flusberg, 2009; Nation, Clarke, Wright & Williams, 2006; Newman, Macomber, Naples, Babitz, Volkmar et al., 2007). In contrast, non-independent samples across different studies were treated as a single study (Happé, 1994, 1997; Jolliffe& Baron-Cohen, 1999a, 1999b, 2000; Kaland, Møller-Nielsen, Callesen et al., 2002; Kaland, Møller-Nielsen, Smith et al., 2005; Minshew, Goldstein, Taylor & Seigel, 1994; Minshew, Goldstein & Siegel, 1995). This resulted in a total of 47 different samples comprising a total of 1487 individuals with ASD. All articles and dissertations were retrieved before 2012.

The coding system had eight categories comprising of: (a) sample sizes for each group and/or sample size of the normative group for standardized measures, (b) mean age of participants, (c) Full Scale IQ (FSIQ), (d) Verbal IQ (VIQ), (e) Performance IQ (PIQ), (f) semantic knowledge, which was generally a measure of receptive vocabulary using pictures or orally presented words, (g) decoding, which was defined as reading accuracy of non-words, single words, sentences and/or passages as well as reading rate, and (h) reading comprehension, which was measured using response accuracy, response times, eye tracking measures, and/or recall scores.

Study Descriptions

The types of studies included in this meta-analysis were highly varied in the questions they were designed to answer. One group of studies examined academic achievement in ASD in general, or reading in particular, and tended to use standardized assessments of reading comprehension (e.g., *Woodcock Reading Mastery Tests-Revised* Passage Comprehension [*WRMT-R*; Woodcock, 1987]), intelligence (e.g., *Wechsler Intelligence Scale for Children-Third Edition* [*WISC-III*; Wechsler, 1991]), decoding (e.g., *WRMT-R* Word Identification, Word Attack) and semantic knowledge (e.g., *Peabody Picture Vocabulary Test—Third Edition* [*PPVT-III*; Dunn & Dunn, 1997]) (cf., Lindgren, et al., 2009; Mayes & Calhoun, 2003; Minshew et al. 1994, 1995). Other studies examined particular aspects of reading comprehension in the ASD population such as (a) to what degree can individuals with ASD integrate prior knowledge with the textbase? (cf., Wahlberg & Magliano, 2004; O'Connor & Klein, 2004); (b) to what degree can individuals with ASD integrate information across the text? (cf., Jolliffe & Baron-Cohen, 1999b;

2000; Saldaña & Frith, 2007); or (c) pre-intervention scores from a study examining the effects of a specific reading intervention (cf., Flores & Ganz, 2009). A final set of studies did not examine reading comprehension per se, but instead were examining the hypotheses of autism. While these studies were not designed to specifically measure reading comprehension, they nevertheless used tasks that required participants to read a sentence or a short text and demonstrate their degree of comprehension of the text, often by answering questions. The Strange Stories test and similar ToM tasks asked: To what degree do individuals with ASD comprehend mental states and understand motivations behind everyday utterances that are not literally true? (cf. Gillott, Furniss & Walter, 2004; Happé, 1994; Heavey, Phillips, Baron-Cohen & Rutter, 2000). Other studies looking at the weak central coherence hypotheses examined the degree to which individuals with ASD could integrate syntactic and semantic context to comprehend meaning, such as using sentence context to correctly pronounce a homograph (cf. Ashcraft-Bills, 2009; López & Leekam, 2003). A summary of all tests used in the studies can be found in the Appendix A.

Some of the texts used to measure reading comprehension were categorized as *high social* texts. This occurred when the task was originally designed to measure ToM rather reading comprehension per se. Thus, the high social texts were: the Strange Stories Test (e.g., Happé, 1994); Stories from Everyday Life (Kaland et al., 2002); False Belief and Social Emotional Texts (LaPoint, 2007); Pragmatic Interpretation Stories (Martin & McDonald, 2004); and Social Knowledge Inferences (Saldaña & Frith, 2007). In contrast, some of the texts used in the reading comprehension tasks were categorized as *low social* texts when they were used in the same study as the high social texts, but had been specifically designed to contain limited social knowledge. These low social texts were: Physical Stories (e.g., Happé et al., 1996); General World Knowledge texts (LaPoint, 2007); and Physical Knowledge Inferences (Saldaña & Frith, 2007).

Statistical Analysis

The current meta-analysis was run using a random effects model, which assumes that the standardized mean differences (SMDs) vary from study to study (Borenstein, Hedges, Higgins & Rothstein, 2009). In this meta-analysis, the SMDs were theorized to be higher or lower depending on semantic knowledge, decoding abilities, and performance IQs of participants as well as the type of text they were reading (i.e., high vs. low social texts.) There were likely a host of other factors that could have led to variations in effect size as well, but that were not testable in this meta-analysis due to lack of data (such as speed of processing, level of ASD symptomology, type of ASD diagnosis, etc.) Since it was assumed that the SMDs in reading comprehension between individuals with ASD and controls would differ from study to study, the SMDs in this study were assumed to be sampled from a distribution of true SMDs.

The Comprehensive Meta-Analysis (CMA) computer program (Borenstein, Hedges, Higgins & Rothstein, 2005) was used for the majority of analyses. First, Hedge's g standardized mean difference (SMD) in reading comprehension between the ASD group and the control group was calculated for each study; however, there were some methodological challenges in computing the SMDs. For example, some studies did not compare the performance of individuals with ASD directly to control groups, but rather reported results for the group with ASD alone on a given standardized measure. In these cases, in order to satisfy CMA's requirement for sample sizes for both ASD and control groups, the control group's sample size was the reported sample size used to norm the standardized test. For example, Turner (2010) gave participants with ASD the *Woodcock-Johnson Tests of Achievement-III* (Woodcock, McGrew, & Mather, 2001), which was normed on 4783 participants. Therefore, the SMD for this study was calculated using a normal sample size of 4783 and an ASD sample of 377.

A second issue was that this meta-analysis took a very broad view of reading comprehension. As explained previously, to understand what we read depends on many different internal processes such as decoding, prior knowledge, comprehension monitoring and inference making abilities. Reading comprehension is also influenced by environmental demands such as text characteristics because each type of text we read requires a unique set of skills and knowledge to be understood (consider for instance, a recipe book, poetry, a history book, etc.). When researchers used multiple assessments of reading comprehension, it was believed that valuable information would be lost by choosing only one measure. For example, Jolliffe and Baron-Cohen (1999a, 1999b, 2000) gave the same participants multiple assessments of reading comprehension, which were designed to assess weak central coherence theory and ToM. These tests included the Global Integration Test, the Homograph Test, Local Coherent Inferences and the Strange Stories Test. While each of the reading comprehension tasks may be tapping into some similar and some different comprehension processes, it was necessary to include each task in the analysis in order to not bias the outcome of how well individuals with ASD can comprehend what they read. Furthermore, while it has been recommended that composite scores based on multiple outcome measures should not be created unless there are correlation values available among the measures (Borenstein et al., 2009), a different approach was taken here. In each case, the means, standard deviations and sample size for both the group with ASD and the control group for each measure of reading comprehension were entered into their own CMA analysis. A random effects model was run and the subsequent Hedge's g SMD and standard error were then entered into the main reading comprehension analysis as, in this example, one entry for Jolliffe and Baron-Cohen (1999a/b, 2000). This same procedure was carried out for all studies that presented multiple outcomes for the same variable.

A third issue was resolved by converting all scores for the three moderators, (i.e., decoding, semantic knowledge and PIQ), to a Hedge's g SMD in order to assess each moderator's impact on reading comprehension. The use of Hedge's g SMD was chosen to provide a more accurate measurement of the skills of the ASD group compared to the TD controls. For example, in the study by Newman et al. (2007), the mean (SD) decoding score for the participants with ASD with hyperlexia (HPL) was 106.18 (12.49). If this result was entered into the model as a raw score, it would suggest that the decoding skills of the ASD group in this study was higher than the norm of M=100 (15) with a SMD of +0.03 SD. However, the corresponding decoding score for the TD group in the Neman et al. (2007) study, which was matched to the group with ASD on age, gender and single word reading score, was actually M = 118.83 (19.29). Using the actual TD group's score to calculate the Hedge's g SMD gives a result of -0.72 SD, demonstrating that in this case, the group with ASD had weaker decoding skills than their TD peers. If the effect size statistic had not been calculated, this important information would have been lost. In sum, converting moderator variables to Hedge's g SMD provided a more accurate estimate of the abilities of the participants with ASD compared to controls and resulted in a more accurate prediction of their reading comprehension skills by each moderator variable.

Heterogeneity

Heterogeneity of the SMDs for reading comprehension was assessed with a Q-test (Borenstein et al., 2009). A significant Q-test suggests that the amount of "total variance is more than we would expect based on within-study error" (Borenstein et al., 2009, p. 191). The Q-test also reports two descriptive statistics: I^2 and Tau^2 (T^2; Borenstein et al., 2009). I^2 explains what proportion of the variance is real and not simply due to random error. In contrast, T^2 quantifies the amount that the SMDs vary from one study to the next and can used to quantify a confidence interval , which is determined by the formula: Prediction Interval = SMD ± 1.96*(Tau) (Borenstein et al., 2009).

Publication bias

There is a potential for publication bias to impact the outcome of a meta-analysis because studies with findings that are significant are published more often than those that find null results. In addition, a disproportionate number of small studies with large effects are published along with a few larger studies showing moderate effects

(Borenstein et al., 2009). These phenomena can bias the summary effect in a meta-analysis. In an a priori attempt to offset publication bias, studies published in grey literature were located, primarily theses and dissertations. As well, post-hoc analyses were conducted to determine the degree of impact that potential publication bias may have had on grand SMDs. First, funnel plots were created because, in the absence of publication bias, the studies should be distributed symmetrically about the Grand SMD (Borenstein et al., 2009). However, when publication bias is present, the studies are distributed *asymmetrically* about the Grand SMD and it becomes important to estimate the impact of this bias using Duval and Tweedie's trim and fill procedure (Borenstein et al., 2009). This procedure forces the funnel plot to become symmetrical by adding the missing studies to the plot and then computing the best estimate of the unbiased SMD (Borenstein et al., 2009). The second method used to estimate publication bias was Rosenthal's Fail-safe N, which computes the number of studies that would be needed to be incorporated into the meta-analysis to nullify the grand SMD or, in other words, the number of studies that would need to be added to make the grand SMD essentially zero (Rosenthal, 1995).

Results

Reading Comprehension in ASD

(Place Fig. 1 about here). The random effects model demonstrated that the grand SMD in reading comprehension scores between ASD and control groups was both large (Cohen, 1992) and negative, g = -0.74 (Z = -6.10, SE = 0.12, p < .0001) (see Figure 1). Further, there was a 95% probability that the interval, -1.0 SD to -0.5 SD, contained the population SMD. (Place Fig. 2 about here). This interval also contained the highest frequency of SMDs in reading comprehension (see Figure 2). These findings suggest that many individuals with ASD find reading comprehension more difficult than their TD peers.

As can be seen in Figure 2, the distribution of SMDs in reading comprehension was negatively skewed and covered a wide range of values. The heterogeneity analysis further demonstrated that 94% of the variance in SMDs was real and could be attributed to differences in the ASD and TD groups, Q(46) = 807.88, I^2=94.31, p < .0001. It was predicted that the population SMD would fall within the range of -2.20 SD and +0.7 SD. Thus, the grand SMD of -0.7 SD suggests that overall reading comprehension is often impaired in ASD and that the reading comprehension skills of some individuals or groups of individuals with ASD may range from quite impaired to within the normal range.

Publication Bias

Rosenthal's file drawer analysis indicated a fail-safe N of 6157 studies, ($Z = -22.52$, $P < 0.0001$), suggesting that over 6000 studies with a SMD of zero, would need to be found and incorporated in the analyses before we could nullify the SMD of -0.7 SD found in this meta-analysis (Rosenthal, 1995). (Place Fig. 3 about here). There was some evidence of publication bias using Duval and Tweedie's trim and fill procedure (See Figure 3). After imputing 15 studies to the left of the mean, the best estimate of the unbiased grand SMD for reading comprehension was -1.25SD. Thus, by continuing with the analysis using a grand SMD of -0.7SD, this analysis is actually reporting a more conservative estimate.

Decoding Skill, Semantic Knowledge and PIQ

Decoding

(Place Fig. 4 about here). The grand SMD in decoding skill for individuals with ASD was not reliably different than zero, $g = -0.09$ ($Z = -0.83$, $SE = 0.11$, $p = 0.41$). The precision of this estimate fell within the range of -0.3 SD to +0.1 SD. (Place Fig. 5 about here). The distribution of SMDs in decoding skill was negatively skewed and the most frequent SMDs were positive, falling between zero and +0.5 SD (see Figures 4 and 5). These findings suggest that across the studies that examined reading comprehension, individuals with ASD tended to have similar decoding skills to their TD peers. The heterogeneity analysis was run to generalize the results of the decoding skills of the ASD group beyond the studies included in the meta-analysis to the population of individuals with ASD. It found a prediction interval for the variation in SMDs to be -1.3 SD to +1.1 SD, $Q(38) = 510.05$, $I^2 = 92.55$, $p < .0001$. This prediction interval suggests that it is likely that in the population of individuals with ASD, some individuals or groups of individuals have slight impairments in decoding skills, while others have decoding skills that are slightly better than average.

Semantic knowledge

(Place Fig. 6 about here). The grand SMD for semantic knowledge was medium in size (Cohen, 1992) and reliably below the mean of typically developing controls, $g = -0.48$ ($Z = -2.84$, $SE = 0.17$, $p = .004$) (see Figure 6). (Place Fig. 7 about here). The precision interval for the Grand SMD was -0.8 SD to -0.1 SD with the most frequent SMDs falling between -1.0 SD and zero (see Figure 7). Thus, these findings suggests that in the studies investigating reading comprehension, individuals with ASD tended to have mild deficits in vocabulary knowledge compared to their TD peers. To generalize these findings to the ASD population, the test of heterogeneity predicted that the population SMD for semantic knowledge fell between -2.2 SD and +1.2 SD, $Q(29) = 521.49$, $I^2 = 94.44$, $p < .0001$.

Thus, it is likely that some individuals or subgroups of individuals with ASD have moderate to severe impairments in semantic knowledge, while the semantic knowledge of others with ASD is strong.

Performance IQ

(Place Fig. 8 about here). Individuals with ASD tended to have lower PIQs of a small effect (Cohen, 1992) than the controls across the reading comprehension studies, with a grand SMD of g = -0.23 SD (Z=-1.98, SE = 0.12, p = .002) (see Fig. 8). The accuracy of the SMD for PIQ was estimated to be within the range of -0.465 SD to 0.002 SD. Thus, on average, across the reading comprehension studies, individuals with ASD did not differ from their typically developing peers in PIQ. (Place Fig. 9 about here). However, the histogram displayed in Figure 9 shows an important caveat. Across the reading comprehension studies, the distribution of SMDs was positively skewed, with the most frequent SMD occurring in the range of -1.0SDs to 0.0SD (see Fig. 9). It is noteworthy, however, that most of the reading comprehension studies used samples of individuals with ASD who had weaker PIQs than controls. The test for heterogeneity predicted that the range of SMDs in the ASD population would range between -1.2 SD to +0.8 SD, Q(24) = 144.028, I^2 = 83.34, p < .001. Thus, when sampling individuals with ASD, some individuals or groups of individuals show borderline deficits in PIQ compared to controls, whereas others will have PIQs in the normal range.

Evidence of Publication Bias in Moderator Variables

(Place Fig. 10, 11 and 12 about here). (See Fig. 10, 11 and 12) Duval's and Tweedie's trim and fill procedure was used to asses evidence of publication bias in the moderator variables (see Table 1). (Insert Table 1 about here.) Further to this, the Fail-safe N analysis suggested that 850 studies needed to be found to nullify the SMD found in the analysis of semantic knowledge (Z = -10.61, p < .0001), 256 studies for decoding (Z = -5.38, p < .0001), and 92 studies for PIQ (Z = -4.23, p < .0001) (Rosenthal, 1995).

Predicting Reading Comprehension from Age, Decoding Skill, Semantic Knowledge and PIQ

Since only a subset of the total studies reported a score for each given moderator, it was important to analyze the grand mean difference and heterogeneity of reading comprehension scores in each subset of studies to ensure that the grand mean difference for a given subset was similar to the overall grand mean difference. (Insert Table 2 about here.) Thus, reading comprehension grand mean differences and heterogeneity analyses are presented in Table 2 for each subset of studies that included a score for one of the moderators.

PIQ reliably predicted the variance in reading comprehension scores, $Q_{model}(1) = 5.56$, $R^2 = .0133$, $p < .0001$. However, it had a very small impact, accounting for only 1.33% of the variance. In comparison, both decoding skill and semantic knowledge reliably predicted reading comprehension, with decoding skill independently explaining 55% of the variance in reading comprehension scores, $Q_{model}(1) = 24.29$, $R^2 = .5516$, $p < .0001$, and semantic knowledge independently predicting 57% of the variance, $Q_{model}(1) = 16.98$, $R^2=0.5656$, $p < .0001$. Thus, semantic knowledge and decoding skill were found to be good predictors of reading comprehension in the ASD population, whereas PIQ was found to be a poor predictor.

The above regression calculations were all run on one predictor at a time, so the interaction between predictors was not accounted for in these analyses. To begin to explore these interactions, a weighted Pearson product-moment correlation coefficient was computed to assess the relationships between reading comprehension, decoding, semantic knowledge, and PIQ. (Insert Table 3 about here.) Reading comprehension by the participants with ASD was most strongly associated with decoding ($r = 0.767$, $n = 1469$, $p < .001$), followed by semantic knowledge ($r = 0.593$, $n = 1080$, $p < 0.001$) and PIQ ($r = 0.410$, $n = 845$, $p < .001$). However, decoding, semantic knowledge, and PIQ were also all moderately associated with each other at approximately $r = 0.4$ (see Table 3).

High vs. Low Social Texts

(Place Fig. 13 about here.) The grand SMD in reading comprehension score on high social texts between individuals with ASD and controls was found to be both large (Cohen, 1992) and negative $g = -1.36$ ($Z = -4.73$, $SE = 0.29$, $p < .001$). (Place Fig. 14 about here.) The precision of this estimate fell in the range of -1.9 SD to -0.8 SD with the most frequent SMDs in reading comprehension ranging from -2.0 SD to -1.0 SD (see Figures 13 and 14). These findings suggest that, on average, individuals with ASD struggle to comprehend texts that demand a good understanding of the social world.

In contrast, across the studies using texts that required limited social knowledge, there was a trend for individuals with ASD to have relatively small (Cohen, 1992) reading comprehension deficits compared to controls, $g = -0.34$ ($Z = -1.73$, $SE = 0.20$, $p =.08$). Furthermore, the accuracy of this estimate likely fell between -0.7 SD and +0.1 SD and the most frequent average SMD occurred within an interval of -0.5 SD and zero (see Figures 15 and 16). Thus, when reading texts that require only a limited amount of social knowledge, individuals with ASD function within the normal range. Furthermore, the 95% confidence intervals for our estimates of the SMDs in reading comprehension for the two texts types were non-overlapping (see Figure 17). This reiterates the point that individuals with ASD are likely to be more competent at understanding texts requiring limited social knowledge compared to texts requiring high social knowledge, and shows that text type was a good predictor of reading comprehension skill in ASD.

To generalize the grand SMD results from both analyses comparing reading comprehension on high and low social texts, the heterogeneity of variance was assessed. The tests for heterogeneity were reliable for both high social texts, $Q(13) = 188.77$, $I^2 = 93.11$, $p < .001$and low social texts, $Q(10) = 40.02$, $I^2 = 75.01$, $p < .001$. The heterogeneity analyses predicted that within the ASD population, particular subgroups of individuals with ASD may have mean differences in reading comprehension between -3.3 SD and +0.6 SD on passages requiring high social knowledge. In comparison, the predicted range of mean differences in the ASD population on texts requiring limited social knowledge was -1.4 SD to 0.7 SD. When individuals with ASD are asked to comprehend text requiring high social knowledge, they are likely to much more severely impaired, at a magnitude of approximately three standard deviations below their TD peers. In contrast, the lower limit of the range of SMD (gLL) in reading comprehension of low social texts (gLL = -1.4) is less than half the size of the lower limit of the SMD when reading high social texts (gLL = -3.3). Thus, there is great variability in the reading comprehension skills in the ASD population, but one variable that seems to strongly predict text understanding is text type.

Discussion

Reading Comprehension in individuals with ASD

The grand SMD in reading comprehension between individuals with ASD and TD controls across all the studies was g = -0.7 SD. As well, the heterogeneity analysis predicted that within the ASD population, reading comprehension varied between -2.2 SD to +0.7 SD. Students with ASD who are performing within 0.7SD of the norm would be considered to be performing slightly higher than average, but within the normal range. For example, if a letter grade of “B” or a 75% is considered average, then performing at 0.7SD above the average would be akin to earning a letter grade of “A” or 85%. However, students with ASD who are performing -2.2SDs below the norm would be struggling significantly. In this case, these students would be receiving a letter grade of “F” or 42%. Thus, while the grand SMD of -0.7 SD suggests that overall reading comprehension is often impaired in ASD and that many of these students are performing at a letter grade of “C” or 65%, this analysis has also shown that the reading comprehension skills in individuals with ASD are quite variable and can range from severe difficulties to within the normal range. Therefore, it would seem that having ASD predicts that an individual is more likely than not to have problems with reading comprehension, but whether a given person actually has reading comprehension deficits depends on more factors than ASD diagnosis alone.

Decoding Skills, Semantic Knowledge and PIQ in Individuals with ASD

The grand SMD for decoding skill was not reliably different from zero, suggesting that individuals with ASD tend to demonstrate similar strengths and weaknesses in word recognition as their TD peers of the same age or that on average, they achieve a letter grade of “B”. This analysis predicted that the decoding skills in the population of individuals with ASD likely ranged between -1.3 SD and +1.1 SD or that students with ASD would be receiving grades for decoding in the range of 56% to 92%. Therefore, this meta-analysis failed to support the theory that individuals with ASD have weaknesses in reading comprehension despite superior word-reading accuracy (cf. Goldstein, Minshew & Siegal, 1994). While it was true that some individuals with ASD (especially those who have both ASD and hyperlexia) had superior decoding skills, the current analysis suggests that decoding skills vary in the ASD population similarly to populations of individuals without ASD.

The grand SMD for semantic knowledge was -0.5 SD or a grade average of 68%. It was predicted that in the population of individuals with ASD, the range of semantic knowledge fell between -2.2 SD and +1.2 SD, which is akin to a grade range of 42% to 93% . This suggests that individuals with ASD tend to range from similar levels of to severe deficits in semantic knowledge compared to controls. These findings confirm that individuals with ASD tend to have slight semantic deficits on average, but that these deficits are not universal and many individuals with ASD have essentially normal semantic skills (Ashcraft-Bills, 2009; Emerich et al., 2003; Griswold et al., 2002; Kjelgaard & Tager-Flusberg, 2001; Mayes & Calhoun, 2003; Minshew et al., 1995). However, it also confirms that some individuals or groups of individuals with ASD have striking semantic weaknesses (Åsberg, 2010, Brent, Rios, Happé & Charman, 2004; Huemer & Mann, 2010; Naples, 2009; O’Connor & Klein, 2004).

In comparison, the grand SMD for PIQ was -0.2 SD, with the predicted population SMD ranging between -1.2 SD to +0.8. This suggests that individuals with ASD have similar to moderately impaired PIQs compared to their TD peers. However, while the range of SMDs in PIQ was narrow in the ASD population, with a prediction interval of approximately ±1 SD, the highest frequency of SMDs in this sample of studies tended to fall in the negative range (see Figure 9). Thus, when sampling from the population of individuals with ASD, the likelihood of having PIQ weaknesses in a given sample from the ASD population may be similar to the likelihood of having PIQ strengths; however, in the samples of individuals with ASD included in the studies investigating reading comprehension, the SMDs in PIQ between the groups with ASD and controls were much more likely to be negative.

Did the Moderators Predict Reading Comprehension?

Decoding and semantic knowledge: The simple view of reading. Each of decoding and semantic knowledge significantly predicted the reading comprehension scores of individuals with ASD, with semantic knowledge independently explaining 57% of the variance in reading comprehension scores across studies and decoding independently explaining 55% of the variance. Further, there was a strong, positive correlation between reading comprehension and each of semantic knowledge and decoding skill. This suggests that some individuals or groups of individuals with ASD have strengths in both semantic knowledge and decoding, and that such individuals may have commensurately strong reading comprehension skills. A moderate positive correlation was also found between decoding skill and semantic knowledge. Therefore, while semantic knowledge and decoding skill may each independently lead to better reading comprehension, it may be that they are both related to language ability more generally, and that increased language skill is predicting better reading comprehension skills.

Dual strengths in decoding and semantic knowledge as potential underpinnings of skilled reading comprehension are in line with Hoover and Gough's (1990) *Simple View of Reading*, which stated that reading comprehension is the product of decoding and linguistic comprehension. One study in this meta-analysis nicely demonstrated the relationship between language skill and reading comprehension. Lindgren et al. (2009) divided their participants with ASD into two groups based on language ability. They distinguished the autism without language impairment group (Autism Language Normal; ALN) from the autism with language delay group (Autism Language Impaired; ALI) using the following criteria: a history of language delay and a standard score on the CELF-III of less than 85. According to the present analyses, the SMD between the group with ALN and their TD peers was $g = 0.6$ for semantic language skills and $g = 0.45$ for decoding skill. In comparison, the SMD between the ALI group and the TD controls was $g = -1.19$ for semantic knowledge and $g = -0.35$ decoding skill. This illustrates nicely how having language strengths may often lead to concordant strengths in decoding and semantic knowledge. Furthermore, as can be seen in Fig. 1, individuals with ALN had reading comprehension strengths of 0.5 SD above TD controls, whereas their peers with ALI had reading comprehension deficits of -0.5 SD below controls. Thus, it may be that language impairment is a strong predictor of reading comprehension deficits in the ASD population.

It will be important for future research to report and control for decoding skill, semantic knowledge, and language ability, more generally. As shown in this meta-analysis, decoding and semantic knowledge are highly variable in the ASD population and have a large influence on reading comprehension ability. Only by using groups that are differentiated based on these lower-order components of reading comprehension will researchers be able to accurately assess the abilities of individuals with ASD on higher-order reading comprehension skills such as inferencing, integration and comprehension monitoring, and to better understand how such higher order skills ultimately impact the ability of individuals with ASD to build coherent mental models of the text.

PIQ. Contrary to expectations, PIQ predicted only 1% of the variance in reading comprehension scores, yet there was a moderate correlation (r = 0.4) between reading comprehension and PIQ. To help explain these disparate findings, it is noteworthy that 72% of the studies that included a measure of PIQ and reading comprehension used individuals with ASD who had PIQs that were lower than controls, with differences ranging from small to large. So, while it was demonstrated that individuals with ASD have similar to moderately impaired PIQs on average, it seems that participants with ASD and impaired PIQs are participating more often in research studies on reading comprehension. Furthermore, in 6 of the 7 studies where the PIQ of the ASD group was similar to or greater than the control group, individuals with ASD tended to have comparable reading comprehension skills to controls (Åsberg, 2010, Åsberg & Dahlgren-Sandberg, 2010; Griswold et al., 2002; Lindgren et al., 2009 - ASD without language impairment; Mayes & Calhoun, 2003, 2008; Nation et al., 2006 - ASD without language impairment). These findings may highlight the need to examine whether impaired and/or typical PIQ can be reliably detected in subgroups of individuals with ASD and how this may relate to reading comprehension skills. Alternatively, it suggests that researchers need to ensure that PIQ is equivalent between groups (whether in reality or by statistical methods) when comparing the reading comprehension skills of individuals with ASD to their TD peers.

Texts requiring high versus limited social knowledge. Similar to White et al. (2009), the current analysis supported the hypothesis that individuals with ASD may have differing levels of success at comprehending different text types. Specifically, individuals with ASD are much better at reading texts that require limited social knowledge than those requiring high social knowledge. The grand SMD in reading comprehension was -0.3 SD or “B-” for texts requiring limited social knowledge and -1.4 SD or an average letter grade of “D” for texts that demand a significant amount of social knowledge. This is a substantial difference in reading comprehension by text type. Further, the two distributions representing the SMDs in reading comprehension by text type were non-overlapping, suggesting that individuals with ASD are categorically better at comprehending texts requiring limited social knowledge compared to texts requiring a considerable amount of social knowledge. However, one caveat must be made. White et al. (2009) noted that some of the original work examining differences in reading comprehension of texts requiring high versus low social knowledge may have failed to properly balance level difficulty for each type of text. In these early studies, the texts requiring limited social knowledge were found to be easier and most participants performed at ceiling (White et al., 2009). However, newer research in this area has ensured equivalent text difficulty across conditions. In sum, domain knowledge, specifically social knowledge, was found to impact the ability of individuals with ASD to comprehend written texts. When demands for social knowledge were reduced, individuals with ASD performed comparably to their typically developing peers at comprehending what they read. As Brock, Norbury, Einav and Nation (2008) state, individuals with ASD may experience less difficulty on integration and inferencing tasks when confounding task demands (in this case, social knowledge) are removed.

Implications for Theory

The heterogeneity of strengths and weaknesses in the ASD population in reading comprehension, semantic knowledge, decoding skill and PIQ support the theory proposed by Towgood, Meuwese, Gilbert, Turner, and Burgess (2009) that the most defining feature of ASD is variability. With regards to reading in particular, “the existing literature makes clear that we should not associate autism with any one particular reading profile” (Nation & Norbury, 2005, p. 28) because both subnormal and supra-normal performance can be observed across groups and within individuals for any aspect of reading (Towgood et al., 2009). The high level of variability in ASD suggests that “heterogeneity in ASD… is not simply due to noise or the complex unfolding of development, but is an unavoidable consequence of variation” (Happé, Ronald & Plomin, 2006, p. 1220) along the dimensions of social interaction, communication, and repetitive and stereotyped behaviours/interests. Thus, the unavoidable consequence of the great variability in ASD suggests that having ASD alone does not necessarily predict that such an individual will have reading comprehension deficits. Instead, more information about the individual needs to be considered, especially language ability, before one can accurately predict whether a given individual with ASD will experience significant difficulties with reading comprehension. While a diagnosis of ASD is generally associated with reading comprehension deficits, the high variability in the ASD population means that there are many other co-occurring individual strengths and weaknesses along with demands posed by the texts that will heavily contribute to the likelihood that any given individual with ASD will demonstrate problems in reading comprehension. It is also possible that the presence of autism is a magnifying factor with regards to academic achievement. For individuals with weaknesses in language ability, decoding, and/or reading comprehension, autism may exacerbate these deficits. In contrast, for individuals with strengths in these areas, autism may enhance these gifts, leading to superior skill.

Limitations

One of the main limitations of archival research is that the parameters that can be explored are limited by the available data. For example, one possible moderator of reading comprehension is processing speed. Previous research has found that slowed processing speed is a risk factor for reading disability (Pennington & Bishop, 2009). It is proposed that impaired processing speed may cause an individual to be slower at accessing previous knowledge, which in turn makes inferencing based on that knowledge more difficult (Cain, Oakhill, Barnes & Bryant, 2001). Given that Mayes and Calhoun (2007) found that 58% of children with high functioning autism have weaknesses in processing speed, it is an important factor to consider when evaluating reading comprehension in this population. However, while a few of the studies from this meta-analysis included measures of processing speed, there were not enough studies to enter this variable as a moderator. Future research needs to continue to examine the impact of processing speed on reading comprehension in the ASD population.

A second issue was that of participant eligibility. This meta-analysis included a heterogeneous group of individuals with ASD in terms of both acceptable methods of diagnosis and range of diagnostic labels. This choice was made in an attempt to allow the findings to best match the natural settings in which we teach and support these students. For example, this meta-analysis included data from research that relied upon various methods for diagnosing ASD, including *DSM-III* or *DSM-IV* criteria, ADOS/ADI gold standard criteria, or parental report of a community diagnosis. As well, participants with ASD who had many different labels were included, such as Asperger's disorder, Autistic disorder, autism, high-functioning autism, autism spectrum disorder, autism with or without intellectual impairment, autism with or without hyperlexia, and autism with or without specific language impairment. Given the large variability of individual traits found in the ASD population (a finding supported in this meta-analysis), it seems less useful to study a group of individuals within one homogeneous set of diagnostic labels. By including a full range of individuals with ASD, it is hoped that a more general picture of the reading comprehension skills of these individuals will emerge along with a better understanding of the range of strengths, needs and other factors that will predict a particular deficit such as reading comprehension. To this end, this meta-analysis endeavored to include all studies that focused on individuals with ASD (regardless of designation) and also studied a broad definition of reading comprehension (where reading comprehension was defined as an activity that first asked participants to read sentences or a short text, and then to use their understanding of what they read to complete some task). This allowed us to describe the full spectrum of what reading comprehension deficits for individuals with ASD might look like in the real-world settings in which we serve these children. It is also important to note that the emergence of these interesting findings from within such a heterogeneous sample is a demonstration of the power of the results. Nevertheless, it may be important that a future meta-analysis examine the reading comprehension skills of individuals with ASD by including only studies that use standardized measures of reading comprehension, and that use only participants diagnosed with gold standard measures (i.e., ADOS/ADI), to see how limiting these variables enhance our understanding of the reading skills of the ASD population.

Directions for future research

After completing this meta-analysis, it is clear that many individuals with ASD struggle with reading comprehension. However, the truism that reading is a language-based skill (Nation & Norbury, 2005) has been clearly exemplified by the findings of this and other studies (Lindgren et al., 2009). Individuals with ASD who also have language deficits may have the most severe reading comprehension weaknesses. However, few of the studies to date have included comprehensive assessments to describe the language skills of the participants. In future research, it is imperative that researchers assess the language skills, including semantic knowledge, and lower order reading skills, including decoding skill, when examining reading comprehension, since these proved to be the strongest predictors of reading comprehension in this analysis. Further, researchers need to be cognizant of the level of background knowledge needed by participants to successfully comprehend the texts. Texts that require a high level of social knowledge are likely to ensure much poorer scores on reading comprehension tasks than texts that require limited social knowledge Finally, research in the area of reading comprehension needs to become more fine-grained and focus on the underpinnings of successful reading comprehension such as processing speed as well as the ability and propensity to make inferences while reading, integrate information across the textbase and with prior knowledge, and monitor comprehension while reading. Only by elucidating the underpinnings of successful reading comprehension for individuals with ASD will educators be enabled to meet the complex needs of these learners.

Figure Caption Sheet

Figure 1. Standardized mean differences in reading comprehension between groups with ASD and controls

Figure 2. Frequency of SMDs in reading comprehension between ASD and control groups

Figure 3. Funnel plot for reading comprehension analysis

Figure 4. Standardized mean differences in decoding skill between groups with ASD and controls

Figure 5. Frequency of SMDs in decoding skill between ASD and control groups

Figure 6. Standardized mean differences in semantic knowledge between groups with ASD and controls

Figure 7. Frequency of SMDs in semantic knowledge between ASD and Control groups

Figure 8. Standardized mean differences in performance IQ between groups with ASD and controls

Figure 9. Frequency of SMDs in PIQ between ASD and control groups

Figure 10. Funnel plot for decoding analysis

Figure 11. Funnel plot for semantic knowledge analysis

Figure 12. Funnel plot for performance IQ analysis

Figure 13. Reading comprehension skills of individuals with ASD on high social texts

Figure 14. Standardized mean differences in reading comprehension for high social texts

Figure 15. Reading comprehension skills of individuals with ASD on low social texts

Figure 16. Standardized mean differences in reading comprehension for low social texts

Figure 17. Grand SMDs and 95% confidence intervals of the reading comprehension performance of individuals with ASD by text type

Table 1. Assessment of bias using Duval's and Tweedie's trim and fill procedure

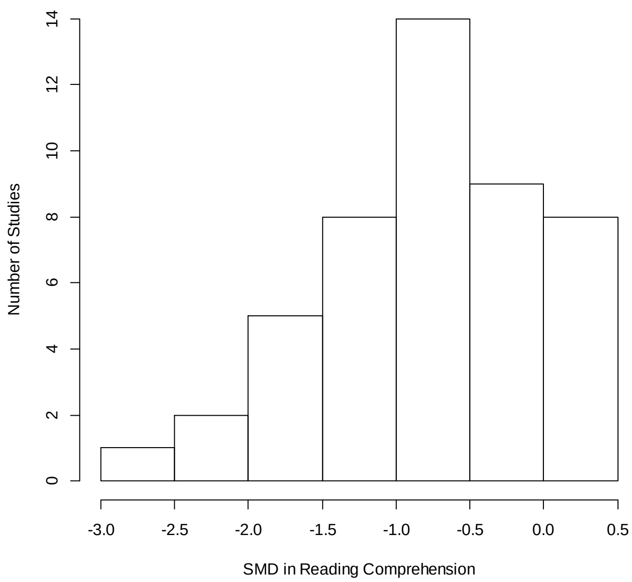
Table 2. Grand SMDs in reading comprehension between ASD groups and controls along with heterogeneity analyses for the reading comprehension studies that also included scores for each moderator variable

Table 3. Relationships between reading comprehension, decoding, semantic knowledge and PIQ.

R Development Core Team (2011). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/.

Fig. 2 Frequency of SMDs in Reading Comprehension between ASD and control groups

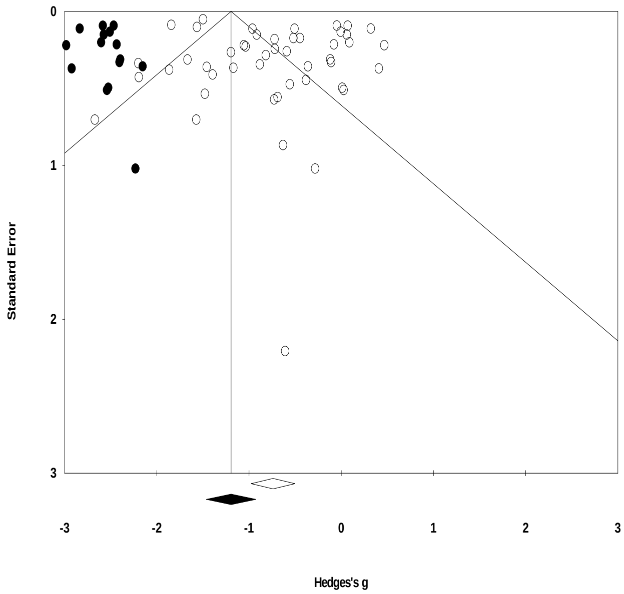
[Figure 2 top]



Borenstein, M., Hedges, L., Higgins, J., & Rothstein, H. (2005). *Comprehensive meta-analysis Version 2*. Englewood, NJ: Biostat.

[Figure 3 top]

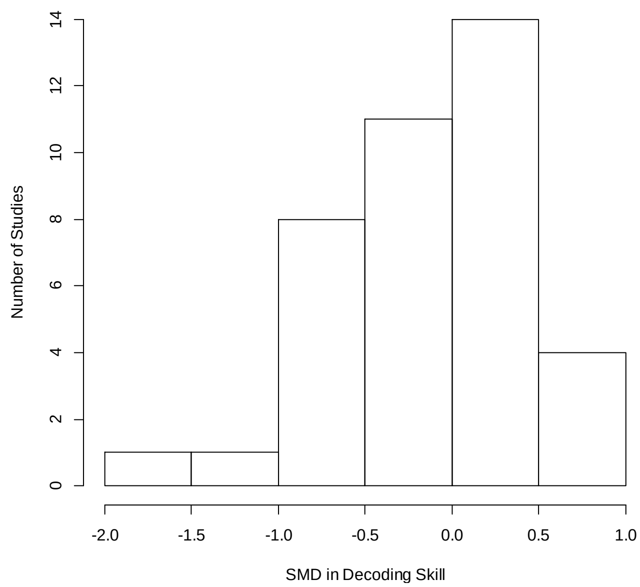
Fig. 3 Funnel Plot for Reading Comprehension Analysis



R Development Core Team (2011). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/.

Fig. 5 Frequency of SMDs in Decoding Skill between ASD and Control Groups

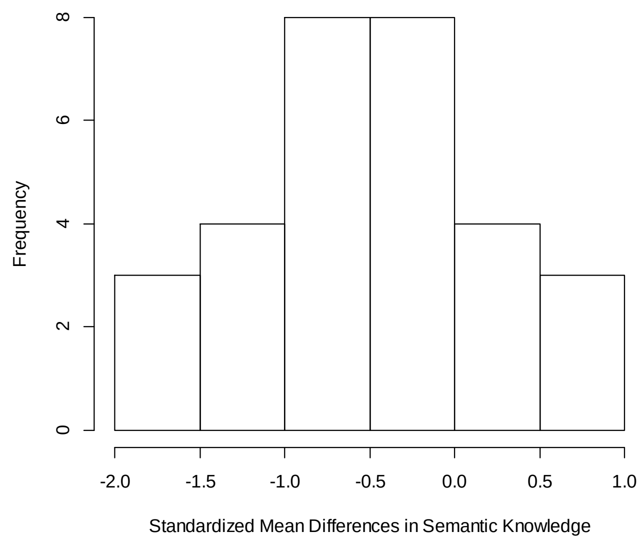
[Figure 5 top]



R Development Core Team (2011). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/.

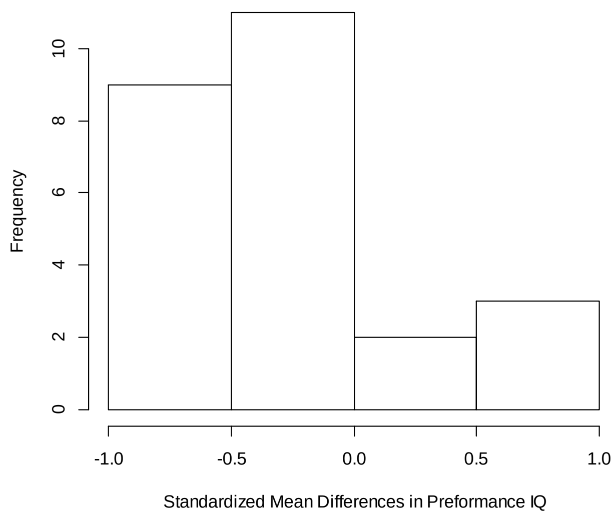
Fig. 7 Frequency of SMDs in Semantic Knowledge between ASD and Control Groups

[Figure 7 top]



R Development Core Team (2011). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/.

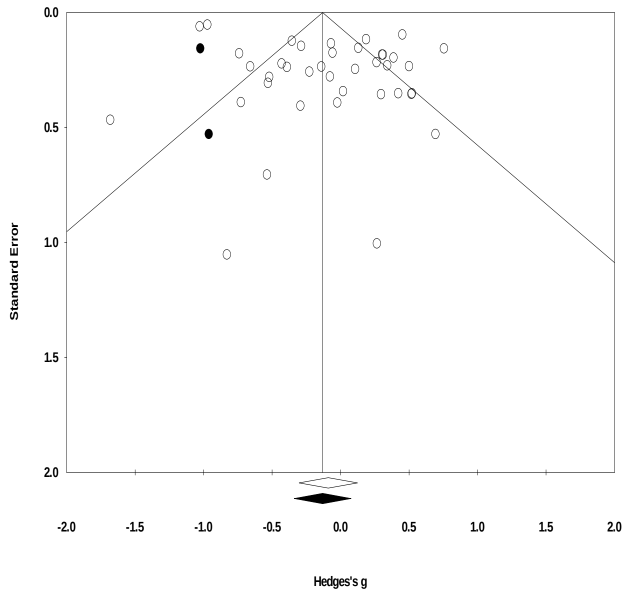
Fig. 9 Frequency of SMDs in PIQ between ASD and Control Groups
[Figure 9 top]



Borenstein, M., Hedges, L., Higgins, J., & Rothstein, H. (2005). *Comprehensive meta-analysis Version 2*. Englewood, NJ: Biostat.

Fig. 10 Funnel Plot for Decoding Analysis

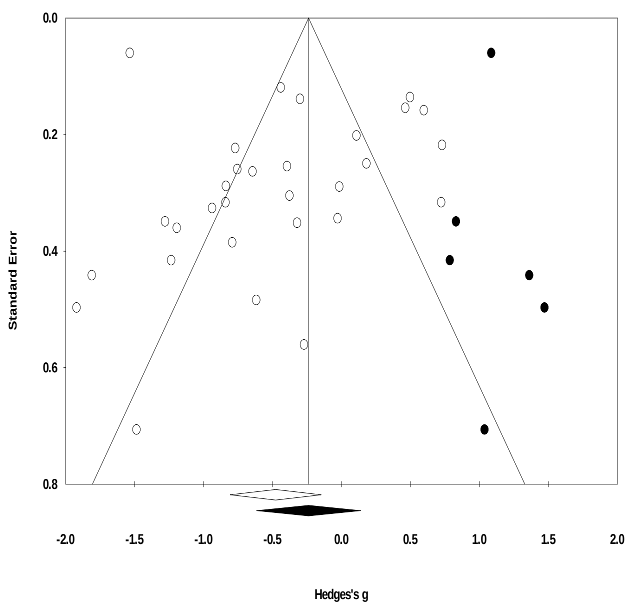
[Figure 10 top]



Borenstein, M., Hedges, L., Higgins, J., & Rothstein, H. (2005). *Comprehensive meta-analysis Version 2*. Englewood, NJ: Biostat.

Fig. 11 Funnel Plot for Semantic Knowledge Analysis

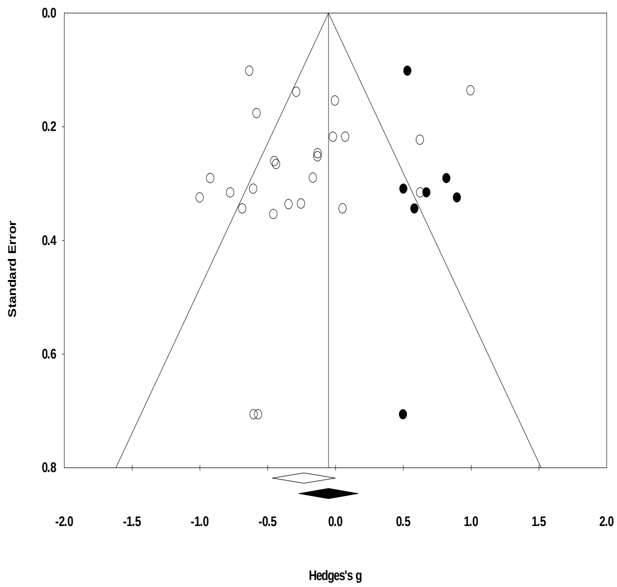
[Figure 11 top]



Borenstein, M., Hedges, L., Higgins, J., & Rothstein, H. (2005). *Comprehensive meta-analysis Version 2*. Englewood, NJ: Biostat.

Fig. 12 Funnel Plot for Performance IQ Analysis

[Figure 12 top]



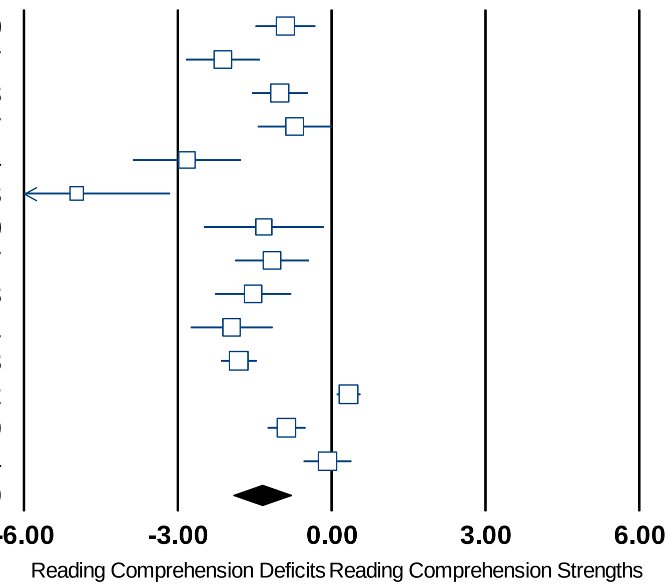
Borenstein, M., Hedges, L., Higgins, J., & Rothstein, H. (2005). *Comprehensive meta-analysis Version 2*. Englewood, NJ: Biostat.

Fig. 13 Reading comprehension skills of individuals with ASD on high social texts

[Figure 13 top]

Study name	Hedges's g	Standard error
Brent et al., 2004	-0.90	0.30
Enoch-Holman, 2004 ASD+HYP	-2.12	0.37
Enoch-Holman, 2004 ASD-HYP	-1.01	0.28
Gillott, Furniss & Walter, 2004	-0.72	0.37
Happé, 1994 Able Autistics	-2.82	0.54
Happé, 1994 No ToM	-4.97	0.93
Happé et al., 1996	-1.32	0.60
Heavey et al., 2000	-1.16	0.37
Jolliffe & Baron-Cohen, 1999a AS	-1.53	0.38
Jolliffe & Baron-Cohen, 1999a AUT	-1.95	0.41
Kaland et al., 2002, 2005	-1.81	0.18
LaPoint-Speer, 2007	0.33	0.12
Martin & MacDonald, 2004	-0.88	0.19
Saldaña & Frith, 2007	-0.08	0.24
	-1.36	0.29

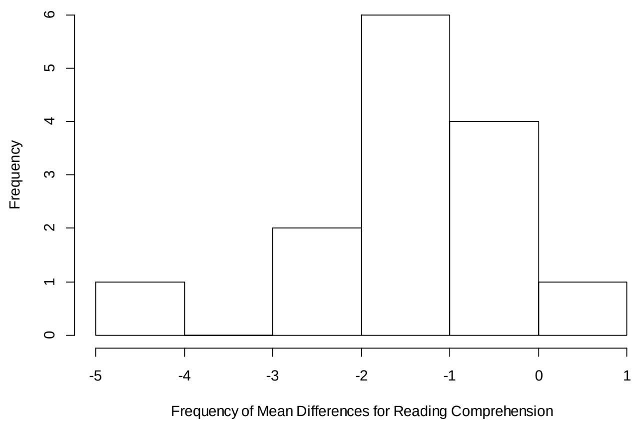
Hedges's g and 95% CI



R Development Core Team (2011). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/.

Fig. 14 Standardized mean differences in reading comprehension for high social texts

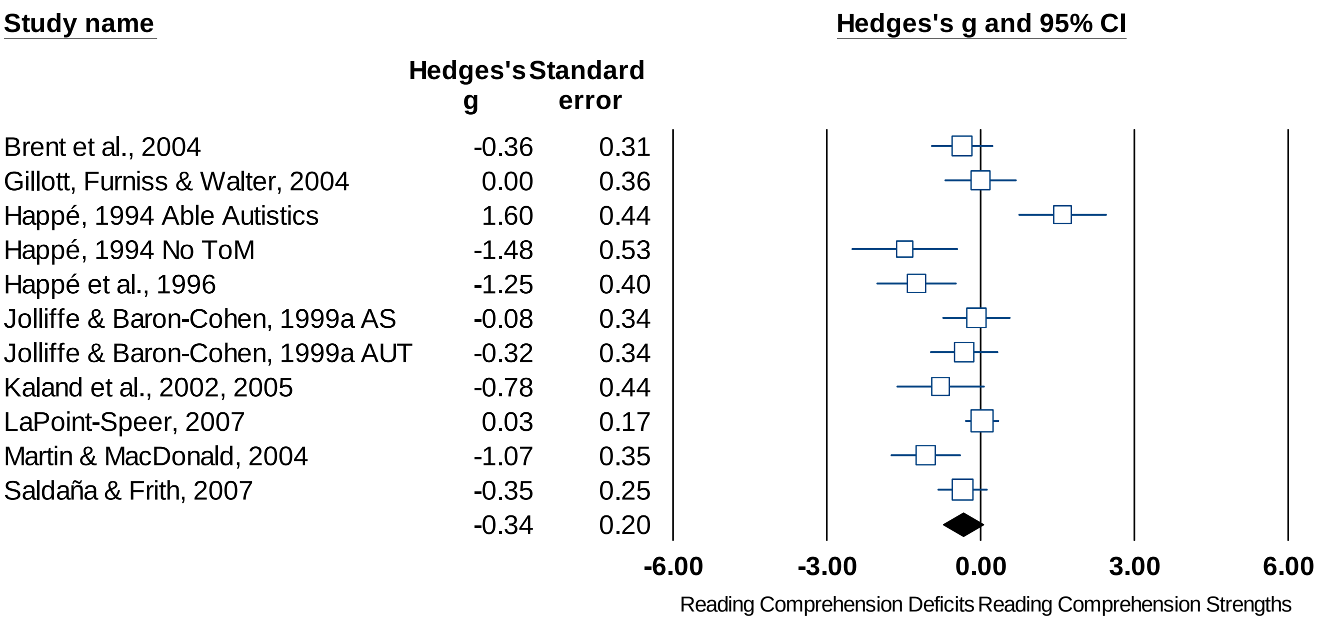
[Figure 14 top]



Borenstein, M., Hedges, L., Higgins, J., & Rothstein, H. (2005). *Comprehensive meta-analysis Version 2*. Englewood, NJ: Biostat.

Fig. 15 Reading comprehension skills of individuals with ASD on low social texts

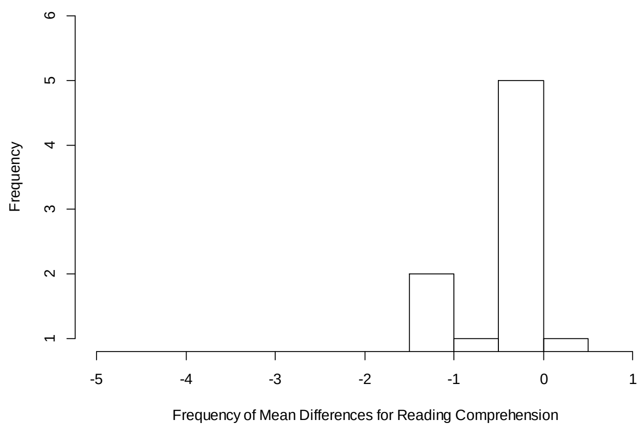
[Figure 15 top]



R Development Core Team (2011). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/.

Fig. 16 Standardized mean differences in reading comprehension for low social texts

[Figure 16 top]



R Development Core Team (2011). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/.

Fig. 17 Grand SMDs and 95% confidence intervals of the reading comprehension performance of individuals with ASD by text type

[Figure 17 top]

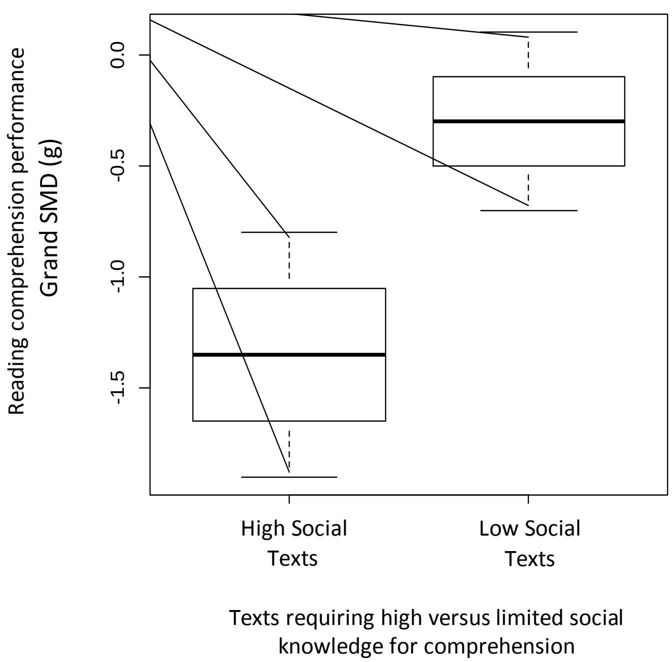


Table 1. Assessment of bias using Duval's and Tweedie's trim and fill procedure

	Number of Studies Imputed	Direction	Original Estimate of the SMD	Unbiased Estimate of the SMD
Decoding	2	Left	g = -0.1	g = -0.4
Semantic Knowledge	6	Right	g = -0.5	g = -0.2
PIQ	7	Right	g = -0.2	g = -0.05

Table 2. Grand SMDs in reading comprehension between ASD groups and controls along with heterogeneity analyses for the reading comprehension studies that also included scores for each moderator variable

Moderator Variable	Number of studies included in analysis	Grand SMD for reading comprehension	Are the SMDs heterogeneous?
Decoding	39	g = -0.8 Z = -5.60, p <.0001	Yes Q (38) = 728.62, I2=94.78, p < .0001
Semantic Knowledge	30	g = -0.7 Z = -4.61, p < .0001	Yes Q (29) = 411.54, I2=92.95, p < .0001
PIQ	25	g = -0.5 Z = 3.50, p < .0001	Yes Q (24) = 287.74, I2=91.66, p < .0001
Total	47	g = -0.7	Yes

Table 3. Relationships between reading comprehension, decoding, semantic knowledge and PIQ.

Variable	1	2	3	4
1. Reading Comprehension	-			
2. Decoding	.767*	-		
3. Semantic Knowledge	.593*	.431*	-	
4. PIQ	.410*	.417*	.389*	-

* Correlation is reliable at the 0.001 level (2-tailed).

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Appendix B. Demographic Characteristics of Participants in each study included in meta-analysis

Study	Experimental Group			Control	
	n	Mean age: (years)	Group	n	Mean age: (years)
Asberg (2010), Asperg and Dahlgren-Sandberg (2010)	12	13.4 ± 1.33	ASD	16	12 ± 2.33
Asberg and Dahlgren-Sandberg (2008)	37	9.74 ± 1.87	ASD	19	8.81 ± 1.34
Asberg et al. (2010)	20	11.8 ± 2.7	ASD	54	12.5 ± 2.6
Ashcraft-Bills (2009)	20	17.67 ± 4.19	ASD	22	17.93 ± 5.17
Booth and Happe (2010)	41	14.4 ± 2.6	ASD	41	14.5 ± 2.7
Brent et al. (2004)	20	9.33 ± 1.5	ASD	20	8.67 ± 1.75
Castles et al. (2010)	2	9.25	ASD	3500	–
Cronin (2008)	4	11.4 ± 1.67	ASD 10-13 years	4201	–
Cronin (2008)	9	8.9 ± 0.83	ASD 7-9 years	4201	–
Emrich et al. (2003)	8	13.4	ASD	8	–
Enoch-Holan (2004)	5	–	ASD + HYP	6	–
Enoch-Holan (2004)	6	–	ASD - HYP	6	–
Flores and Ganz (2009)	2			8108	
Gillott et al. (2004)	15	10.26	ASD	15	10.26
Goldstein et al. (1994)	29	–	Autism; 12 years & younger	19	–
Goldstein et al. (1994)	35	–	Autism; 13 years & older	27	–
Griswold et al.(2002)	21	10	AS	4252	–
Happe (1994; 1997)	6	17.6	Autism No ToM	13	19.4
Happe (1994)	18	20.6	Autism Able Autistics	10	20.5
Happe (1997)	5	16.6	Autism 1st ToM	13	7.7
Happe (1997)	6	17.5	Autism 2nd ToM	13	7.7

Happe et al. (1996)	5	24	ASD	10	–
Heavey et al. (2000)	16	34.7 ± 9.5	Autism	15	30.7 ± 8.1
Huemer and Mann (2010)	78	–	AS	1677	–
Huemer and Mann (2010)	145	–	AUT	1677	–
Jolliffe and Baron-Cohen (1999a/b, 2000)	17	27.77 ± 7.81	AS	17	30 ± 9.12
Jolliffe and Baron-Cohen (1999a/b, 2000)	17	30.71 ± 7.84	Autism	17	30 ± 9.12
Jones et al. (2009)	100	15.5 ± 0.5	ASD	2200	–
Kaland et al. (2002), Kaland et al. (2005)	21	15.9 ± 3.2	ASD	20	15.6 ± 3.3
LaPoint-Speer (2007)	17	17.81 ± 4.43	ASD	17	17.35 ± 4.87
Lindgren et al. (2009) ALI	32	10.4 ± 2.6	ALI	6359	–
Lindgren et al. (2009) ALN	20	10.3 ± 2.6	ALN	6359	–
Lopez and Leekam (2003)	15	13.83 ± 2.33	ASD	16	14.33 ± 0.83
Martin and MacDonald (2004)	14	19.64 ± 1.7	ASD	24	19.75 ± 3.4
Mayes and Calhoun (2003)	42	–	ASD IQ > 80	4252	–
Mayes and Calhoun (2008)	54	–	ASD IQ > 80	5586	–
Minshew et al. (1994;1995)[1]	62	17.79 ± 10.09	ASD	50	16.91 ± 9.96
Naples (2009)	4	7.8 ± 1.5	HPL	9	9.78 ± 2.91
Nation et al. (2006)	10	10.06 ± 2.87	ALI	3500	–
Nation et al. (2006)	10	10.5 ± 2.47	ALN	3500	–
Newman et al. (2007)	11	–	ASD + HPL	18	9.99 ± 4.07
Newman et al. (2007)	20	12.33 ± 3.39	ASD - HPL	18	9.99 ± 4.07
O'Connor and Klein (2004)	20	15.11 ± 0.99	ASD	4201	–
Pijnacker et al. (2009)	28	26.8 ± 5.2	ASD	28	26.3 ± 5.2
Saldana and Frith (2007)	16	14.75 ± 1.92	ASD	16	13.92 ± 1.92
Turner (2010)	377	–	ASD	4783	–

Wahlberg and Magliano (2004)	12	–	ASD	12	–

Notes:
[1] The data from Minshew et al., 1995 was entered for illustrative purposes.

ASD: Autism spectrum disorder

AS: Asperger's Syndrome

AUT: Autism

ASD + HYP: ASD + Hyperlexia

ASD - HYP: ASD – Hyperlexia

ALI: Autism Language Impaired

ALN: Autism Language Normal

Autism Able Autistics: high-functioning ASD

Autism No ToM: Autism + No Theory of Mind

1st ToM: Autism + 1st Order Theory of Mind

2nd ToM: Autism + 2nd Order Theory of Mind

– data not reported