

Cognitive Contributors to Reading Difficulties in Autism Spectrum Disorder:  
A Systematic Review

by

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B.Sc., University of Michigan, 2016

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## Abstract

Children with autism spectrum disorder (ASD) commonly experience reading difficulties, especially in reading comprehension. Children with ASD also commonly experience deficits in cognitive processes, including attention, executive functions, inferencing, among other cognitive abilities. In particular, there is evidence that attention and EF abilities are important for reading proficiency and that such deficits in ASD may contribute to reading difficulties in this population, although this area is understudied. The Integrated Model of Reading Comprehension (IMREC) conceptualizes comprehension as the product (i.e., a coherent mental representation of text in the reader's mind) of automatic (e.g., the availability of recently processed information in working memory) and strategic (e.g., effort for predicting and monitoring text for meaning) processes. As such, it outlines cognitive contributors to reading comprehension, thus making it potentially valuable in the conceptualization of reading comprehension in ASD. The aim of the current study was to investigate underlying cognitive components associated with reading comprehension in children with ASD, as informed by the IMREC model. A systematic review of the association between cognitive variables and reading comprehension in individuals with ASD was conducted. The review included articles published between 2000 and 2020. 1,430 articles were initially screened, and 22 articles met study inclusion criteria and were included in the final review. Results indicated that working memory, intelligence, and verbal memory are important for reading comprehension in ASD, though there is much research to be done in the area, especially around factors such as inference and attention allocation. Future research should utilize more clearly defined samples, theoretically-based cognitive variables, and theoretically-based study design.

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## **Cognitive Contributors to Reading Difficulties in Autism Spectrum Disorder: A Systematic Review**

It is estimated that 38-73% of children with Autism Spectrum Disorder (ASD) struggle with reading comprehension, thus impacting their academic achievement and life success (Brown et al., 2013; Mayes & Calhoun, 2007; Nation et al., 2006). Reading comprehension is the most complex literacy task, the ultimate goal of reading, and a vital contributor to academic success and full participation in society (Brown et al., 2013; Randi et al., 2010; van den Broek & Espin, 2012). Reading comprehension problems occur due to a range of cognitive deficits, including attention and executive functions, auditory processing, and language-based deficits; however, little is known about the specific cognitive constructs that contribute to reading comprehension problems in the ASD population. It is well accepted that individuals with ASD exhibit a range of cognitive differences, particularly in the areas of attention and executive functions (EF; e.g., working memory, inhibitory control, flexibility/switching; Fein, 2011; Keehn et al., 2010) and that attention/EF deficits have far-reaching consequences that affect social skills, behavior, and academic achievement (Monette et al., 2011; Pellicano, 2012). In particular, attention/EF have been closely linked to difficulties with reading comprehension beyond basic reading skills and independently of other cognitive predictors (Butterfuss & Kendeou, 2018; Sesma et al., 2009; van den Broek & Espin, 2012). The aim of the current study was to investigate underlying cognitive components associated with reading comprehension in children with ASD, an important yet understudied area. The selection of cognitive variables for investigation was informed by the Integrated Model of Reading Comprehension (IMREC), which is a cognitively-based model of reading that posits comprehension as the product (i.e., a coherent mental representation of text in the reader's mind) of automatic (e.g., the availability of

recently processed information in working memory) and strategic (e.g., effort for predicting and monitoring text for meaning) processes. This model emphasizes the role of attention/EFs in reading comprehension (Butterfuss & Kendeou, 2018; van den Broek & Espin, 2012), among other cognitive factors and, as such, was felt to be appropriate for more broadly understanding the causes of reading comprehension difficulties and more specifically investigating the contribution of attention/EF to reading comprehension in ASD.

### **Autism Spectrum Disorder**

Autism Spectrum Disorder (ASD) is a neurodevelopmental disorder (NDD) characterized by restricted, repetitive patterns of behavior and interests and atypicalities in social interaction (American Psychiatric Association, 2013). ASD affects roughly 1 in 54 people, does not discriminate across racial, ethnic, or socioeconomic groups, and is diagnosed in nearly four times as many males than females (Centers for Disease Control, 2019). The most recent Diagnostic and Statistical Manual (DSM-5) recognizes ASD as a spectrum disorder with levels of impairment varying from mild to severe (American Psychiatric Association, 2013). Under DSM-5, a diagnosis of ASD requires 1) persistent deficits in social-communication and social interaction across multiple contexts, and 2) restricted and repetitive patterns of behaviors, interests, or activities (American Psychiatric Association, 2013). The DSM-5 also requires that symptoms are present in the developmental period and that the individual is demonstrating functional impairment, assigns specifiers based on the severity of autistic symptoms, and permits comorbidities such as ADHD, learning disorders, and intellectual impairment (American Psychiatric Association, 2013).

The previous iteration of the DSM (DSM-IV-TR, 2000-2013) separated ASD into distinct categories, including Autistic Disorder, Asperger Syndrome, Childhood Disintegrative Disorder,

and Pervasive Developmental Disorder Not Otherwise Specified (PDD-NOS) under a broader classification called Pervasive Developmental Disorders (American Psychiatric Association, 2000; American Psychiatric Association, 2013). Using DSM-IV-TR criteria (2000-2013), a diagnosis of Autistic Disorder (AD) required that individuals must exhibit qualitative impairments in social interaction, qualitative impairments in communication, and restricted and repetitive behaviors, with at least one symptom presenting before the age of three years (American Psychiatric Association, 2000). A diagnosis of Asperger's Syndrome (AS) required impairment in social interaction and restricted and repetitive behaviors or interests without a clinically significant delay in language, cognitive development, or adaptive behavior (American Psychiatric Association, 2000). PDD-NOS was described as severe, pervasive impairment in social interaction with impairment in either communication skills or restricted, repetitive behaviors where symptoms may be subthreshold or presenting atypically (American Psychiatric Association, 2000).

Before the DSM-IV-TR, the DSM-III-R was used to diagnose autistic disorder (AD; American Psychiatric Association, 1987). In order to receive this diagnosis, an individual needed to display eight symptoms from a list of sixteen, with at least two coming from each distinct category (American Psychiatric Association, 1987). These categories included qualitative impairment in reciprocal social interaction, qualitative impairment in verbal and nonverbal communication and imaginative activity, and markedly restricted interests and activities (American Psychiatric Association, 1987). Additionally, the individual's symptoms must have presented in infancy or early childhood (American Psychiatric Association, 1987).

Though DSM-III-R nor DSM-IV-TR criteria are not currently being used to establish diagnoses, since the advent of DSM-5 in 2013, research using samples collected prior to 2013

would have used DSM-IV/TR criteria and research using samples collected prior to 2000 would have used DSM-III-R criteria. Given that the current systematic review included studies published between 2000 and July 2020, the samples may have been diagnosed under DSM-III-R, DSM-IV/TR or DSM-5 criteria. Although the DSM is most commonly used in North America, the ICD-10 classification system is globally recognized and thus diagnoses under this system will be accepted in this review as well (World Health Organization, 1992).

In addition to the core social, behavioral, and communication symptoms that define ASD, ASD is characterized by a range of cognitive difficulties, including attention and EF impairments (Demetriou et al., 2019; Keehn et al., 2010). These cognitive difficulties offer some explanation for the higher incidence rate of reading and learning disorders in the ASD population (Mayes & Calhoun, 2007; O'Brien & Pearson, 2004). However, learning disorders, which are common in the ASD population and significantly impact life outcomes, are an understudied area.

### ***Cognitive Theories of ASD***

There are several cognitive theories that researchers have explored as potentially causal for ASD, although no one theory has met the universality, specificity, and primacy criteria to be considered the one central deficit (Sigman & Capps, 1997). In other words, the cognitive differences seen are either not present across individuals with ASD, are seen in clinical disorders other than ASD, and/or do not emerge in early development prior to the unfolding of clinical symptoms (Sigman & Capps, 1997). Nevertheless, these theories hold value in describing the aspects of cognition, social-communication, and behavior affected in ASD and will be briefly reviewed below. The most well-known cognitive theories in the ASD literature are the Theory of Mind (Baron-Cohen, 2000), Weak Central Cohesion (Frith, 1989), and Executive Dysfunction hypotheses (Pennington & Ozonoff, 1996).

The Theory of Mind hypothesis proposes that cognitive deficits in ASD are a result of failures to attribute mental states to oneself and others (Baron-Cohen, 2000). This theory does not explain repetitive behaviors particularly well but reasonably accounts for the social-communication differences seen in ASD (Baron-Cohen, 2000; Hill, 2004b). The Weak Central Coherence theory asserts that individuals with ASD process information in a fragmented rather than integrative style, favoring the processing of individual details over the greater context (Frith, 1989). This theory best accounts for the hyper-focus on details and some of the social deficits seen in ASD (Fein, 2011), but does not adequately explain repetitive behaviors and restricted interests. Finally, the Executive Dysfunction theory of ASD proposes that ASD symptoms are a result of impairment in the higher order cognitive processes that regulate goal-directed behavior (Pennington & Ozonoff, 1996). The Executive Dysfunction hypothesis is able to account for some of the rigidity and behavioral challenges seen in ASD but does not explain communication or social deficits particularly well (Craig et al., 2016). In addition, EF deficits, while commonly present in ASD, are not specific to this population as they are also seen in other NDDs that do not present with symptoms similar to ASD (e.g., attention deficit disorder, learning disorders, fetal alcohol spectrum disorder, etc.; Fein, 2011).

While it is clear that no one theory fully explains the constellation of symptoms seen in ASD (including the Executive Dysfunction Theory), there is ample evidence that children with ASD exhibit significant problems with aspects of attention and EF that impact their quality of life, symptom severity, and academic performance (Demetriou et al., 2019; Keehn et al., 2010; Mayes & Calhoun, 2007; O'Brien & Pearson, 2004). In addition to exacerbating core symptoms and limiting functional outcomes (Demetriou et al., 2019), attention/EF deficits have a significant impact on academic achievement in ASD populations (Fleury et al., 2014).

### ***Attention/Executive Function in ASD***

Up to 78% of children with ASD show attention and EF deficits severe enough to meet thresholds for ADHD (Gargaro et al., 2011). Although there is no one profile of attention/EF deficits in this population, deficits have been identified in a range of attention/EF abilities including orienting and shifting attention (Fein, 2011; Posner & Rothbart, 2007), regulating attention (Keehn et al., 2010), focusing attention (Fein, 2011; Keehn et al., 2010), working memory (Kercood et al., 2014), inhibitory control (Sanders et al., 2008), and cognitive flexibility (Demetriou et al., 2018; Sanders et al., 2008). These deficits negatively impact behavior, mental health, and learning and have been implicated in a range of negative long-term outcomes including school success, mental health, and overall adaptive skills for individuals with ASD (Demetriou et al., 2019; Fleury et al., 2014; Ozonoff & Schetter, 2007). Specifically, difficulties with inhibitory control have been identified in ASD (Demetriou, et al., 2019; Garon et al., 2018; O’Hearn et al., 2008; Pennington & Ozonoff, 1996). Research on working memory in ASD has been inconsistent across studies, with some studies showing deficits in WM (Williams et al., 2005; Sachse et al., 2012) and others not (Nakahachi et al., 2006; Oliveras-Rentas et al., 2013; Ozonoff & Strayer, 2001). Evidence does suggest, however, that spatial working memory is more likely to be impacted than verbal working memory (Fein, 2011; Garon et al., 2008; Williams et al., 2005). In particular, individuals with ASD exhibit more difficulty on working memory tasks that are complex and involve manipulation (as opposed to maintenance) of information (Fein, 2011). Cognitive flexibility, or attention switching, appears to be particularly problematic in ASD (Demetriou et al., 2019; Fein, 2011; Pellicano, 2012). Deficits in switching are associated with lower social, academic, and adaptive skills throughout development in individuals with ASD (Demetriou et al., 2019; Fleury et al., 2014; Pellicano, 2012).

Though the presentation of affected underlying EF abilities may vary across individuals with ASD, attention and EF deficits are commonly seen in ASD (Demetriou et al., 2019; Fein, 2011; Garon et al., 2008; O’Hearn et al., 2008). As detailed previously, EFs underlie goal-directed behavior and are crucial for social and academic functioning as well as behavior regulation, and the disruption of these abilities put individuals with ASD at greater risk for a host of negative outcomes, including reading difficulties (Fein, 2011; Fleury et al., 2014; Miyake et al., 2000; Pennington & Ozonoff, 1996).

### **Reading Comprehension**

Reading comprehension is a complex process that can be conceptualized in multiple ways. As such, a range of theoretical models to explain reading development and difficulties in reading have been developed. One such conceptualization is the Simple View of Reading, which breaks reading into two equally critical processes (Hoover & Gough, 1990). The first process involved is that of decoding, or the recognition of written symbols as words stored in the mental lexicon (Hoover & Gough, 1990). This involves cipher knowledge and lexical knowledge, or knowledge of both the systematic and irregular relationships between written letters and the phonemes they represent (Hoover & Gough, 2000). The second process is language comprehension, or the construction of literal and inferred meaning from spoken words (Hoover & Gough, 2000). This requires linguistic knowledge, or knowledge about the formal structure of a language, as well as background or contextual knowledge (Hoover & Gough, 2000). With the importance of both the decoding and linguistic comprehension processes in mind, there are multiple pathways through which an individual may struggle with reading comprehension.

In contrast, The Construction-Integration Model is a theory of reading comprehension that takes a bottom-up approach (Kintsch, 1988). This theory posits that a representation of text

is created by using both what has already been read and an individual's knowledge held in long-term memory. Within this model, as the individual reads, the information they take in is continuously integrated with this constructed representation (Kintsch, 1988). This requires the reader to have adequate inference making skills in order to effectively integrate their background knowledge with the text (Kintsch, 1988; Oakhill & Cain, 2018).

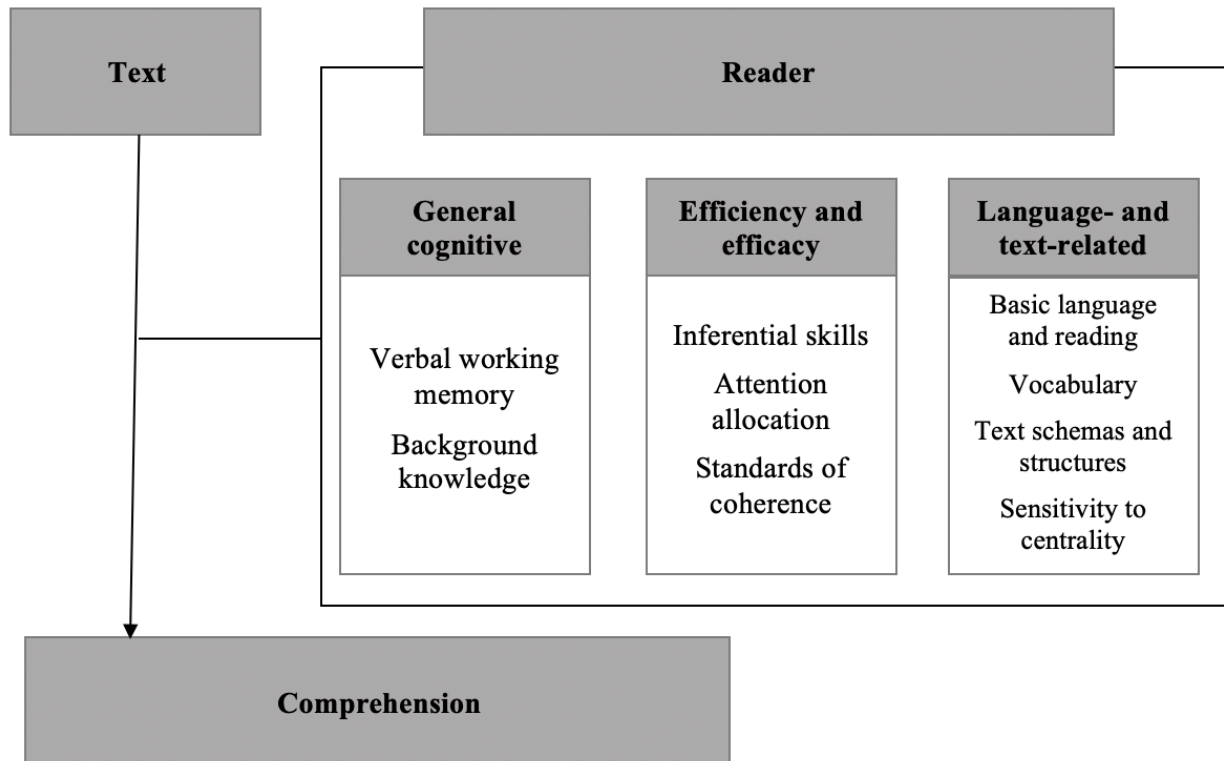
Finally, while word reading has long been studied as the primary cause of reading comprehension difficulties, there has been a recent shift to acknowledge that a child may have proficient word reading skills but still struggle with reading comprehension (Cutting et al., 2009; Sesma et al., 2019; Swart et al., 2017). This shift in research focus has begun to highlight the many cognitive processes necessary to effectively read beyond word reading and has led to the development of cognitive models that more clearly delineate the specific cognitive processes that underlie reading.

### **The Integrated Model of Reading Comprehension**

The Integrated Model of Reading Comprehension (IMREC) is a cognitive model of reading that combines many of the notions previously described in its conceptualization of reading comprehension (van den Broek & Espin, 2012). The IMREC model suggests that reading comprehension involves multiple processes and strategies aimed at the management of mental resources and information in order to build coherence (van den Broek & Espin, 2012). Within this model, the reader processes incoming text using a range of cognitive processes in order to create a representation of the text's information in their mind, referred to as 'the product' (van den Broek & Espin, 2012). A visual representation of the IMREC components is provided in Figure 1 to illustrate the various cognitive processes considered to support reading comprehension.

**Figure 1**

*A Diagram of the Integrated Model of Reading Comprehension as described by van den Broek & Espin, 2012*



The IMREC model breaks reader characteristics into three key domains: 1) general cognitive functions, 2) cognitive processes that aid the efficiency and efficacy of reading, and 3) language- and text-related skills (van den Broek & Espin, 2012).

General cognitive function refers to more broadly-applicable factors such as verbal working memory and background knowledge. Though the model does not specify what other cognitive processes comprises this category, I have included long-term memory as a contributor to storing background knowledge.

‘Efficiency and efficacy’ refer to the balancing of cognitive resources as well as the efficiency with which these resources are used to achieve comprehension (van den Broek &

Espin, 2012). The level of understanding a reader aims to achieve is referred to as the ‘standard of coherence,’ which depends upon reader characteristics, text characteristics, and the purpose of the text (van den Broek & Espin, 2012). As an efficiency- and efficacy-related process, ‘standards of coherence’ act as a benchmark during comprehension monitoring. If the standard is not being reached, another process may need to be activated. This multi-componential, dynamic aspect of reading comprehension requires the allocation of attention, or switching, between the cognitive processes active at different stages of comprehension building (van den Broek & Espin, 2012). Though not explicitly defined in the model, attention allocation also involves the ability to sustain attention and inhibit distractors in order to maintain efficiency (Petersen & Posner, 2012). ‘Inferential skills’ as specified in the model contribute to efficiency- or efficacy-ensuring processes by facilitating the reader’s understanding of implicit information without requiring extra searching (van den Broek & Espin, 2012). In the context of reading, ‘inference skills’ require the integration of text and background knowledge in order to reach an understanding beyond what is explicitly stated (Fitch Hauser, 1984; Oakhill, 1984). It is impossible to exhaustively include all relevant information in any text, so readers must make inferences about the underlying or implied information in order to fully understand a text’s message (Oakhill & Cain, 2018). This entails making inferences between different sections of the text as well as between the text information and their background knowledge (Oakhill & Cain, 2018). Inference therefore increases efficiency by allowing the reader to use information they already hold rather than re-reading or searching for additional background information (Oakhill & Cain, 2018).

Language- and text-related skills are those that the reader specifically uses to interpret text. Basic language and basic reading skills are necessary to engage with the text at the most

rudimentary level and include abilities such as grammar and word decoding (van den Broek & Espin, 2012). Vocabulary is also a large part of both language, basic reading, and reading comprehension. Beyond the word level, knowledge about text structures and schemas can help inform a reader's selection of strategy when automatic processes are not enough (van den Broek & Espin, 2012). Sensitivity to structural centrality is the understanding of what information is most important in a certain text, thus allowing the reader to focus their efforts (van den Broek & Espin, 2012).

It should be noted that the cognitive components subsumed under the three domains of the IMREC model are not mutually exclusive and there is major overlap between the cognitive components across domains (van den Broek & Espin, 2012). For example, the model places attention allocation (or shifting) and 'inferential skills' under efficiency/efficacy, yet these processes are also general cognitive processes that would fit within the general cognitive domain. Similarly, verbal working memory is housed under the general cognitive domains but is also critical to effective/efficient processing. Attention allocation is also necessary to focus on centrally important information, so attention allocation and sensitivity to structural centrality could go together as well. In fact, many of the cognitive contributors to reading that make up the IMREC model could easily be placed within any of the three IMREC domains, and as such, the distinction between domains is somewhat artificial. Regardless of under which domains they are categorized, the IMREC model proposes that it is the interaction of these cognitive functions with text information that enables reading comprehension. For this reason, I am not specifically breaking apart IMREC domains or investigating the structure of this model with respect to ASD but rather I am using the model to select a range of cognitive processes across each of the domains to inform our search.

## **Cognitive Processes in Reading: Attention and Executive Functions**

### ***Attention and Executive Functions***

Although this paper is not exclusively focused on attention/EF, these abilities are a core component of the IMREC model and are of particular interest given the cognitive profile of ASD, so I will take the time to define these constructs here. Though there is disagreement on the true nature of executive function (EF), the definition of EF as “a set of general-purpose control processes that regulate one’s thoughts and behaviors” (p. 8) is perhaps the most well accepted (Miyake & Friedman, 2012). EF processes are both unitary and diverse, exhibiting some underlying commonalities and correlation but also showing separability of function and differential connections to other tasks (Miyake & Friedman, 2012). This underlying commonality has been termed the “common EF” and encompasses the basic ability to maintain task goals and related information in order to direct processing (Miyake & Friedman, 2012). Miyake’s model, identifies three subcomponent EF processes (inhibition, updating, shifting) which are considered foundational and underlie more complex aspects of EF such as planning and organization (Miyake et al., 2000).

Inhibition refers to the ability to deliberately suppress predominant responses in order to maintain attention on target stimuli or responses (Fein, 2011; Miyake et al., 2000). Response inhibition is the simple stopping of a response and develops between ages three to six years old (Muller & Kerns, 2015). Another form of inhibition is interference control, or the ability to stop one response while also carrying out a separate, competing response (Muller & Kerns, 2015).

Updating, or working memory, refers to the updating and monitoring of information in working memory, a revision process integrating new input and eliminating irrelevant information (Miyake et al., 2000). Under Baddeley’s definition, working memory has three components that

work together to maintain and manipulate information (Baddeley, 1983). These components include the visuospatial sketchpad and phonological loop to maintain visual and auditory information and the central executive to coordinate, manipulate and update the information from the subsidiary systems (Baddeley, 1983).

Shifting, also known as cognitive flexibility, is defined as the ability to shift attention between tasks or operations and is implicated in the more complex attentional control (Miyake et al., 2000). Shifting necessitates the ability to disengage from and overcome priming to the previous set as well as the ability to engage with and sustain attention on the new set (Miyake et al., 2000). Shifting abilities span a range of complexity and begin to emerge around age three, though they continue to develop through adolescence (Muller & Kerns, 2015). The ventrolateral prefrontal cortex is implicated in shifting (Muller & Kerns, 2015).

Similar to EF, attention is also seen as unitary and diverse (Petersen & Posner, 2012). Attention comprises a network of cognitive processes that includes alerting (maintaining focus), orienting (prioritizing input and shifting attention), and executive attention (regulation of focal attention and processing during cognitively challenging situations; Petersen & Posner, 2012). These processes work together, and basic levels of attention (alerting) must be intact to engage higher order levels of attention (orienting and executive attention; Petersen & Posner, 2012). The neural substrates for attention and EF are similar (Petersen & Posner, 2012), and the processes show considerable overlap at both a neural and behavioral level. The concept of executive attention, or the ability to monitor and regulate responses in conflicting situations, is analogous to attention and inhibition's role in EF (Posner & Rothbart, 2007). Additionally, Baddeley's central executive component of working memory involves the ability to divide and shift attention in order to temporarily store information while processing, thus inherently linking attention and

EF (Baddeley, 1983; Sohlberg & Mateer, 1987). Because of their similarity and interconnectedness, there is disagreement over what constitutes attention and what constitutes EFs, though basic levels of attention must be intact in order to engage EF and we can be certain that they are strongly associated. Thereafter, for the purposes of this thesis, I will utilize the term EF, understanding that this encompasses both attention and EF abilities.

### ***EFs and Reading***

Executive functions (EFs) are strongly associated with academic performance, with some studies finding that these cognitive processes predict more than half the variance in academic outcomes and do so independently from IQ (Blair & Peters Razza, 2007; Visu-Petra et al., 2011). Research on EFs and academic achievement in reading, writing, and math has shown that working memory and inhibition has a broad influence, as most academic tasks require that an individual attend to and update information relevant to the task at hand (Best et al., 2011; Monette et al., 2011; St. Clair-Thompson & Gathercole, 2006). Similarly, flexibility/switching has also been shown as critical for academic tasks that require multiple levels of processing, including written expression and math problem solving (Bull & Scerif, 2001; St. Clair-Thompson & Gathercole, 2006). Additionally, EFs are important for functioning appropriately in a classroom where one must inhibit behavior, follow instructions or procedures, move between tasks, and implement different strategies in order to effectively learn (Biederman et al., 2004; Fuglestad et al., 2015; St-Clair Thompson & Gathercole, 2006). Though the specific associations vary by age, EFs have been associated with academic performance as early as the pre-kindergarten ages all the way through age 18 (Best et al., 2011; Bull & Scerif, 2001; Monette et al., 2011).

Recently, there has been a focus on the role of EFs in reading specifically (Meixner et al., 2019; Sesma et al., 2009). EFs have been shown to affect early stages of reading development such as decoding in addition to later, more complex aspects of reading such as comprehension (Meixner et al., 2019). Further, early EFs have been shown to predict later reading comprehension beyond early reading comprehension levels, indicating that EF may play an ongoing role in reading development (Meixner et al., 2019). EFs support reading comprehension even beyond basic reading skills or general intellectual function (Butterfuss & Kendeou, 2018; Nouwens et al., 2020; Sesma et al., 2009). In addition to contributing directly to reading comprehension, EF abilities also contribute indirectly by supporting other fundamental processes that contribute to reading comprehension, including lower level reading skills (Butterfuss & Kendeou, 2018; Nouwens et al., 2020).

Specifically within the reading literature, working memory has been linked to vocabulary acquisition as well as to the integration of knowledge and inferring meaning (Swart et al., 2017). In the early stages of reading, working memory has been shown to be a key component of phonological processing as the reader must hold and manipulate phonemes into something they recognize and understand (Savage et al., 2007). As mentioned, in both the IMREC and Construction-Integration Model, working memory plays a role in the holding of text representation in mind as background and text information is integrated (Butterfuss & Kendeou, 2017; Davidson et al., 2018). Thus, as processing demands increase due to an increase in the complexity of text or decreased phonological skills, the demand on working memory increases as well (Cain et al., 2004). These studies suggest that working memory is a crucial component of reading comprehension and uniquely contributes to comprehension across stages of reading

development, even beyond components such as word reading, fluency, and vocabulary (Cain et al., 2004; Sesma et al., 2009).

Broadly, shifting contributes to reading comprehension independently from word reading, working memory, fluency, and phonological skills in addition to contributing to early literacy skills themselves (Kieffer et al., 2013; Nouwens et al., 2016). Shifting may facilitate reading comprehension by allowing children to attend to different elements of text, to move between reading strategies appropriately (e.g., skimming versus searching for specific information), or to process both lexical and semantic information (Kieffer et al., 2013; Nouwens et al., 2016). Additionally, shifting indirectly affects reading comprehension via its impact on oral language comprehension skills (Kieffer et al., 2013).

Inhibition facilitates engagement in cognitive and reading processes, such as inhibiting responses in order to maintain attention towards relevant information or to stay engaged in the multiple steps of comprehension (Meixner et al., 2019; van den Broek & Espin, 2012). Inhibitory control may also influence reading comprehension by filtering out irrelevant information while decoding or synthesizing text (Kieffer et al., 2013). In turn, this facilitates efficiency and lessens strain on working memory (van den Broek & Espin, 2012).

As can be seen above, core EFs such as inhibition, flexibility, working memory (in addition to higher order EF's such as planning, organization and monitoring) are important cognitive processes for reading comprehension (Cutting et al., 2009; Miyake et al., 2000; Sesma et al., 2009; van den Broek & Espin, 2012). With respect to the IMREC model, reading comprehension relies heavily on updating or working memory to both create and maintain a representation of the text's information by managing elements of the text itself, background information, and lower level reading processes such as decoding (Sesma et al., 2009; van den

Broek & Espin, 2012). Although not clearly specified in the IMREC model, the maintenance of necessary information in working memory requires the ability to inhibit irrelevant information (Butterfuss & Kendeou, 2018). Shifting/flexibility, or attention allocation, is crucial for balancing engagement of the various cognitive processes necessary for reading comprehension (van den Broek & Espin, 2012). In other words, the coherence and accuracy of the reader's comprehension depends on the reader's ability to balance limited working memory resources with accurate integration of textual information and background knowledge (van den Broek & Espin, 2012). In order to carry out these tasks, the reader relies on a set of automatic (e.g., neural activation, working memory) and strategic processes (e.g., re-reading of text, searching of background knowledge; van den Broek & Espin, 2012). The processes that are specifically engaged depend on an individual's capabilities as well as their 'standard of coherence' (i.e., goal) of reading (van den Broek & Espin, 2012). Finally, EF's such as inhibition, working memory, and flexibility play a large role in the efficiency of processing, the ability to automatize more complex functions, and the ability to maintain a reading goal in mind (van den Broek & Epstein, 2012).

Deficits in EFs in children with NDDs such as ADHD, ASD, and FASD are known to increase risk for academic underachievement (Biederman et al., 2004; Bull & Scerif, 2001; Fuglestad et al., 2015; St. John et al., 2018). Correspondingly, strong EF abilities predict better academic outcomes (Alloway et al., 2013; Kirk et al., 2015; Monette et al., 2011). The mechanism by which stronger EF is associated with better academic performance is unclear. It may be that improving EFs such as working memory, inhibition, or shifting could widen otherwise "bottlenecked" processing, thus allowing children to learn more efficiently (Alloway et al., 2013). Another possibility is that improving EFs increases goal-directed behavior, which

in turn increases academic engagement and attainment (Alloway et al., 2013). A final alternative possibility could be the influence of EFs on variables such as self-regulation, frustration, and social function, which can affect academic performance (Kirk et al., 2015; Monette et al., 2011). No matter the pathway, there is significant evidence for EFs' contributions to academic outcomes, including reading (Monette et al., 2011; Sesma et al., 2009). As a result of the significant role of EF in reading comprehension (van den Broek & Espin, 2012), children with neurodevelopmental disorders such as ASD that impact EFs are at increased risk for reading difficulties (Brown et al., 2013; Mayes & Calhoun, 2007; Ricketts, 2011).

### **Reading Comprehension Deficits in ASD**

Individuals with ASD experience comorbid learning disabilities (LD) at a rate higher than that of the typically developing population, with studies estimating that 29.4% - 75% of those with ASD also have an LD (Mayes & Calhoun, 2007; O'Brien & Pearson, 2004). There's a great deal of heterogeneity in academic performance in individuals with ASD, both across individuals and academic domains. However, reading and writing in general tend to be more typically affected than math skills (Brown et al., 2013; Mayes & Calhoun, 2007).

Reading comprehension is often impaired in ASD, affecting 38% - 73% of those with ASD (Brown et al., 2013; Davidson et al., 2018; Knight et al., 2019; McIntyre et al., 2017). However, reading profiles vary widely across the ASD population and the cause for reading comprehension difficulties is unclear (Brown et al., 2013). Research is limited in this area, but research to date suggests that problems in semantic abilities (Brown et al., 2013; Davidson et al., 2018), social deficits (McIntyre et al., 2017), and oral language (Ricketts et al., 2013) may contribute to reading comprehension problems while lower level reading abilities such as word decoding tend to remain intact (Knight et al., 2019).

Semantic abilities relate to the meaning of language and contribute to reading by facilitating understanding of words in context, as a sort of link between decoding and comprehension (Perfetti et al., 2005). Accordingly, better vocabulary predicts better reading comprehension (Brown et al., 2013; Davidson et al., 2018). Better oral language skills, including syntactic knowledge, also predict better reading comprehension among those with ASD, as this closely relates to constructing meaning of the passage from words read (Davidson et al., 2018; McIntyre et al., 2017; Ricketts et al., 2013). In these ways, core language skills contribute to reading comprehension.

Reading comprehension in ASD is especially impaired when the required background knowledge is of a social nature, likely due to the social and communicative nature of many symptoms of the disorder (Brown et al., 2013; McIntyre et al., 2017; Ricketts et al., 2013). As in social situations, comprehension of a socially-based text requires the ability to identify presented social information, to understand the context that information creates, and to apply that context to their own interpretations of the situation (Brown et al., 2013). In this way, social-communicative difficulties can also impact reading comprehension. However, it may also be the case that a lack of oral language and semantic abilities underlie both social deficits and reading comprehension deficits in ASD (Ricketts et al., 2013).

Interestingly, individuals with ASD exhibit decoding skills at a similar level as their typically developing peers, although there is more variability within individuals with ASD (Brown et al., 2013; Knight et al., 2019; Ricketts et al., 2013). The presence of reading comprehension difficulties in the context of intact early phonological processing skills is not a pattern that is typical outside of the ASD population (Brown et al., 2013; Knight et al., 2019;

McIntyre et al., 2017), suggesting that the cognitive contributors to reading comprehension problems may be unique in the ASD population.

Overall, it is likely that while some reading comprehension deficits in ASD stem from deficits in semantic abilities, oral language, and social deficits, it is also likely that the EF deficits commonly seen in ASD are a cause of reading comprehension problems (Brown et al., 2013; Davidson et al., 2018). For example, EFs such as inhibition, working memory and shifting are implicated in most aspects of reading comprehension and underlie much of the “integration” that is central to reading comprehension (Ricketts, 2011; Sesma et al., 2009; van den Broek & Espin, 2012) and tend to be impaired in in ASD (Fein, 2011; Pennington & Ozonoff, 1996).

### **The Current Study**

The aims of the current review were to investigate underlying cognitive components associated with reading comprehension difficulties in individuals with ASD, as informed by the IMREC model of reading comprehension. The IMREC model was selected as it is a cognitively informed model that has been used in reading comprehension research (Kendeou et al., 2014; Kraal et al., 2019; Witmer et al., 2014). Further, this model emphasizes the importance of EFs in reading comprehension which are cognitive processes that have been consistently to be deficient in children with ASD. IMREC does not clearly specify an exhaustive listing of the cognitive processes that contribute to reading comprehension, and as a result this study did not investigate all possible contributors to reading comprehension. Based on a review of the included studies, I intend to draw conclusions on the current state of the literature with respect to 1) the cognitive variables that have been shown to relate to reading comprehension in ASD, 2) the contribution of EF abilities to reading comprehension in ASD, and 3) the utility of the IMREC model for research into cognitive variables that contribute to reading comprehension problems in ASD.

## Methods

### Preregistration

This protocol is pre-registered in the Open Science Framework at <https://osf.io/3gkcx> .

### Study Eligibility Criteria

Study inclusion criteria were as follows: 1) the study included participants diagnosed with an Autism Spectrum Disorder (ASD), using DSM-III-R, DSM-IV/TR, DSM-5, or ICD-10 criteria; 2) the study's focus was on reading; 3) the participants completed at least one cognitive and one reading task; 4) the study directly associated cognitive variables with reading scores in the ASD population using quantitative methods.

With respect to the ASD inclusion criteria for reviewed studies, studies presented a range of ASD diagnoses including Autistic Disorder (AD) under DSM-III-R or DSM-IV-TR or ICD-10, Asperger syndrome (AS), Pervasive Developmental Disorder, Not Otherwise Specified (PDD or PDD-NOS) under DSM-IV-TR, or Autism Spectrum Disorder under DSM-5. No studies were excluded based on intellectual (IQ) level of participants. For a study to be included, participants' ASD diagnoses must have been confirmed by the study authors via health records, community referrals, parent report, or through administration of psychometrically standardized measures. There was no single diagnostic route required for inclusion because the approach to diagnosis varied between studies and across time, though participants must have met criteria for diagnosis of ASD, AS, AD, or PDD-NOS as defined by the appropriate diagnostic manual via one of the above diagnostic methods.

To meet the criteria of a focus on reading, the study must have measured some aspect of reading. Though the end product of the IMREC model is reading comprehension, word reading was also included since it is included in the IMREC model as an upstream component of reading

comprehension. As a result, the impact of cognitive processes on reading comprehension may occur indirectly through word reading ability.

In order to meet the inclusion criteria for an association between cognitive processes and reading, a study must have measured at least one cognitive variable and at least one reading variable. Without measuring at least one of each, it would have been impossible for a study to provide evidence on the potential relationship between underlying cognitive factors and reading.

Finally, the study must have directly associated a cognitive variable with a reading variable within the ASD population. Many studies measured cognitive and reading variables in individuals with ASD but only conducted between-group comparisons (usually between an ASD group and typically developing (TD) or other clinically-defined group) without doing a within-group comparison in the ASD sample. Because the between-group comparison does not specifically assess the relationship between the cognitive process and reading ability in the ASD population, those studies were not included.

Exclusion criteria were as follows: 1) studies without a clearly diagnosed ASD sample, as specified by the methods above; 2) studies that did not quantitatively assess reading outcomes; 3) studies that did not quantitatively assess at least one cognitive variable; 4) studies that did not directly associate a cognitive variable with reading outcomes; and 5) studies that did not assess the association between a cognitive variable and reading outcomes within an ASD sample. With respect to the first exclusion criteria, studies that collapsed ASD participants into a larger “neurodevelopmental disorders” group for all analyses or studies that presented samples with subclinical autistic symptomology but no formal diagnosis of ASD were not included. Intervention studies, neuroimaging studies, and eye-tracking studies were also not included as these were deemed to not be of direct relevance to the objectives of this review.

## Search Strategy

The search was conducted on July 24, 2020. The online databases APA PsycInfo, MEDLINE with Full-Text, and ERIC were searched for peer-reviewed journal articles and dissertations published within the last 20 years (2000-2020). Articles must have been conducted in or translated into English, though the original studies did not have to be conducted in English. Search and index terms referencing reading, cognitive abilities, and ASD were used in order to find articles that met each of the inclusion criteria described above. Index terms were specifically selected per database from the databases' thesauri and subject headings. Search terms must have been found in either the title or the abstract while the index terms are designated "labels" on the article by the authors or publishers. The search in APA PsycInfo is listed here as an example:

[TI (autism OR ASD OR "autism spectrum disorder\*" OR "autistic disorder\*" OR Asperger\* OR "pervasive developmental disorder\*" or PDD) OR AB (autism OR ASD OR "autism spectrum disorder\*" OR "autistic disorder\*" OR Asperger\* OR "pervasive developmental disorder\*" or PDD) OR DE "autism spectrum disorders" ] AND [ TI (reading OR "reading comprehension" OR "reading disabilit\*" OR "reading disorder\*" OR literacy OR dyslexia OR "language based learning disorder\*" OR "language based learning disabilit\*" OR "phonological processing" OR "phonemic awareness") OR AB (reading OR "reading comprehension" OR "reading disabilit\*" OR "reading disorder\*" OR literacy OR dyslexia OR "language based learning disorder\*" OR "language based learning disabilit\*" OR "phonological processing" OR "phonemic awareness") OR DE ( "reading" OR "reading disabilities" OR "reading comprehension" OR "phonological awareness") ] AND [ TI (cogniti\* OR "executive function\*" OR

memory OR attention OR “set shifting” OR processing OR inferen\*) OR AB  
 (cogniti\* OR “executive function\*” OR memory OR attention OR “set shifting”  
 OR processing OR inferen\*) OR DE (“cognitive ability” OR “cognitive  
 processes”)]

Title and abstract screening was conducted by two evaluators with a third acting as tie-breaker for any disagreement on article inclusion. Articles that passed an initial screen by title and abstract were then fully read by the two evaluators and the tie-breaker to assess their eligibility. Additionally, I manually searched through reference lists of all studies included in the data extraction stage in order to find relevant articles that may have been missed and then incorporated these into the studies to be reviewed.

### **Data Extraction**

Data were extracted independently from selected studies and coded for the following variables: 1) sample characteristics and study inclusion criteria (e.g., diagnosis, age range, study location); 2) reading outcomes assessed (e.g., word reading, reading comprehension); 3) cognitive variables assessed (e.g., working memory, shifting, language, inference); 4) study design (e.g., cross-section, longitudinal, prospective cohort); and 5) quality of methodology. See Appendix A for full extraction criteria.

### ***Sample Characteristics***

Data were collected on sample characteristics such as sample size, location of study, age of participants, diagnoses given, diagnostic criteria used, and comorbid diagnoses. Autism diagnoses included ASD, AD, AS, and PDD-NOS. Because of the time frame of the studies reviewed (2000 to July 2020), diagnoses were accepted if they were made under DSM-III-R,

DSM-IV, DSM-IV-TR, DSM-5, or ICD-10 criteria. Data were also collected on the tools used to assign or confirm autism diagnoses, such as the ADOS, ADI-R, or full clinical assessment.

### ***Reading Variables Assessed***

The main aspects of reading investigated in each study were extracted, including basic reading skills (e.g., word reading) as well as more complex reading skills (e.g., reading comprehension). Though reading comprehension was the main reading outcome of interest, I extracted data on more basic reading skills since these are included in the IMREC model and cognitive variables may impact reading comprehension indirectly through these lower level reading skills (van den Broek & Espin, 2012). The tools used to measure these aspects of reading were also recorded, such as standardized psychometric tests or experimental measures.

### ***Cognitive Variables Assessed***

Data on the cognitive variables assessed within each study were collected. While EFs were the main variable of interest, I extracted the main cognitive variables included in the IMREC model as operationally defined above, although this was not an exhaustive listing of variables that could potentially be considered components of IMREC. The variables extracted included memory, inference, vocabulary, basic language and foundational reading skills (e.g., phonemic awareness, morphology) in addition to EFs such as working memory and attention. I further extracted any other cognitive variables or characteristics reported in the studies that were not specified in IMREC (e.g., nonverbal intelligence, adaptive behavior, etc.). Similarly to the data extracted for the reading variables, the tools, psychometric measures, or experimental tasks used to measure cognitive processes were also recorded.

### ***Study Design***

Details on study design were also recorded. This included the study type (i.e., cross-sectional or longitudinal), study objectives and stated hypotheses. Statistical analyses used to relate the cognitive and reading variables, such as correlations, ANOVAs/ANCOVAs, or regression models were also recorded.

### ***Study Quality***

The quality of each included study was assessed using the Agency for Healthcare Research and Quality (AHRQ) Methodology Checklist for Cross-Sectional Studies (Zeng et al., 2015; see Appendix B). This is an eleven-item questionnaire intended to guide the evaluation of each study's described methods. Evaluators can note whether the study does, does not, or is unclear about whether the checklist's criteria are met. Not all questions apply to all study designs, (e.g., a question about blinding to subjective variables when no subjective variables were measured) and studies are not penalized for questions that inherently did not apply to them. Since studies had varying numbers of applicable questions, I created a reversed quality score based on the number of unmet or unclear criteria rather than awarding points for criteria met. Thus, the higher a study's score, the lower its quality as determined by the checklist (see Appendix B). Other studies that used this checklist designated a score of eight to eleven satisfied criteria as high quality, four to seven as moderate quality, and zero to three as low quality (Guan et al., 2015; Silva et al., 2018; Xie et al., 2020), so I set a limit of three missed criteria using my reversed cut-off score. However, an unmet criterion could not cast doubt on the participants included in the analysis, such as inclusion criteria, data completeness<sup>1</sup>, or reasons for exclusions. Thus, studies that held more than three unmet criteria or were missing this "critical" information were deemed to be of insufficient quality.

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<sup>1</sup> Data completeness refers to studies that may have indicated sample size in their methods but did not indicate any data loss or sample size within the results section.

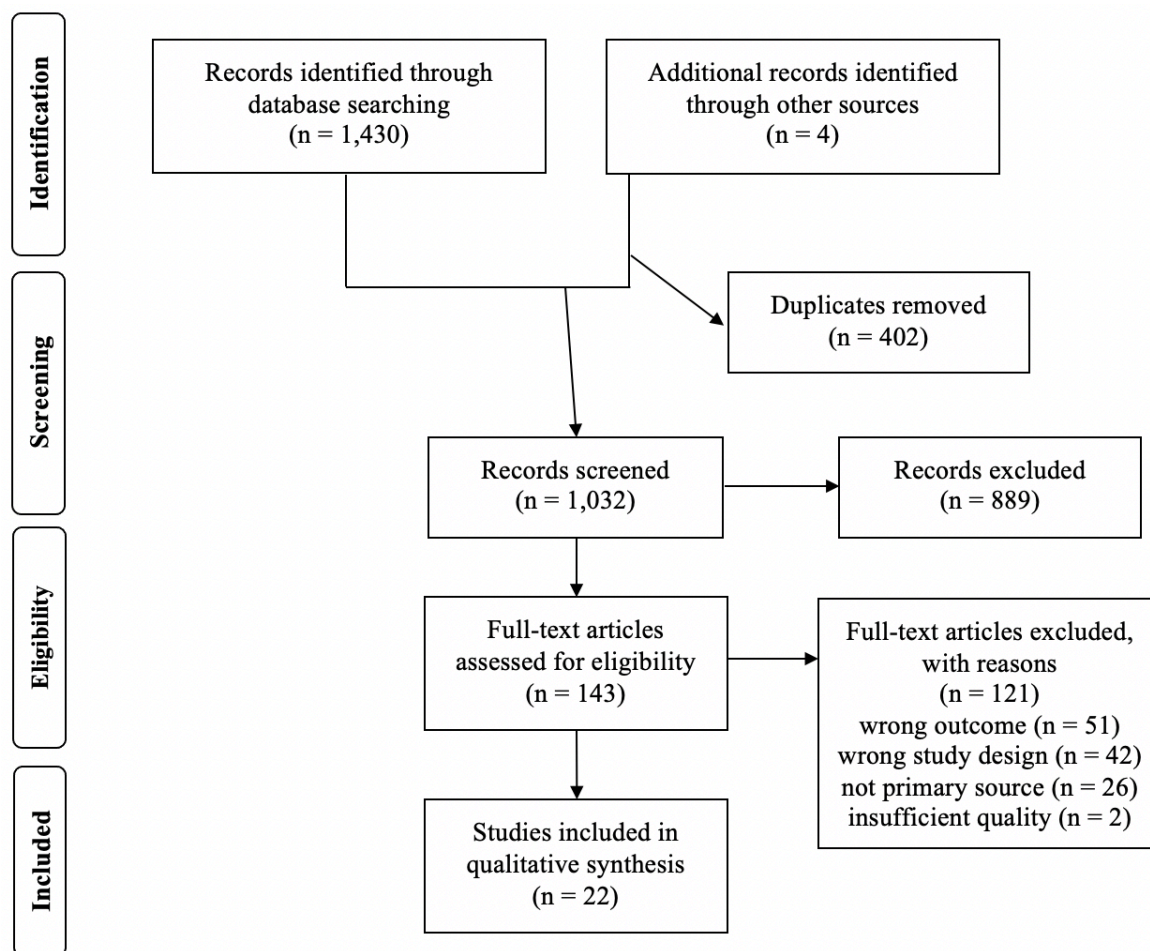
Two studies were excluded on the basis of insufficient quality. One of these studies did not report the completeness of data collection and so it was impossible to tell if any participants had been excluded or how these exclusions may have been handled in the analyses. This study also did not report clear inclusion or exclusion criteria so the sample was unclearly defined. The other study did report data completeness but did not explain why exclusions occurred or how they were handled in the analyses, so it is unclear whether these exclusions were appropriately made or handled. Additionally, neither of these studies reported prevention of confounding, quality assurance methods, nor the time period in which data was collected. The studies held quality scores of 7 and 5, thus putting them over the cut-off score of 3 or fewer points and into the category of insufficient quality.

## Results

The initial search identified 1,430 articles. Article titles and abstracts were first reviewed and studies that were deemed relevant were moved on to full text screening. There were 139 articles assessed at the full-text level with 18 of those studies included in this review. The reference lists of the 18 articles that met inclusion criteria were reviewed for additional articles, resulting in 4 more articles for a total of 22 included studies. Following PRISMA guidelines, a summary of the number of studies at each screening step is included in Figure 2 (Moher et al., 2009).

**Figure 2**

*PRISMA Flowchart for Articles Through the Search and Screening Process*



## Study and Sample Characteristics

Sample characteristics and quality scores for included studies are given below in Table 1.

**Table 1**

*Summary of Studies' Sample Characteristics*

Authors	N (male)	Ages	Location	Diagnoses	Diagnostic criteria/approach	Quality of methodology
Davidson, 2016	21 (18)	8-14yr	USA	ASD	Existing diagnosis confirmed by CARS-2	2
Westerveld et al., 2018	41 (35)	49-70mo T1, 66-81mo T2	Australia	ASD	Existing diagnosis confirmed by ADOS or SCQ	2
Nation et al., 2006	41 (36)	6-15yr	UK	AD (15), AD with Fragile X (1), 13 PDD-NOS, 12 AS	Diagnosis by clinician following ICD-10	3
McIntyre et al., 2017	81 (66)	8-16yr	USA	ASD/"HFASD", 67% with clinically elevated ADHD symptoms	Existing diagnosis confirmed by ADOS-2, ASSQ, SCQ, & SRS	1
St. John et al., 2018	32 (27)	109-127mo	USA	ASD	Assessment in study using ADI-R & ADOS-G and following DSM IV criteria	3
Nash & Arciuli, 2016	29 (24)	5-11yr	Australia	AD (25), AS (2), PDD-NOS (2) 5 comorbid ID	Existing diagnosis under DSM IV criteria	3
Chen et al., 2019	114 (all)	7-12yr	USA	ASD	Existing diagnosis confirmed using ADI-R & ADOS	3
Estes et al., 2011	30 (25)	9yr	USA	ASD	Assessment in study using ADI-R and ADOS-G under DSM IV criteria	3
May et al., 2015	40 (20)	7-12yr	Australia	AD, Asperger's (proportions not reported)	Existing diagnosis under DSM IV-TR confirmed by SRS	3

Mayes & Calhoun, 2008	54 (48)	6-14yr	USA	AD (54)	Existing diagnosis confirmed by CAYC, PBS, interviews and observation	3
Weissinger, 2013	10 (8)	9-14yr	USA	ASD	Existing diagnosis	3
Asberg et al., 2008	37 (33)	7-14yr	Sweden	ASD, AS (proportions N.R.)	Diagnosis by external child psychiatrist following DSM-III-R (ASD) or Gillberg & Gillberg Criteria (AS)	2
May et al., 2013	64 (32)	7-12yr	Australia	AD (16 male, 7 female), AS (16 male, 25 female)	Existing diagnosis reviewed following DSM IV-TR	3
Davidson & Weismer, 2014	94 (82)	2.5yr T1, 5.5yr T2	USA	ASD (89), PDD-NOS (5)	ADI-R at beginning and end of longitudinal study	2
Davidson et al., 2018	19 (15)	8-14yr	USA	ASD	CARS-2	2
McIntyre et al., 2018	70 (66 in original 81, unclear after exclusions)	9-17yr	USA	“HFASD”; 28% qualify for ADHD by parent report	Existing diagnosis confirmed by ADOS-2	2
Tong et al., 2020	42 (38)	7-9yr	Hong Kong	AD (14), AS (11), PDD-NOS (17)	Existing diagnosis following DSM IV criteria	3
Miller et al., 2017	26 (22)	8-10yr	USA	ASD, AD, PDD-NOS (varies over time points)	Comprehensive evaluation using ADOS, CARS, MSEL	2
Inoue et al., 2014	35 (24)	5-12yr	Japan	AS (9), “HFAD” (7), PDD-NOS (19)	Diagnosis by child psychiatrist following DSM IV-TR criteria	2
White et al., 2006	22 (20)	8-12yr	UK	AD, ASD, AS (proportions N.R.)	Existing diagnosis	2
Cronin, 2014	13 (11)	6-14yr	USA	“HFAD”	Existing diagnosis by psychologist	3
Gabig, 2010	14 (12)	5-7yr	USA	ASD	Existing diagnosis by clinician with ADI-R or ADOS under DSM IV criteria	2

*AS: Asperger's syndrome; AD: autistic disorder; PDD-NOS: pervasive developmental disorder not otherwise specified, ASD: autism spectrum disorder; HFASD/HFAD: "high-functioning" ASD/AD*  
*ADOS: Autism Diagnostic Observation Schedule; ADI-R: Autism Diagnostic Interview, Revised; CYAC: Checklist for Autism in Young Children; PBS: Pediatric Behavior Scale; CARS-2: Child Autism Rating Scale, 2<sup>nd</sup> edition; SRS: Social Responsiveness Scale; SCQ: Social Communication Questionnaire; ASSQ: Autism Spectrum Screening Questionnaire, MSEL: Mullen Scales of Early Learning*

Summed across all the studies, there were 929 participants and 767 of those participants were males (82.56%). The ages of participants ranged from 4 to 17 years.

All participants were diagnosed with an autism spectrum disorder, with 42.6% ( $n = 396$ ) diagnosed with ASD, 18.4% ( $n = 171$ ) with "high-functioning" ASD or AD, 14.2% ( $n = 132$ ) with AD (and unspecified level of function), 8.1% ( $n = 75$ ) with AS, 6% ( $n = 56$ ) with PDD-NOS, and 10.7% ( $n = 99$ ) not specified beyond an umbrella ASD diagnosis. The definition of "high-functioning" ASD varied between studies but was always determined by an IQ cut-off of either  $\geq 70$  or  $\geq 75$ .

In order to make these diagnoses, 40.1% ( $n = 9$ ) of the studies confirmed an existing diagnosis using either a questionnaire, diagnostic tool, or clinical observation. 22.7% ( $n = 5$ ) relied on an existing diagnosis alone and 22.7% ( $n = 5$ ) relied on their own assessment of the child within-study to give a diagnosis. In 13.6% ( $n = 3$ ) of studies, diagnoses were obtained from external clinicians. Only 45.5% ( $n = 10$ ) of studies reported the diagnostic criteria used in the study. Of those 10 studies, 50% used DSM-IV, 30% used DSM-IV-TR, and 10% each used DSM-III-R or ICD-10.

Two studies reported participants with an ADHD comorbidity (87%,  $n = 54$  and 28%,  $n = 20$ ), one study reported a single participant with Fragile X syndrome, and one study reported five participants with comorbid intellectual disability (ID). Eighteen of the included studies (81.8%) did not report on diagnostic comorbidities.

## Study Quality

Twenty-two studies passed the quality screening with quality scores ranging from 1 to 3. The majority of studies did not report on the time period in which data were collected ( $n = 21$ ) or specific measures undertaken to ensure quality data ( $n = 20$ ).

## Study Findings

The results extracted from each study are summarized below in Table 2. For each study, the cognitive processes measured, the reading abilities measured, and the significant relationships between these variables are reported including p-values and effect sizes when reported in the study.

**Table 2**

### *Study Findings*

Authors	Study Design	Cognitive contributors & measures used	Reading abilities & measures used	Statistical Test Used	Results	p-value and effect size
Davidson, 2016	Cross sectional	WM (n-back, Corsi blocks), Inh (go/no-go, flanker task), OL – Vo (PPVT-4), Mo (TOLD), CC (TVPS-3 Figure Ground, Embedded Figures task)	RC (WRMT-III Passage Comp)	Correlations, Linear regression	Working memory, oral language* (defined as vocabulary and morphology), word reading, and central coherence are significantly correlated with reading comprehension. Only oral language and word reading predict reading comprehension.	$p \leq .001$ * $p < .05$  $p < .001$ , $R^2 = 0.76$
Westerveld et al., 2018	Prospective cohort	ASD, PA (PALS-PreK), RAN (WRMT-	RC (YARC) WR (Castles	Correlations, regression	Phonemic awareness, RAN,	$p < .01$ $r = .41-$ .71

		R), Vo, OL (CELF), WM (NEPSY-II Digit Span), NV (MSEL)	and Coltheart Test 2)		vocabulary, and nonverbal cognition, and working memory are significantly related to word reading and reading comprehension, and word reading* is also correlated with reading comprehension. Nonverbal cognition predicts word reading and both RAN and vocabulary predict reading comprehension.	*p < .001 r = .9  p < .001 r <sup>2</sup> = .53  p < .001 r <sup>2</sup> = .81
Nation et al., 2006	Cross sectional	NV & Ve (WISC-III), Vo (BPVS-II)	WR (British Ability Scales II, NARA-II), RC (NARA-II)	Correlations	Vocabulary, verbal knowledge, and word reading* are correlated with reading comprehension.	p < .01, r = .67-.72  *p < .001, r = .48
McIntyre et al., 2017	Cross sectional	Vo (WASI-II), Inf (TAPS-3), VeM (WRAML2), CC (Happe sentence completion), OL (CELF-4), Mo (experimental measure)	RC (GORT-5 & QRI-5), WR (ToWRE)	Confirmatory factor analysis, correlations	Oral language, vocabulary, verbal memory, morphology, and inference are correlated with word reading and reading comprehension. Word reading is also correlated with reading comprehension. Inference and verbal memory	p < .001 r = .54-.95  p < .05, r = .65

					predict reading comprehension.	
St. John et al., 2018	Prospective cohort	IQ & NV (DAS), WM, Inh & Sh (A-not-B Invisible Displacement task, Spatial Reversal)	WR (DAS Achievement)	Regression	Executive functions at ages 6 and 9yo do not predict word reading.	p = .4-.42 r = .02
Nash & Arciuli, 2016	Cross sectional	PA (CTOPP), OL (CELF-4), Vo (PPVT-4), NV (ToNI-3), Py (Mispronunciation & Compound Noun tasks)	WR (WRMT-R Word Identification & Word Attack)	Correlations	Oral language, phonemic awareness, vocabulary, and prosody are correlated with word reading.	p < .001 r = .74-.81
Chen et al., 2019	Cross sectional	FSIQ, Ve, NV (WASI), ASD (ADI-R, ADOS), soc/beh (CBC), WM (block & VeWM digit recalls)	WR & RC (WIAT-II)	ANOVA, multiple regression	Verbal working memory and IQ, are correlated with word reading and reading comprehension. Word reading is also correlated with reading comprehension. IQ and verbal working memory predict word reading, but only IQ predicts reading comprehension.	*p < .05, p < .001, RC: r = .33*-.65  p < .001, WR: r = .47-.5  p < .001, β = .23 <sup>+</sup>
Estes et al., 2011	Longitudinal	Soc (SRS), Beh (ABC), IQ (DAS)	WR (DAS Achievement)	Correlations, regression	IQ is related to word reading. Social skills predict later word reading.	P = .02, r N.R.  p = .04, r <sup>2</sup> = .23
May et al., 2015	Longitudinal	IQ, Ve, & NV (WISC-IV), Sh & Sust. Attn (Wilding Attn Tasks), VeM (Auditory	WR (WIAT-II)	ANOVA, regression	Shifting attention, verbal intelligence*, nonverbal intelligence, and verbal memory* are	P < .01     *p < .001  r = .42-.74

		Processing Test spans)			correlated with but do not predict word reading.	
Mayes & Calhoun, 2008	Cross sectional	IQ, Ve, NV, PS, WM (WISC-IV)	WR & RC (WIAT-II)	ANOVA	IQ is significantly correlated with word reading and reading comprehension. IQ, working memory, and verbal intelligence predict reading comprehension while only IQ and working memory predict word reading.	For all indices: p N.R. r = .42-.68 WR: p < .0001, r = .63-.64 RC: p < .0001, r = .68-.7
Weissinger, 2013	Cross sectional	Vo (PPVT-4), VeWM (Sentence Span test), Pl (DKEFS Tower), ToM (Strange Stories)	WR (WMRT-R Word Identification & Word Attack, ToWRE Sight Word Efficiency), RC (SDRT-4 Comp.)	Correlations	Vocab*, verbal working memory, planning**, and theory of mind are correlated with reading comprehension.	*p ≤ .001 **p ≤ .01 p ≤ .05 r = .72-.95
Asberg et al., 2008	Cross sectional	FSIQ & Ve (WISC-III), VeM & Mem (verbal & object recall)	WR (wordchains), RC (OS-400 & S-50 test)	ANOVA	Word reading is correlated with reading comprehension, even after controlling for verbal ability.	P < .001, pr = .72
May et al., 2013	Cross sectional	IQ, Ve, & NV (WPPSI-III, WISC-IV), VeM (Auditory Processing Test), Sh & Sust attn (Wilding's Attention Tasks)	WR (WIAT-II)	ANCOVA, regression	IQ, verbal memory, and sustained attention are correlated with word reading. IQ predicts word reading,	P < .01 r = .34-.61 p < .001 B = .48+

					but nothing else does.	
Davidson & Weismer, 2014	Longitudinal	NV (MSEL), Soc (VABS-2), OL (PLS-4)	RC (TERA-3 Meaning)	Correlations, multiple regression	Nonverbal ability, social skills, and oral language are correlated with reading comprehension. Nonverbal cognition and oral language predict reading comprehension.	$p < .01$ , $r = .49-.87$  $p < .01$ , $\beta = .38-.4^+$
Davidson et al., 2018	Cross sectional	OL – Vo (PPVT-4) & Mo (TOLD-P4), WM (n-back)	WR & RC (WRMT-III Word Identification, Word Attack, & Passage Comp)	ANOVA	Vocabulary and working memory are correlated with both word reading and reading comprehension, and morphology and word reading are correlated with reading comprehension.	$p < .05$  $*p \leq .001$  $r = .47-.74$
McIntyre et al., 2018	Longitudinal	FSIQ, Ve, & NV (WASI-2), OL – Vo (WIAT-III) & VeM (WRAML-2), ToM (Strange Stories & Silent Films)	WR (ToWRE-2 Sight Word and Phonemic Decoding Efficiencies), RC (GORT-5)	ANOVA, ANCOVA	IQ, vocabulary, verbal memory, theory of mind, oral language, and word reading are correlated with reading comprehension, and all but word reading predict reading comprehension.	$p < .001$  $r = .48-.75$
Tong et al., 2020	Cross sectional	NV (WASI-II), WM (backward digit span), Vo (picture definition task),	WR (HKT-P II), RC (YARC)	MANOVA	Nonverbal intelligence*, vocabulary, theory of mind*, and	$p < .001$  $*p < .01$  $r = .48-.63$

		ToM (social referencing, emotion recognition, basic understanding of ToM tasks)			word reading are correlated with reading comprehension. Working memory is not.	
Miller et al., 2017	Prospective cohort	FSIQ, NV & Ve (MSEL, DAS-II), Com (VABS-II), ASD (ADOS-G, CARS)	WR & RC (WIAT-II)	Multiple regression	Communication, verbal intelligence, and ASD symptomology predict reading comprehension. Communication also predicts word reading.	$p < .01$ , $\beta = .44-.76$ $p < .01$ , $\beta = .73$
Inoue et al., 2014	Cross sectional	FSIQ, VeM, NV, Ve, Vo, PS (WISC-III, K-ABC)	RC & WR (K-ABC Reading: Decoding & Understanding)	Correlations	Verbal memory, nonverbal intelligence, verbal ability, and vocab are correlated with word reading and comprehension. Processing speed is correlated with word reading as well. Word reading is correlated with reading comprehension.	WR: $p < .05$ , $r = .34-.55$ RC: $p < .05$ , $r = .35-.85$
White et al., 2006	Cross sectional	PA (Phoneme Categorization), Visual Proc. (Motion & Form Coherence), Motor (MABC), NV (Raven's Matrices)	WR (WRAT-3)	ANOVA, regression	Only phonemic skills are correlated with word reading.	$p < .05$ , $r = .65-.67$
Cronin, 2014	Cross sectional	Vo (PPVT-4), OL (CELF-4,	RC (WRMT: Word & Passage	Correlations	Oral language and word reading are	* $p \leq .05$ , $r = .55$

		OWLS:LC), PA (CELF-4)	Understanding) & WR (ToWRE Phonemic Decoding Efficiency & WRMT Word Attack)		strongly correlated with reading comprehension. Oral language is strongly correlated with word reading.*	$p \leq .001$ $r = .72-.94$
Smith Gabig, 2010	Cross sectional	Vo (PPVT-4), PA (CTOPP), NV (DAS)	WR (WRMT- R Word Attack & Word Identification)	Correlations	Phonemic awareness is not correlated with word reading.	$r = .02-.18$

*Ve: verbal intelligence; NV: nonverbal intelligence; PS: processing speed; WM: working memory; Vo: vocabulary; OL: oral language; Com: Communication skills; ToM: theory of mind; VeM: verbal memory; VeWM: verbal working memory; Inh: inhibition, Inf: inference; Sh: shifting; Sust: sustained attention; PA: phonemic awareness; Soc: social skills; RAN: rapid automatized naming; Py: prosody; Mo: morphology; CC: central coherence MSEL: Mullen Scales of Early Learning; BPVS-II: British Picture Vocabulary Scales, 2<sup>nd</sup> ed.; WISC: Weschler Intelligence Scale for Children; ToNI-3: Test of Nonverbal Intelligence; CELF-4: Clinical Evaluation of Language Fundamentals; CTOPP: Comprehensive Test of Phonological Processing; CBC: Child Behavior Checklist; DAS: Differential Ability Scales; ABC: Aberrant Behavior Checklist; SRS: Social Skills Rating System; MABC: Movement Assessment Battery for Children; OWLS:LC: Oral and Written Language Skills; PALS-PreK: Phonological Awareness Literacy Screening, PreK; WASI: Weschler Abbreviated Scales of Intelligence; NEPSY: Developmental NEUROPSYCHOLOGICAL Assessment; WPPSI: Weschler Preschool & Primary Scale of Intelligence; PLS-4: Preschool Language Scale; VABS: Vineland Adaptive Behavior Skills; KABC: Kaufman Assessment Battery for Children; PPVT: Peabody Picture Vocabulary Scales; TOLD-P4: Test of Language Development-Primary; TERA-3: Test of Early Reading Abilities; WRMT-R: Woodcock Reading Mastery Test, Revised; GORT-5: Gray Oral Reading Test, 5<sup>th</sup> edn; QRI-5: Qualitative Reading Inventory, 5<sup>th</sup> edn; ToWRE: Test of Word Reading Efficiency; DAS: Differential Ability Scales; WIAT: Weschler Individual Achievement Test; SDRT: Stanford Diagnostic Reading Test; NARA-II: Neale Analysis of Reading Ability, 2<sup>nd</sup> edn; WRAT-3: Wide Range Achievement Test, 3<sup>rd</sup> edn.; HKT-P II: Hong Kong Test of Specific Learning Difficulties in Reading and Writing for Primary School; YARC: York Assessment of Reading for Comprehension*

<sup>†</sup>Regression coefficients marked + were either unstandardized or unlabeled as standardized or unstandardized.

Some studies only reported unstandardized beta coefficients for their regression analyses and because these values cannot clearly communicate effect size without information about the distribution of the variables and theoretical relationship between said variables, these values will not be carried further in analyses or interpretation in this review (Gelman & Hill, 2007).

The results summarized in Table 2 were then tabulated across all included studies. I calculated the percentage of studies that assessed each cognitive variable and reading measure extracted in order to identify the cognitive factors and reading variables that are and are not commonly measured in the ASD-reading literature. I subsequently calculated the percentage of studies that found significant relationships between each cognitive variable and reading measure

(e.g., either word level reading or reading comprehension). The frequency of relationships between cognitive variables and reading measures at the word reading and comprehension levels are summarized in Table 3.

**Table 3**

*Proportion of studies reporting significant relationships between cognitive variables, word reading, and reading comprehension*

	Total #	Total % (out of 22)	RC correlations		WR correlations		RC predictors		WR predictors	
			#	%	#	%	#	%	#	%
IQ	10	45.45%	3	30.00%	4	40.00%	3	30.00%	4	40.00%
Nonverbal	15	68.18%	4	26.67%	3	20.00%	1	6.67%	1	6.67%
Verbal	9	40.91%	2	22.22%	2	22.22%	2	22.22%		
Proc. Speed	3	13.64%	0	0.00%	1	33.33%	0	0.00%	0	0.00%
Memory	7	31.82%	5	71.4%	4	57.14%	2	28.57%		
<i>VeM</i>	6	27.27%	4	66.67%	4	66.67%	2	33.33%		
EF	11	50.00%	6	54.55%	5	45.45%	1	9.09%	2	18.18%
<b>WM</b>	9	40.91%	6	66.67%	3	33.33%	1	11.11%	2	22.22%
<i>VeWM</i>	4	18.18%	3	75.00%	2	50.00%			1	25.00%
<b>Attn alloc.</b>	4	18.18%			2	50.00%				
<i>Shifting</i>	3	13.64%			1	33.33%				
<i>Sust. attn</i>	2	9.09%			1	50.00%				
<i>Inhib</i>	2	9.09%								
Planning	1	4.55%	1	100.00%						
<b>Inference</b>	4	18.18%	3	75.00%	1	25.00%	2	50.00%		
<i>ToM</i>	3	13.64%	2	66.67%			1	33.33%		
ASD	5	22.73%	1	20.00%			1	20.00%		
Cent. Coh.	2	9.09%	1	50.00%						
Soc	3	13.64%	1	33.33%	1	33.33%			1	33.33%

Beh	2	9.09%						
Comm	1	4.55%					1	100.00%
<b>Basic lang.</b>	8	36.36%	6	75.00%	5	62.50%	3	37.50%
Oral lang.	5	22.73%	4	100.00%	3	60.00%	2	40.00%
Phon. awar.	6	27.27%	1	16.67%	3	50.00%		
Morph.	3	13.64%	3	100.00%			1	33.33%
Prosody	1	4.55%			1	100.00%		
*WR	20	90.91%	10	50.00%			1	5.00%
RAN	3	13.64%	1	33.33%			1	33.33%
<b>Vocab</b>	12	54.55%	9	75.00%	4	33.33%	3	25.00%

*EF: executive function, WM: working memory, VeWM: verbal working memory, Sh: shifting, Inh: inhibition, Vo: vocabulary, Morph: morphology, VeM: verbal memory, Phon Awar: phonemic awareness, WR: word reading, NV: nonverbal intelligence, Ve: verbal intelligence, PS: processing speed, Cent Coh: central coherence, RAN: rapid automatized naming, Soc: social skills, Beh: behavior, Comm: oral communication, Pl: Planning*

### **Reading Variables Assessed**

The articles reported on a range of different reading abilities. For the purpose of these analyses, reading outcomes are summarized at the word reading and reading comprehension levels. Though the structure of the IMREC model includes word reading only as a factor underlying reading comprehension, word reading is a separate reading ability as well and will be analyzed as such. The word reading level was measured in 90.9% of studies ( $n = 20$ ) and consisted of measures of word reading/decoding ( $n = 19$ ), non-word reading ( $n = 3$ ), and word recognition ( $n = 2$ ). Reading comprehension was a measured outcome in 68.2% studies ( $n = 15$ ) and included comprehension at the level of sentences and passages.

### **Cognitive Variables and Their Associations with Reading in ASD**

**Intellectual function.** Full-scale IQ was measured in 45.5% ( $n = 10$ ) of studies. Thirty percent of these studies found IQ to both significantly correlate with ( $r = 0.65-0.68$ ) and predict

reading comprehension (44%-52% of the variance). Forty percent of the studies found intellectual ability to significantly correlate with ( $r = 0.50-0.64$ ) and predict ( $\beta = 0.48$ , 52% of variance) word reading. Nonverbal intelligence was specifically assessed in 68.2% ( $n = 15$ ) of included studies. Of the studies that measured nonverbal intelligence, 26.7% found a significant correlation with reading comprehension ( $r = 0.41-0.70$ ) and 20% found a significant correlation with word reading ( $r = 0.45$ ). Nonverbal intelligence predicted word reading (18% of the variance) and reading comprehension (standardized  $\beta$  n.r.) in 6.7% of these studies. Verbal intelligence was measured in 40.9% ( $n = 9$ ) of included studies and was significantly correlated with word reading ( $r = 0.35-0.57$ ) and reading comprehension ( $r = 0.46-0.70$ ) in 22.2% of these studies. Verbal intelligence was also found to significantly predict reading comprehension in 22.2% of the studies in which it was measured (standardized  $\beta = 0.40-0.58$ ).

**Attention-related abilities and EFs.** Of the 22 articles included in the analysis, 50% ( $n = 11$ ) measured some aspect of EF. This included working memory (40.9%,  $n = 9$ ), shifting (13.6%,  $n = 3$ ), sustained attention (9.1%,  $n = 2$ ), inhibition (9.1%,  $n = 2$ ), and planning (4.6%,  $n = 1$ ). Executive functions were significantly correlated with word reading and reading comprehension in 45.5% and 54.6% of the studies that measured them, with correlations ranging from  $r = 0.34-0.63$  and  $r = 0.33-0.81$  respectively. Executive functions were shown to meaningfully predict word reading in 18.2% and reading comprehension in 9.1% of the studies, with standardized beta values of  $\beta = 0.80$  and  $\beta = 0.60$ .

Of the included studies, 40.9% ( $n = 9$ ) measured working memory. Of those studies that measured working memory, 66.7% found significant correlations with reading comprehension ranging from  $r = 0.45-0.70$  and 11.1% found working memory to be a significant predictor of reading comprehension (standardized  $\beta = 0.60$ ). Working memory was found to be a predictor in

22.2% of these studies (standardized  $\beta = 0.80$ ) and correlated with word reading in 33.3% of studies assessing it, with correlations ranging from  $r = 0.41-0.63$ . Of the included studies, 18.2% ( $n = 4$ ) measured verbal working memory specifically, with 75% of those studies reporting a correlation with reading comprehension ( $r = 0.33-0.70$ ) and 50% reporting verbal working memory as correlated with word reading ( $r = 0.47$ ). Additionally, 25% of studies measuring verbal working memory found it to predict word reading though no proportion of variance or standardized beta was reported.

Attention allocation was studied in 18.18% ( $n = 4$ ) of included studies and was significantly correlated with word reading in half of those studies ( $r = 0.34-0.42$ ). Shifting was measured in 13.6% ( $n = 3$ ) of the included studies and was correlated with word reading in 33.3% of those studies ( $r = 0.42$ ). Sustained attention and inhibition were each measured in 9.1% ( $n = 2$ ) of the included studies, with sustained attention correlating with word reading in one of those studies ( $r = 0.34$ ). Inhibition was not found to correlate with or predict either word reading or reading comprehension.

Planning was measured in only 1 of the included studies (4.6%) and was found to significantly correlate with reading comprehension ( $r = 0.81$ ).

Finally, information processing speed was measured in 13.6% ( $n = 3$ ) of studies and was significantly correlated with word reading in 33.3% of these studies ( $r = 0.34$ ); however, processing speed was not significantly correlated with reading comprehension. Further, processing speed did not significantly predict either word reading or reading comprehension scores.

**Inference.** Inference was measured in 18.2% ( $n = 4$ ) of included studies. It was found to correlate with reading comprehension in 75% of those studies ( $r = 0.43-0.95$ ) and with word

reading in 25% of those studies ( $r = 0.42$ ). Inference predicted reading comprehension in 50% of those studies that measured it (6% of the variance, standardized  $\beta = 0.65$ ). For the purposes of this review, I included theory of mind as an inferential skill given the closely related deductive nature of both abilities. Theory of mind specifically was measured in 13.6% ( $n = 3$ ) of studies and was correlated with reading comprehension in 66.7% of those studies ( $r = 0.43-0.72$ ) while predicting reading comprehension in 33.3% of those studies (6% of the variance,  $\beta = 0.65$ ).

**Memory.** Verbal and visual memory were measured in 31.8% ( $n = 7$ ) of the included studies and correlated with reading comprehension and word reading in 71.4% and 57.1% of those studies, respectively. Of the studies that measured memory, 28.6% found it to predict reading comprehension. Verbal memory specifically was measured in 27.3% ( $n = 6$ ) of studies, with 66.7% of those studies finding significant correlation with reading comprehension ranging from 0.41-0.59 and word reading ranging from 0.4-0.74. Verbal memory significantly predicted reading comprehension in 33.3% of these studies (16% of the variance, standardized  $\beta = 0.65$ ).

**Basic Language and Reading Skills.** For the purposes of this review, as informed by the IMREC model, basic language skills were defined as encompassing phonemic awareness, oral language, morphology, and prosody and were measured in 36.4% ( $n = 8$ ) of included studies. Basic language skills were significantly correlated with reading comprehension in 75% and word reading in 62.5% of studies in which they were measured, with correlations ranging from  $r = 0.49-0.94$  and  $r = 0.53-0.76$  respectively. Basic language skills significantly predicted reading comprehension in 42.9% of these studies (4% of the variance).

Phonemic awareness was measured in 27.3% ( $n = 6$ ) of studies, with 16.7% and 50% of those studies finding significant correlations with reading comprehension ( $r = 0.49-0.67$ ) and word reading ( $r = 0.53-0.74$ ), respectively. Oral language was measured in 22.7% ( $n = 5$ ) of the

studies, 80% of which found it to correlate significantly with reading comprehension ranging from 0.49-0.94 and 40% of which found oral language to meaningfully predict reading comprehension (standardized  $\beta$  n.r.). Oral language was also significantly correlated with word reading 60% of the time it was measured,  $r = 0.55-0.76$ . Of the studies that assessed morphology, 13.6% ( $n = 3$ ) found it to significantly correlate with reading comprehension ( $r = 0.52-0.92$ ) and 33.3% found morphology to significantly predict reading comprehension, accounting for 4% of the variance. Morphology was also significantly correlated with word reading in one-third of the studies measuring with a correlation of  $r = 0.76$ . Prosody was measured in 4.6% ( $n = 1$ ) of studies and was found only to correlate with word reading ( $r = 0.67$ ).

Rapid automatized naming (RAN) is a basic reading ability that was measured in 13.6% ( $n = 3$ ) of studies, with 33.3% finding RAN to correlate with and predict reading comprehension ( $r = 0.54$ , standardized  $\beta$  n.r.) and to correlate with word reading ( $r = 0.53$ ). Word reading was also included as a correlate or predictor of reading comprehension as a basic reading skill underlying comprehension, as specified by IMREC (van den Broek & Espin, 2012). Word reading was measured in 90.9% ( $n = 20$ ) of included studies and found to be significantly correlated with reading comprehension in 45% ( $n = 9$ ) of those studies while meaningfully predicting reading comprehension in 5%. The correlations ranged from  $r = 0.48-0.92$  and word reading predicted 82% of the variance in reading comprehension.

**Vocabulary.** Vocabulary was measured in 54.6% ( $n = 12$ ) of studies. Of the studies that assessed vocabulary, 33.3% ( $n = 4$ ) found vocabulary to be significantly correlated with word reading while 75% ( $n = 9$ ) found it to be significantly correlated with reading comprehension. The correlations ranged from  $r = 0.38-0.81$  for word reading and  $r = 0.46-0.95$  for reading

comprehension. Vocabulary significantly predicted reading comprehension in 25% ( $n = 3$ ) of the studies that measured it and accounted for 4-16% of the variance when reported.

**Other assessed variables.** Social skills were measured in 13.6% ( $n = 3$ ) of studies, with 33.3% of those studies finding a significant correlation with reading comprehension ( $r = 0.21-0.60$ ) and word reading ( $r = n.r.$ ). Of those studies, 33.3% found that social skills significantly predicted predict word reading, accounting for 23% of the variance in word reading ability. Behavior was assessed in 9.1% ( $n = 2$ ) of studies but was not found to relate with reading comprehension or word reading. Communication skills were measured in 4.6% ( $n = 1$ ) and were found to significantly predict reading comprehension (standardized  $\beta = 0.44$ ) and word reading (standardized  $\beta = 0.73$ ). Autism symptoms were measured in 22.7% ( $n = 5$ ) of studies, with 20% finding symptomology to correlate with or predict reading comprehension ( $r = 0.38$ , standardized  $\beta = 0.45$ ). Central coherence was measured in 9.1% ( $n = 2$ ) of studies, with half of those studies finding a significant correlation with reading comprehension ( $r = 0.82$ ).

### ***Summary of the Association between Cognition and Reading in ASD***

These results indicate that in ASD, factors such as basic language skills, vocabulary, word reading, inference, and verbal memory were most strongly correlated with reading comprehension with  $r = 0.90-0.95$  in the strongest cases. Basic language skills and vocabulary were most strongly correlated with word reading, with top correlations of  $r = 0.76-0.81$ .

The greatest predictor of reading comprehension was word reading at 82% of the variance, though verbal memory, inference, and working memory were also moderate predictors with standardized  $\beta = 0.60-0.65$ . The strongest predictors of word reading were communication skill and working memory, with standardized  $\beta = 0.73-0.80$ . Of note, the results summarized here do not include any unstandardized beta values given their limited interpretability without

contextual information on the distribution of and theoretical relationships between variables (Gelman & Hill, 2007). Many studies did not report  $r^2$  values and instead reported standardized beta coefficients, so interpretations of effect size of predictors must be interpreted with caution and are only interpreted in this way given the limited results available. This limitation is discussed further later on.

Executive functions overall ranged from weak to moderate correlates and moderate predictors of reading comprehension as indicated by standardized beta values. EFs weakly to moderately correlated with word reading but ranged from weak to strong predictors of word reading. Working memory was a weak to moderate correlate with reading comprehension and moderate predictor. Working memory was also a strong predictor of word reading but only a moderate correlate. Verbal working memory had a weak to moderate correlation with reading comprehension and a weak correlation with word reading. Verbal working memory was a weak predictor of word reading as well. Attention allocation showed a weak to moderate correlation with word reading but no relationship otherwise to reading. Planning was a strong correlate to reading comprehension.

A summary of these results is provided in Table 4.

**Table 4**

*Summary of the Significant Associations Between Cognitive Variables and Reading in ASD*

	Studies reporting ( <i>n</i> )	Relationship with reading comprehension	Average effect size	Relationship with word reading	Average effect size
Word reading	20	Weak to strong correlation, strong predictor	$r = 0.69$ $r^2 = 0.82$	- -	- -
Vocabulary	12	Weak to strong correlation, weak predictor	$r = 0.69$ $r^2 = 0.10$	Weak to strong correlation, moderate predictor	$r = 0.66$ -

Basic language skills	8	Weak to strong correlation, weak predictor	$r = 0.73$ $r^2 = 0.04, \beta = 0.38$	Moderate correlation -	$r = 0.68$ -
Inference	4	Weak to strong correlation, weak to moderate predictor	$r = 0.70$ $r^2 = 0.06, \beta = 0.65$	Weak correlation -	$r = 0.42$ -
Verbal memory	6	Weak to strong correlation, moderate predictor	$r = 0.66$ $r^2 = 0.16, \beta = 0.65$	Weak to moderate correlation	$r = 0.53$ -
IQ	10	Moderate correlation, moderate predictor	$r = 0.66$ $r^2 = 0.48$	Moderate correlation, moderate predictor	$r = 0.59$ $r^2 = 0.52$
Nonverbal IQ	15	Weak to moderate correlation, moderate predictor	$r = 0.53$ $\beta = 0.41$	Weak to moderate correlation, weak predictor	$r = 0.47$ $r^2 = 0.18$
Verbal IQ	9	Weak to moderate correlation, moderate predictor	$r = 0.63$ $\beta = 0.49$	Weak to moderate correlation	$r = 0.51$ -
WM	9	Weak to moderate correlation, moderate predictor	$r = 0.55$ $\beta = 0.60$	Moderate correlation, strong predictor	$r = 0.55$ $\beta = 0.80$
Verbal WM	4	Weak to strong correlation	$r = 0.52$ -	Weak correlation, weak predictor	$r = 0.47$ $\beta = 0.23$
Attention allocation	4	- -	- -	Weak correlation -	$r = 0.38$ -
Planning	1	Strong correlation -	$r = 0.81$ -	- -	- -
Social-commun. skills	4	Weak to moderate correlation, moderate predictor	$r = 0.41$ $\beta = 0.44$	Weak to moderate predictor	$r^2 = 0.23$ $\beta = 0.73$
Central coherence	2	Strong correlation -	$r = 0.82$ -	- -	- -

### Use of the IMREC Model for Assessing Reading in ASD

Of the included studies, no one study addressed all six of the cognitively-based IMREC components (attention allocation, inference, verbal working memory, vocabulary, basic language and reading skills, verbal memory). The majority of studies addressed at least one cognitive process (86.4%,  $n = 19$ ) with the most common number of contributors addressed being two (45.5%,  $n = 10$ ). A somewhat equal number of studies addressed zero (13.6%,  $n = 3$ ), one

(18.2%,  $n = 4$ ), and three components (13.6%,  $n = 3$ ) of the IMREC model, while only one study each addressed four or five of the cognitive components. In general, studies seem to home in on and investigate specific cognitive variables within the ASD population rather than looking at the cognitive contributors to reading ability more broadly.

The following components of the IMREC model were found to be studied in reading comprehension in ASD. Overall, executive functions were studied in about 50% of the studies. General working memory was studied in 40% of studies, with verbal working memory included in 20% of the studies. Attention allocation (including shifting, sustained attention, and inhibition) was studied in 25% of studies. Vocabulary was studied in about 50% of the studies while basic language skills were studied in about 33% of studies. Verbal memory and inference were only assessed in about 20% of the studies. Further, inference is a broad construct and even fewer studies deconstructed it to look at foundational cognitive processes underlying inference, such as Theory of Mind which was studied in only 13.6% of included articles. Finally, word reading was measured in 90% of studies.

Of course, studies may have used theoretical models other than the IMREC model to inform their design. The Simple View of Reading (Hoover & Gough, 1990) was used to inform 40.9% ( $n = 9$ ) of the included studies. Of those studies implementing the Simple View of Reading, 66.7% studied variables in addition to the model. Other theoretical models included the Triangle Model, which conceptualizes reading as the interaction between orthographic, semantic, and phonological processes (Seidenberg & McClelland, 1989) or the involvement of factors such as Theory of Mind, working memory, memory, social skills, and IQ. Conversely, 59.9% ( $n = 13$ ) of included studies did not specify following a theoretical model; rather, these studies chose variables based on past research into reading deficits.

## Discussion

The purpose of this systematic review was to summarize the state of the literature on cognitive processes that may be impacting reading comprehension in individuals with ASD. Reading comprehension is critical for academic success and an important contributor to quality of life, thus competence in this area is of utmost importance (Brown et al., 2013; Nation et al., 2006). It is estimated that up to 73% of children with ASD struggle with reading comprehension, putting them at risk for negative academic and life outcomes (Brown et al., 2013; Mayes & Calhoun, 2007), yet this is an understudied area. While aspects of reading (including reading comprehension) have been studied in individuals with ASD, the bulk of the existing literature has compared reading between typically developing children and those with ASD. Very few studies actually assess the underlying cognitive processes that support reading comprehension in ASD though this information is crucial for developing interventions and improving reading outcomes. The current review used the IMREC model of reading comprehension to help select specific cognitive variables to focus on within this systematic review. The Integrated Model of Reading Comprehension (IMREC) combines cognitive factors with basic reading skills to conceptualize how an individual extracts meaning from text (van den Broek & Espin, 2012), and the model's conceptualization is frequently used to describe components of reading and identify intervention targets (Kendeou et al., 2014; Kim, 2015; Kulesz et al., 2016; McMaster et al., 2015; Witmer et al., 2014). The cognitive variables that are specified under the IMREC model include verbal working memory, attention allocation, inference, basic language and reading skills, background knowledge (interpreted in the current review as verbal memory), and vocabulary. Within the current study, I was particularly interested in cognitive deficits that are both associated with reading difficulties in the literature (Butterfuss & Kendeou, 2018; Sesma et

al., 2009) and commonly seen in ASD, including attention and EF (Fein, 2011; Keehn et al., 2010). The goal of this systematic review was to examine the state of the literature in the field and to add to the understanding of the specific cognitive processes that underlie reading comprehension in ASD, as informed by the IMREC model. It was hoped that the information gained would inform explanations of reading comprehension difficulties in ASD and help to guide future intervention approaches.

### **Overview of the Literature**

A search of literature over the past 20 years (2000-2020) yielded only 22 articles that specifically investigated the association between cognitive processes and reading comprehension in the ASD population. The dearth of studies found demonstrates that there is a lack of research in this area, despite evidence of reading comprehension difficulties in ASD and the importance of reading comprehension for life outcomes (Brown et al., 2013; Knight et al., 2019). Further, the review revealed a range of concerns around study quality and design within the existing literature, summarized below. For example, of the 22 studies reviewed, only one would have been conceptualized as high quality using the AHRQ Methodology Checklist as interpreted by the examiner, and the majority fell in the moderate quality range. Study limitations can be conceptualized as falling within the following categories: 1) problems with sample identification/description, 2) flaws in study design, and 3) studies that were not theoretically informed (though this final category is not a variable on the AHRQ Checklist).

The first main issue found in the reviewed studies pertained to problems with sample identification and description. First, there was lack of clarity around sample identification which applied to 54.5% of studies. When studying clinical populations, it is crucial that the sample population is clearly and unambiguously defined so that accurate conclusions can be drawn

about who the results may apply to. Many studies did not specify time period in which data were collected or the diagnostic system used for sample inclusion (i.e., DSM or ICD as well as edition), making it difficult for the reader to better understand the types of individuals that were included in the sample and to generalize the findings.

Second, only a small percentage of studies reported on diagnostic comorbidities. Only four studies out of the 22 included in the current review reported on comorbidities despite how common they are within the ASD population, with learning disorders and attention deficit disorders affecting up to 78% and 75% and individuals with ASD respectively (Gargaro et al., 2011; Mayes & Calhoun, 2007; O'Brien & Pearson, 2004). Importantly, these comorbidities would be expected to have an impact both on cognitive processes and academic outcome variables (Monette et al., 2011; St. Clair-Thompson & Gathercole, 2006). The low number of reported comorbidities seen within the current review may be due to studies not assessing for comorbidities, not reporting on comorbidities, or excluding comorbidities without stating so. If studies include comorbidities that they are not reporting, this influences the interpretation of the results. Additionally, if the studies are not including samples with comorbidities, this may not be representative of the broader ASD population. Either way, this lack of reported comorbidities may limit generalizability of results to the broader population of individuals with ASD.

The second limitation found in the literature reviewed pertained to study design. First, many studies measured a much larger range of variables than they reported in analyses and it was unclear why these variables were not reported on. Studies typically did not explain whether these variables were control variables (i.e., to appropriately match a control population to the clinical population) or whether they were not reported because they were non-significant. As one example, many studies first compared ASD and control populations on cognitive and reading

variables and then ran a set of within-group analyses to investigate cognition and reading specifically within the ASD sample. In these cases, not all variables that were measured were reported in the ASD within-group analyses without clear explanation for why variables that were analyzed in the between-group analysis were not reported in the within-group analysis. Given that cognition and reading in ASD is an understudied and important area, valuable information may be missed, and misinterpretations of the data could occur. Second, of the studies that used regression models to assess predictors of reading comprehension, several did not report appropriate effect size statistics and instead only reported standardized, or even unstandardized, beta coefficients. Beta coefficients are not easy to interpret as measures of effect size and particularly so when they are unstandardized given the dependency upon distribution of and relationship between the variables for proper interpretation (Gelman & Hill, 2007). This again reflects a pattern of reporting results that may detract from the usefulness of the research in advancing understanding of cognitive contributors to reading comprehension in ASD.

Third, the majority of studies in this systematic review were cross-sectional even though longitudinal designs are better able to assess how cognitive processes contribute to reading comprehension across development. Specifically, cross-sectional studies can measure the relationships between variables at one specific point in time, but longitudinal studies permit measurement of the variables of interest across time and thus can speak better to the predictive relationship between variables (Cottrell & McKenzie, 2010). As a result, most of the studies summarized in the current review could provide valuable information about how cognitive and reading variables relate at the time of measurement, but only a few could provide valid information on how cognitive variables might predict reading outcomes over time.

Finally, it is this reviewer's perspective that many of the studies could have better planned their designs to permit a more nuanced assessment of the relationships between cognitive processes and reading comprehension. While the majority of studies reported correlations and regressions, they did not typically analyze moderating or mediating factors that may influence the relationships between cognitive processes and reading comprehension. Given that cognitive processes very likely influence reading comprehension through mediating or moderating factors (as one example, cognition impacts word decoding which impacts reading comprehension), this is a clear limitation within the literature as it pertains to reading comprehension in both ASD and other populations.

Finally, many of the reviewed studies did not appear to be theoretically informed. Less than half of the studies reported using a theoretical model of reading in ASD, and those that did use a clear model tended to use the Simple View of Reading (Hoover & Gough, 1990). The Simple View of Reading is compelling in its simplicity; however, it only considers word decoding and oral language abilities as contributing to reading comprehension and does not specify any other cognitive processes (Hoover & Gough, 1990). Two-thirds of the studies that studied reading comprehension using the Simple View of Reading added additional cognitive factors (e.g., working memory, theory of mind, and intelligence), even though these are not components of this particular model. This suggests that the Simple View of Reading Model likely does not provide sufficient detail for studying contributors to reading comprehension in ASD. Conducting theoretically informed research is important for selecting the correct variables to investigate, leading to better targeted research and likely clearer elucidation of targets for intervention.

## **Cognitive Contributors to Reading in ASD**

The current review extracted studies that investigated cognitive contributors to both reading comprehension and word reading, with word reading conceptualized as an intermediary step towards reading comprehension under the IMREC model. Intelligence, vocabulary, working memory, verbal memory, and basic language were the variables that were studied and reported on most frequently. Of these variables, vocabulary and basic language were most closely related to word reading or reading comprehension ability in ASD, followed by intelligence and working memory, and finally, verbal memory.

### ***Cognitive Contributors to Word Reading in ASD***

Verbal memory, basic language, intelligence, vocabulary, and EFs such as general working memory (WM; i.e., visual, verbal, & central executive aspects of WM combined or aspect of WM assessed unspecified), verbal working memory and attention allocation were the cognitive processes that were most frequently significantly associated with word reading. These correlations ranged from weak to strong, with most falling in the moderate range. Intelligence and verbal working memory were the strongest predictors of reading comprehension, similar to what is seen to the literature for typically developing populations (de Jonge & de Jong, 1996; Johann et al., 2020).

Basic language ability as operationalized in this review (e.g., morphology, oral language, prosody) was found to be moderately correlated with word reading. Vocabulary level was also moderately correlated with word reading, with correlations ranging from weak to strong depending on the study.

Intelligence overall was moderately correlated with word reading, with both nonverbal and verbal intelligence showing weak to moderate correlations. One study demonstrated that

global intelligence predicted 52% of the variance in word reading ability, whereas another study found that 17.9% of the variance was explained by nonverbal intelligence. These findings are not surprising in that both verbal and nonverbal abilities are involved in reading comprehension in typically developing populations, as verbal intelligence relates to understanding the use of words and language and nonverbal abilities contribute reasoning that aids comprehension (Cain et al. 2004; de Jonge & de Jong, 1996). Individuals with ASD are more likely to suffer intellectual deficits than typically developing children with a prevalence of ID comorbidity estimated at 55% (Charman et al., 2011). Thus, a higher prevalence of deficits in intellectual functioning place the ASD population at particular risk for word reading difficulties.

Executive functions were weakly to moderately related to word reading, though the reviewed studies only investigated a limited range of EF processes (e.g., WM, attention allocation, and planning). General WM demonstrated weak to moderate correlations with word reading whereas verbal WM and attention allocation were only weakly correlated with word reading. One study reported general WM as a moderate predictor (Mayes & Calhoun, 2007) and one study reported verbal WM as a significant predictor of word reading, though no interpretable effect sizes were reported (Chen et al., 2019). However, EFs were not otherwise found to be predictors of word reading. In general, EFs were only infrequently included in regression analyses and were understudied, limiting the conclusions that can be made regarding the role of EFs in word decoding.

Overall, the results suggested that within ASD populations, word reading ability is most highly determined by factors such as intellectual functioning and basic language abilities, though more research is needed. Executive functions, and particularly general working memory, also contribute to word reading although the limited research would suggest this is to a lesser degree.

### ***Cognitive Contributors to Reading Comprehension in ASD***

The cognitive contributors to reading comprehension that were investigated across studies included intelligence (broad, verbal, and nonverbal), WM, verbal WM, attention allocation, vocabulary, verbal memory, basic language skills, processing speed, inference, planning, and social-communicative skills.

Overall intelligence, verbal intelligence, and nonverbal intelligence were the cognitive processes that were most frequently assessed in studies of reading comprehension in ASD, though these variables were found to be only weakly to moderately correlated with reading comprehension. However, across studies, intellectual functioning was found to explain 44%-52% of the variance in reading comprehension, indicating that intelligence does have a large impact on reading comprehension in ASD. The strong predictive ability of IQ is likely because IQ would underlie other cognitive variables as well as reading ability.

Verbal memory was also a frequently studied cognitive variable pertaining to reading comprehension in ASD. Verbal memory was significantly related to reading comprehension, with significant correlations ranging from weak to strong being found in 66.7% of the studies reviewed and one study reporting verbal memory as a predictor of 16% of the variance in reading comprehension. These results suggest that verbal memory is likely an important cognitive process for reading comprehension, although IMREC does not specifically include it. The current results are consistent with past research that has shown verbal memory is important for reading comprehension in typically developing children (Perfetti & Goldman, 1976), likely because verbal memory is required to integrate knowledge with textual information to support comprehension (van den Broek & Espin, 2012). It is also likely that verbal memory affects

reading comprehension through the mediating effect of word reading, though no studies in ASD have looked specifically at this.

A limited range of EFs (working memory, attention allocation and, very rarely, planning) were investigated (50% of studies), though WM (40.9% of studies) was studied much more frequently than attention allocation (18.2% of studies) and planning (4.6% of studies). General working memory was found to be weakly to moderately related to reading comprehension, while planning was highly correlated in the one study that measured it. Verbal working memory specifically was weakly to moderately correlated with reading comprehension. Working memory, and particularly verbal and central executive aspects of WM (Baddeley 1983), have been shown to impact reading in typically developing children (Dawes et al., 2015), so we might expect a similar pattern in readers with ASD.

Attention allocation was not found to relate to reading comprehension despite evidence that shifting, an aspect of attention allocation, is important for reading comprehension in typically developing readers (Kieffer et al., 2013). However, attention allocation and planning were studied too infrequently to know their true relationship with reading comprehension in ASD. Given the importance of these abilities to reading in typically developing children, and common deficits in these areas in ASD, these processes should be studied more extensively to elucidate their role.

Only two studies included EFs in regression analyses with one study finding that neither WM or attention allocation predicted reading comprehension and the other study finding that WM was a moderate predictor of reading comprehension in ASD. Working memory has been shown to be a significant predictor of reading comprehension in typically developing populations (Cain et al., 2004), so we might expect similar findings in ASD. Alternatively, EFs may relate to

reading comprehension differently in individuals with ASD. Past literature has shown EFs and reading comprehension to have a bidirectional relationship (Meixner et al., 2019; Peng et al., 2018), and it is possible that because both abilities are impaired in ASD, they may be facilitative to each other and thus not as closely linked. This variability in results within the two studies reported is also likely simply due to a lack of studies that have assessed this predictive relationship. Because EFs were so infrequently included in regression analyses, and only a very limited range of EFs at that, there is very limited evidence regarding their contribution to reading comprehension in ASD and future research should aim to fill this gap.

Overall, EFs do appear to hold some relation to reading comprehension in ASD, though they are understudied or not included in appropriate analyses to learn more about their predictive relationships with comprehension. Future studies should aim to include more aspects of EF such as attention allocation or planning and to report on regression analyses for WM, attention allocation, and planning.

Inference and theory of mind, a common component of inference, were not as frequently studied in the ASD literature, despite evidence that these abilities contribute to reading comprehension and are known to be deficit areas in ASD (Baron-Cohen, 2000; Brown et al., 2012). Of the studies that investigated inference, 75% found moderate to strong correlations with reading comprehension. Inference and theory of mind are necessary for the understanding of narrative texts and thus highly involved in reading comprehension, so this pairing of deficits is no surprise in ASD (Bodner et al., 2015; Brown et al., 2012; Dore et al., 2018). Even fewer studies examined theory of mind (13.6%) specifically, though this cognitive domain is important to investigate further given it is a well-recognized deficit area in ASD (Baron-Cohen, 2000) that very likely may impact reading comprehension. Of note, central coherence is another cognitive

feature commonly impacted in ASD (Frith, 1989) that was investigated in only 9.1% of studies but was found to be highly correlated with reading comprehension. Similar to inference and theory of mind, the impact of central coherence on both reading comprehension (Bodner et al., 2015) and ASD (Frith, 1989) makes it a variable of interest for future research in reading in ASD.

### ***Other Contributors to Reading Comprehension in ASD***

Beyond the cognitive associations reported above, studies did also report on other associations with reading comprehension, including word reading and autism symptomatology. Correlations between word reading and reading comprehension ranged from weak to strong, though primarily fell in the high moderate to strong range. For example, in one study (Davidson, 2018), word reading predicted 82% of the variance in reading comprehension, indicating that word reading makes a large contribution to comprehension. This finding is consistent with and well supported in the reading literature as it pertains to typically developing children (Perfetti & Hogaboam, 1976; Verhoeven & van Leeuwe, 2008) and has been previously found as in ASD (Norbury & Nation, 2011).

Finally, some studies also reported on the association between clinical symptoms in ASD (e.g., ASD symptom severity and level of impairment in social-communication skills) and reading comprehension. These factors were shown to be moderately related to reading comprehension in ASD, although it is very difficult to interpret these findings given that clinical symptoms are influenced by a range of different cognitive factors (Fein, 2011). The cognitive processes that contribute to clinical symptoms, such as language, intellect, EFs, theory of mind, etc. likely also contribute to reading comprehension in various ways and it is very likely that

clinical severity and reading comprehension are linked through the mediating and moderating influence of such cognitive factors. This is a research area that clearly requires expansion.

### **Cognitive Contributors to Reading in ASD as Defined by the IMREC Model**

As interpreted by the current author, the IMREC model predominantly features the cognitive processes of working memory, attention allocation, verbal memory, inference, basic language, word reading skills, and vocabulary. In the studies that were extracted, these cognitive processes were studied with varying frequency and found to hold varying relationships with reading comprehension in ASD. It is important to note that the research also reported on other cognitive factors that were commonly studied and associated with reading comprehension but were not specified in the IMREC model.

The IMREC model specifies that EFs are cognitive processes that are important for reading comprehension, particularly verbal WM and attention allocation. Specifically, verbal WM supports the integration of text information with other areas of text and background knowledge, as the reader must hold all relevant information in mind to create the representation and then update it (van den Broek & Espin, 2012). Attention allocation is important for moving between the components of reading comprehension and maintaining efficiency in processing (van den Broek & Espin, 2012). This systematic review revealed that verbal WM and attention allocation were infrequently studied (18.2% of studies each). As reported above, in the studies that investigated verbal WM, it was found to correlate weakly to moderately with reading comprehension in children with ASD. Further, one study found that general WM (i.e., a combination of verbal, visual, and unspecified WM tasks) was a moderate predictor of reading comprehension as well as a weak to moderate correlate. Working memory has been shown to underlie reading comprehension in typically developing children, with verbal and central

executive aspects of working memory being particularly important (Dawes et al., 2015).

Therefore, it is surprising that WM was not shown to be more significant in this review. This may be due to a limitation of the IMREC model in that it does not clearly specify the range of WM processes that may influence reading comprehension (e.g., models of WM such as Baddeley's central executive, phonological loop, and visuospatial sketchpad model; Baddeley, 1983), thus diminishing correlation by restricting the range of WM variables. Alternatively, this may also reflect limitations in the literature that WM has not been sufficiently investigated as it pertains to reading comprehension in ASD.

Attention allocation too, although a key factor specified in IMREC, was only sparingly studied and not shown to hold a strong relationship with reading comprehension, though it was weakly correlated with word reading. The IMREC model specifies that attention allocation balances the demands and timing of the various cognitive processes necessary in successful reading comprehension and that it is critical to reading comprehension, at least within typically developing samples (Kieffer et al., 2013; van den Broek & Espin, 2012). The current systematic review did not yield significant relationships between attention allocation and reading comprehension in the ASD population which is surprising given cognitive deficits in this area in ASD (e.g., shifting, inhibition, and flexibility; Demetriou et al., 2018; Fein 2011; Sanders et al., 2008). Again, it is difficult to determine if the lack of clear results in this area relates to insufficient research in this area, or whether this pertains to limitations in the IMREC model. For example, there are different cognitive aspects of attention allocation (e.g., shifting, flexibility, etc.) that are not sufficiently specified within the IMREC model, and it may be that certain aspects of attention allocation have more of an effect on reading comprehension in ASD than

others. Regardless, it is possible that further study would better elucidate the role of attention allocation in reading ability since this review has so few studies from which to draw conclusions.

Inference is specified as a key feature in the IMREC model, but surprisingly was reported on in only 18.2% of the studies reviewed, despite children with ASD having well-documented problems in this area (Bodner et al., 2015; Leibovitch, 2013). Importantly, 75% of the studies that did measure inferential skills found them to hold correlations with reading comprehension that ranged from weak to strong and 50% of these studies found inference to be a significant predictor of reading comprehension in ASD. It is a strength of the IMREC model as applied in ASD that it specifies the importance of inference to reading comprehension. However, inference is a complex skill that is supported by a range of cognitive functions impacted by ASD such as theory of mind (Baron-Cohen, 2000) and, as with the other components of the IMREC model, this component warrants a more detailed operationalization.

The IMREC model includes basic language (e.g., oral language, morphology, etc.) and reading skills (e.g., decoding) as well as vocabulary (e.g., breadth and depth of word understanding) as important contributors to reading comprehension (van den Broek & Espin, 2012). Vocabulary was studied in approximately half of the studies extracted and exhibited moderate to strong correlations with reading comprehension. Further, it held significant but weak predictive ability. Basic language skills were also measured frequently and were moderately to strongly associated with reading comprehension 75% of the time, though they were only weak predictors, suggesting that other factors contribute to reading comprehension beyond basic language. Again, these results highlight the utility of this aspect of the IMREC model for understanding reading comprehension in ASD as well as the need for the IMREC model to define its components further. The IMREC model does not specify the aspects of basic language

that may be important for understanding reading comprehension in ASD (e.g., oral language, morphology, phonemic awareness, and prosody; Norbury & Nation, 2011; Ricketts et al., 2013). It is up to the individual researcher to define what is meant by ‘basic language’, meaning that different studies that use the IMREC model will likely focus on different aspects of language, making it challenging to compare across studies. This again speaks to the need for the IMREC model to more clearly define/operationalize its key components.

As defined in the IMREC model, basic reading skills at the word level (i.e., word reading/decoding) were investigated in nearly all studies. Most studies showed word reading to be moderately to strongly associated with reading comprehension in ASD, although this varied with studies showing effect sizes that ranged from weak to strong. Variability was also seen in the two regression studies found, with one study finding that word reading accounted for 82% of the variance in reading comprehension and the other study not finding word a significant association. This wide variability across studies may be due to a range of factors including sample composition, specific reading measures used, and ultimately a scarcity of studies investigating this predictive relationship. The IMREC model is limited in this regard in that it is a relatively flat model that does not link cognitive variables with reading comprehension outcomes in a hierarchical manner. As such, it is difficult to determine the specific cognitive variables that contribute to word reading, reading comprehension, or both. Future research should seek to clarify the relationships between cognition, word reading and reading comprehension in a more nuanced manner.

Finally, the IMREC model does not specify certain cognitive variables that are clearly being reported on in the literature (e.g., verbal memory and intelligence). The IMREC model does not specifically outline verbal memory as a key variable for reading comprehension, though

this could be conceptualized as an aspect of background knowledge which is specified in IMREC. No studies investigated background knowledge as a variable, although verbal memory was reported on and was found to exhibit moderate to strong correlations with both word reading and reading comprehension. Again, the IMREC model needs to more clearly define its contributors as well as specify the component cognitive processes that make up these contributors. Further, the IMREC model also does not include intellectual function as an important variable, though it is frequently studied. In the ASD population, IQ was significantly correlated with reading comprehension in 30% of studies and was highly predictive. Though the results indicate that there are many other factors impacting reading comprehension separate from intelligence, the important role of IQ should still be factored into cognitive models of reading comprehension.

### **Utility of the IMREC Model for Studying Reading Comprehension in ASD**

The IMREC model as currently specified has varied utility for assessing reading comprehension in ASD. The components of reading comprehension specified in the IMREC model that were reported on in studies of reading comprehension in ASD (inference, verbal memory, verbal working memory, basic language, vocabulary, and attention allocation) were associated with reading comprehension to varying degrees, with basic language and vocabulary most associated, followed by inference, verbal memory, and verbal working memory. However, the research also demonstrated several cognitive variables that appeared to be significantly associated with reading comprehension that are not specified in the IMREC model or were unclearly defined (e.g., intelligence, verbal memory).

It should be noted that the IMREC model does have strengths for studying reading comprehension in ASD. First, the inclusion of inference in the IMREC model is especially

relevant to readers with ASD, given that individuals with ASD have significant challenges in this area. Inference was rarely studied in the literature but, when it was, it demonstrated moderate predictive ability for reading comprehension in individuals with ASD, matching deficit patterns we would expect to see (Bodner et al., 2015; Oakhill & Cain, 2018). Second, EFs are also commonly impaired in ASD and are featured prominently in the IMREC model. Working memory was commonly studied and moderately correlated with reading comprehension. Surprisingly, attention allocation was only infrequently studied and, in the few studies that reported on it, not found to be related to reading comprehension. Interestingly, attention allocation within the IMREC model is related to reading comprehension in TD individuals (Kieffer et al., 2013; Nouwens et al. 2016), and further research must be done to determine its relevance to reading comprehension in ASD.

Alternatively, the IMREC model does have a number of limitations when studying reading comprehension in ASD, and likely within other populations as well. With respect to ASD, there were a number of cognitive processes that are being studied in the ASD literature and that have been found to meaningfully relate to reading comprehension (e.g., intelligence, theory of mind, verbal memory), which are not specified or clearly defined in the IMREC model. At a foundational level, IMREC does not operationally define its cognitive components, leaving the exact components that are studied up for interpretation. As an example, “basic language and reading skills” as specified in IMREC could include an extraordinarily large range of functions that might all be considered contributors to reading comprehension. Specific to ASD, language profiles can vary widely and may include deficits in social language, pragmatics, and discrepancies between expressive and receptive language, all of which may differentially impact reading comprehension (Nevill et al., 2019). While the broad, general definitions used by

IMREC allow it to encompass more variables, the lack of specification does not allow precise measurement of the true contributing cognitive processes that impact reading comprehension or facilitate comparisons across studies. Similarly, the IMREC model does not specify what constitutes inferential skill, background knowledge, or attention allocation. These are all complex constructs comprised by a range of underlying cognitive processes. In order to be useful for research and clear identification of contributors to reading ability, the IMREC model should more clearly specify and operationally define the factors it features.

An additional limitation of this model is that it has artificially constructed its main three categories (general cognitive reader characteristics, efficiency/efficacy of comprehension-related processes, and language- and text-related skills and processes) in spite of the fact that many cognitive processes could easily operate within any of these given categories and likely interact with each other. While the IMREC describes reading as a multi-componential, dynamic process it does not describe or reflect this dimensionality and interactive nature sufficiently. This includes illustrating how these different components are interrelated and whether there are mediating or moderating variables that impact reading comprehension. This is particularly apparent when situating word reading within the model, as word reading likely serves as a mediating variable between cognition and reading comprehension or is moderated by cognitive variables. To function adequately as a cognitive model, the IMREC must take into account the interaction and scaffolding of cognitive processes and functions. In order to truly assess the fit of this model to reading in ASD, the component cognitive processes must be clearly defined and arranged so that all who use the model to communicate are using the same construct. This is important in both research and clinical settings as we seek to learn more about reading in ASD and to implement effective interventions. The above reported limitations are interesting given

that IMREC was developed as a way to guide assessment of reading and intervention, which would be limited by a lack of clarity on what variables are most important for reading outcomes.

In summary, the IMREC model has some strengths for conceptualizing reading comprehension in ASD such as its inclusion of certain key impaired abilities in ASD, though it requires further clarification and expansion in order to fully encapsulate all of the factors that may be contributing to comprehension. Some support exists for the model as it applies to typically developing populations and ASD, but future research is needed to elucidate whether its key components are truly the most crucial factors for reading comprehension and how these factors should be structured. Individuals with ASD suffer difficulties in several of the areas IMREC specifies (e.g., attention, EFs, inference; Fein, 2011; Gargaro et al., 2011; Posner & Rothbart, 2011); however, more detail and clarity in the model is needed.

### **In the Context of Other Literature**

I was only able to locate three prior reviews (one systematic review, one meta-analysis and one scoping review) that attempted to elucidate the cognitive factors underlying reading comprehension in ASD, although using different lenses than the current study. One such review investigated reading comprehension in children with developmental disorders using the Simple View of Reading framework (Ricketts, 2011). This review found that oral language, word recognition, nonverbal intelligence, and working memory were meaningful contributors to reading comprehension in ASD, Down Syndrome, and individuals with specific language impairment (Ricketts, 2011). These results are consistent with the results of the current review, which also found these factors to be meaningful contributors to reading in ASD. Ricketts' review (2011) also sporadically included considerations of inference as a contributor to reading comprehension in ASD, though it did not propose this was a main factor. These findings support

the inclusion of cognitive variables beyond the Simple View of Reading, which provides support for cognitive models such as IMREC. However, the review did not quantitatively summarize their results and thus can be compared only qualitatively.

The second review summarized studies that compared ASD and typically developing readers in a meta-analysis, finding that decoding and semantic knowledge were the most important contributors for predicting reading comprehension while ASD symptomology and nonverbal intelligence were less important (Brown et al., 2012). This review highlighted the individual skills and the heterogeneity of reading in ASD (Brown et al., 2012), supporting future investigation into the component skills that contribute to reading comprehension using individual difference models as opposed to exclusively using between-group comparisons. Brown et al.'s (2012) review indicated that semantic knowledge and decoding were significant predictors of reading comprehension and is consistent with our review which found that vocabulary and word reading were significant predictors of reading comprehension. Additionally, Brown et al.'s (2012) study showed that nonverbal intellectual ability was a significant but minor predictor of reading comprehension, consistent with the current review that found intelligence to be somewhat related to reading comprehension. Of note is that the Brown et al. (2012) meta-analysis did not assess a wide range of cognitive variables and thus was not able to provide a nuanced picture of the cognitive processes that contribute to reading comprehension.

Finally, Randi et al. (2010) conducted a scoping literature review focused on the cognitive processes underlying reading as well as interventions for these processes. Consistent with the current review, Randi et al. (2010) demonstrated that componential processes (i.e., cognitive contributors such as working memory and foundational reading skills such as phonological processing and word reading) contribute to reading comprehension in ASD. This

review also provides support for the inclusion of inference in supporting reading comprehension in ASD. However, this review did not use a systematic approach for reviewing literature and thus is limited in the claims it can make.

Taken together, the current and past reviews provide support for investigating cognitive components as contributors to reading comprehension in ASD. Though each of these past reviews offers insight into the reading abilities and contributing processes in individuals with ASD, none brings together the cognitively-based, componential nature of reading comprehension in ASD as extensively as the current review. The current review summarized research on a broad range of cognitive functions, including those specifically impaired in ASD as well as those abilities that are less impacted in ASD but still implicated in reading comprehension. This included a focus on EF abilities, which are known to be impacted in ASD and are associated with reading comprehension difficulties in other populations.

### **Current Limitations and Future Directions**

The current systematic review has a number of limitations that are important to note as these limit the conclusions that can be made about cognitive contributors to reading comprehension in ASD. First, this review was clearly limited by a small sample size, although it accurately reflects the state of the literature in the field. The review was also strongly limited by problems with study clarity and quality, which again reflects the literature on reading in ASD.

Out of nearly 1,500 articles initially screened, only 24 directly analyzed the relationship between cognitive processes and reading in ASD and only 22 met the quality standard. Further narrowing the pool, most of the studies that were included measured only a handful of variables and the variables ranged across studies, thus limiting the ability to amalgamate conclusions about the contributions of each cognitive variable. In order to better understand what factors are

implicated in reading comprehension in ASD, theoretically-informed research must be conducted. Less than half of the studies were theoretically-informed, and none used a cognitively-informed model, although approximately one quarter of the studies investigated additional cognitive functions beyond a chosen non-cognitively informed model. By conducting research using well-defined cognitive models, the choice of cognitive processes to assess is narrowed down and conclusions can be better drawn within an evidence-based framework. Future studies should be theoretically informed, using models that apply both to reading comprehension and ASD with clear operationalizations to permit more nuanced and accurate conclusions regarding the relationship between cognitive variables and reading outcomes.

The current review was also limited by the fact that, in order to have an adequate sample size, studies were included even if the diagnostic process was not clear, leading to a lack of clarity on diagnoses and comorbidities. Studies were included even if it was unclear what diagnostic criteria they were using, even though these different criteria comprise different definitions of ASD. Additionally, the majority of studies were included despite not reporting on the identification of comorbidities. Finally, studies were included despite vague descriptions of diagnostic tools that did not allow judgment of the rigor or reliability of given diagnoses. These inclusions mean that studies could have theoretically included very different samples without sufficient evidence on how this impacts results, so claims about cognition and reading in ASD drawn from this review must be made with some caution. Researchers must clearly state the diagnostic criteria under which their participants fall, and they must do their due diligence to investigate and report any comorbidities that may exist within the sample, especially when studying populations high in comorbidities. Future studies should clearly specify diagnostic criteria, report on comorbidities, and use gold standard tools for ASD diagnoses.

Many of the included studies had flawed study designs, which limits the conclusions that can be drawn from this review. Most studies implemented cross-sectional designs, meaning that the results can truly only speak to the relationship between cognitive and reading variables at the specific time the participants were measured. Longitudinal designs would permit a better assessment of the predictive relationship between cognitive variables and reading comprehension, as well as informing how developmental trajectories of cognitive and reading variables align or diverge over time.

Finally, many studies also failed to maximize the impact of their data by only reporting on a portion of the cognitive variables that were assessed. Even null findings are important to report with respect to increasing our understanding of how cognition and reading comprehension relate. Further, researchers should directly relate cognitive and reading abilities within the ASD sample rather than primarily analyzing between-group comparisons. Studies should investigate predictive relationships in addition to correlations and should include analysis of mediating or moderating variables to reading comprehension. Much valuable information about the reading comprehension process in ASD is lost when these analyses are not conducted or reported.

In sum, future studies should aim to increase the quality and clarity of their samples in order to better define the populations included in the research. Studies should also be theoretically informed and use theoretical models to select and analyze the appropriate cognitive variables. Finally, studies need to implement designs that can clearly delineate the relationship between cognitive processes and reading comprehension. Only when these issues are addressed can we better understand the cognitive processes that contribute to reading and develop effective interventions to target these underlying cognitive processes.

## Conclusion

Overall, this systematic review demonstrated that literature in this field is limited in terms of scope and quality, despite many children with ASD experiencing reading comprehension difficulties and the broader life repercussions of such difficulties. Additionally, it became clear that while there are key contributing cognitive processes to reading comprehension difficulties in ASD, we are still only beginning to understand these relationships. Along this line, it is too early to assume that we've identified all of the specific cognitive variables that contribute to reading comprehension in ASD and whether these are the same or different as what is found in other populations with reading difficulties. In order to answer these questions, more high quality, theoretically informed research must be conducted in this area. Only then can we more completely understand and most effectively support the reading comprehension process in ASD.

This research is important not only in theoretically understanding the factors contributing to reading comprehension in ASD, but also in informing assessment tools and clinical interventions to improve reading skills. Interventionists must not only consider the text and goal, but the reader's cognitive profile as well when constructing an intervention or literacy instruction plan (Carnahan et al., 2011). For instance, children with ASD who struggle with inference may benefit from priming, or children who struggle to attend to text may benefit from texts in their areas of interest (Carnahan et al., 2009). Recognizing where a deficit may be occurring allows for targeted interventions that may be more successful by supporting that specific deficit function. This is critical within the ASD population, as many interventions are not tailored to their specific needs and evidence for successful interventions is limited despite the importance of reading comprehension for academic performance as well as quality of life (Brown et al., 2013; Mayes & Calhoun, 2007; Nation et al., 2006; Whalon et al., 2009).

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## **Appendix A**

### *Data Extraction Items*

1. Study title
2. Lead author
3. Year published
4. Journal of publication
5. Article type (peer-reviewed scholarly journal, thesis, report, etc.)
6. Method used for locating study
7. Location of study
8. Sample SES
9. Gender (& gender breakdown of ASD participants)
10. Age range
11. Population – clinical diagnoses and diagnostic criteria
12. Control population
13. Sample setting (community, school, clinic, etc.)
14. Receiving services?
15. Study objective
16. Hypotheses
17. Study description
18. Study design (survey, cross-sectional, prospective cohort, etc.)
19. Cognitive contributors considered and measures used
20. Aspect of reading measured and measures used
21. Key findings of the study

22. Statistics presented

23. Effect sizes (if relevant)

## Appendix B: AHRQ Quality Check

From Zeng et al., 2015

Items are marked as “yes,” “no,” or “unclear.”

1. Define the source of information (survey, record review).
2. List inclusion and exclusion criteria for exposed and unexposed subjects (cases and controls) or refer to previous publications.
3. Indicate time period used for identifying patients.
4. Indicate whether or not subjects were consecutive if not population-based.
5. Indicate if evaluators of subjective components of study were masked to other aspects of the status of the participants.
6. Describe any assessments undertaken for quality assurance purposes (e.g., test/retest of primary outcome measurements).
7. Explain any patient exclusions from analysis.
8. Describe how confounding was assessed and/or controlled.
9. If applicable, explain how missing data were handled in the analysis.
10. Summarize patient response rates and completeness of data collection.
11. Clarify what follow-up, if any, was expected and the percentage of patients for which incomplete data or follow-up was obtained.