Reading and Writing (2023) 36:1487–1514
https://doi.org/10.1007/s11145-022-10338-7

A meta-analysis on the cognitive and linguistic correlates of reading skills among children with ASD

Ying Wang[1] · Zhu Lan[1] · Isabella Duan[2] · Peng Peng[3] · Wei Wang[4] · Tengfei Wang[5]

Accepted: 18 July 2022 / Published online: 31 August 2022

Abstract

This meta-analysis aimed to systematically investigate the cognitive and linguistic correlates of both word decoding and reading comprehension among children with Autism Spectrum Disorder (ASD) across orthographies. Based on data from 26 studies of 1.92- to 18.92-year-old children with ASD, we found that (1) intelligence, theory of mind, and executive function exhibited modest associations (*r*s = .41, .46, and .39, respectively) with reading; (2) phonological awareness, semantic skills, and syntax skills also showed modest associations (*r*s = .53, .50, and .53, respectively) with reading; (3) cognitive and linguistic skills showed comparable contributions to word decoding and reading comprehension, when both skills were analyzed in the same model with meta-analytic structural equation modeling; (4) age, language type, publication type, sample type, and reading measures did not moderate the relations. Taken together, these findings suggested that although children with ASD exhibit language weaknesses, their linguistic skills still made important contributions to reading development beyond cognitive skills. Further, cognitive skills may compensate for language deficits in children with ASD's reading development. Implications for reading interventions in children with ASD were also discussed.

Keywords Meta-analysis · Autism spectrum disorder · Cognitive skills · Linguistic skills · Word decoding · Reading comprehension

✉ Wei Wang
wwang@gc.cuny.edu

✉ Tengfei Wang
tfwang@zju.edu.cn

Extended author information available on the last page of the article

Introduction

Autism Spectrum Disorder (ASD) is a neurodevelopmental condition typified by social communication difficulties and restricted interests and behaviors (American Psychiatric Association [APA], 2013). Reading is an essential life skill for children with ASD, as it enables cognitive development, greater participation in social activities, expanded interests, and an understanding of how to adjust to new environments (Lanter & Watson, 2008; Tipton et al., 2017). However, the factors important for reading among children with ASD remain unclear. The current meta-analysis aimed to investigate the unique roles of cognitive and linguistic skills in both word decoding and reading comprehension among children with ASD.

Cognitive and linguistic correlates of reading in typical development

According to Simple View of Reading (SVR), decoding and linguistic comprehension are the two components necessary for skilled reading. Decoding "refers to the ability to read printed nonwords by applying the grapheme-phoneme correspondence rules, and linguistic comprehension refers to the ability to interpret sentences and discourse presented orally" (Georgiou et al., 2009). For typically developing (TD) children, both decoding skills and reading comprehension skills can be predicted by domain-general cognitive skills and domain-specific linguistic skills. Within the cognitive domain for TD children, executive function skills such as working memory, attentional shifting, and inhibitory control show moderate positive relations (rs = .30–.39) with both decoding and comprehension (Follmer, 2018; Jacob & Parkinson, 2015; Peng et al., 2018). Within the linguistic domain for TD children, metalinguistic skills such as phonological awareness and rapid naming are strongly associated with word decoding across orthographies (e.g., McBride-Chang & Kail, 2002), while morphological awareness, syntactic awareness, vocabulary, and grammar predict comprehension (Dong et al., 2020; Hung & Loh, 2021; Muter et al., 2004). Metalinguistic skills may also indirectly affect reading comprehension through decoding (Peng et al., 2021).

Similarly, cognitive skills may indirectly affect reading comprehension through linguistic skills for TD children. For example, Peng et al.'s (2018) meta-analysis on the unique contribution of working memory to reading comprehension suggested that working memory may influence reading comprehension indirectly through decoding and language skills. Quinn and Wagner (2018) used the meta-analytic structural equation modeling (MASEM) technique to study the relations among components of reading comprehension. They demonstrated that after controlling decoding and linguistic comprehension, cognitive skills did not contribute additional variance to reading comprehension, suggesting that cognitive skills may influence reading comprehension indirectly via decoding and linguistic comprehension. Therefore, although cognitive and linguistics skills are both important for reading development, linguistic skills seem to play a more important role than cognitive skills in reading comprehension for TD children. In the present study, we aimed to systematically investigate the extent to which cognitive skills and linguistic skills affect reading development of children with ASD, in order to provide evidence-based suggestions on their early reading intervention.

Cognitive and linguistic correlates of reading development among children with ASD

The theory of SVR and empirical studies discussed thus far have laid out the cognitive and linguistic correlates of reading and suggested the larger role of linguistic skills (relative to cognitive skills) in reading comprehension for the TD population (Florit & Cain, 2011; Peng et al., 2021). In children with ASD, however, the opposite may be true. Because evidence suggests that the relation between cognitive skills and academic performance is typically stronger for children with severe disorders, than for TD children (Peng et al., 2016), and because children with ASD usually present with language delay or impairment (APA, 2013), we have reason to believe that children with ASD may compensate for their poor language skills by relying more heavily on cognitive skills while reading. Furthermore, few studies have focused on the extent to which cognitive skills (e.g., IQ, executive functions, theory of mind) and linguistic skills (e.g., phonological awareness, semantic skill, syntactic skill) of children with ASD contribute to their reading development.

Cognitive correlates

Within the cognitive domain, IQ is a core cognitive skill with complicated implications for children with ASD's reading development. Some studies have shown that IQ can help distinguish between varying levels of reading performance in children with ASD (Bullen et al., 2022; Mayes & Calhoun, 2008). However, Layton and Hao (2017) showed that Chinese students with high-functioning autism (HFA) and low-functioning autism (LFA) performed remarkably similarly on reading skills (e.g., reading simple words, and comprehending short paragraphs), as did age-matched peers who were intellectually disabled (ID), suggesting that IQ and reading skills in children with ASD may not be highly correlated. Another basic cognitive skill, visual processing, must also be taken into consideration amongst the population with ASD, as Ostrolenk et al.'s (2017) systematic review of cases and group studies demonstrated that children with ASD's visual word form area of the visual cortex exhibited higher engagement during reading tasks, compared to TD controls.

Another important cognitive skill for reading and an area of consistent deficit in children with ASD is executive function (EF; Vanegas & Davidson, 2015). EF is the set of domain-general mechanisms that enables the dynamics of human cognition and action (Miyake & Friedman, 2012), and that usually includes (but is not limited to) working memory, attentional switching, updating, and inhibition (Miyake et al., 2000). There is mixed evidence on how different components of EF are related to reading among children with ASD. For example, for working memory, whereas some researchers have demonstrated that various types of working memory and comprehension are related in populations with ASD (Davidson et al., 2018), others have found working memory to have little relation to verbal comprehension for gifted students with ASD (Assouline et al., 2012) and little relation to comprehension of syntactic structures involving reflexives (Fortunato-Tavares et al., 2015). For attentional switching, updating, and inhibition, several studies have provided evidence that attentional switching is significantly correlated with word reading, and that mental flexibility, planning, and organizing are associated with reading comprehension in children with ASD (May et al., 2015; Kasirer, 2014). However, May et al., (2013) found no difference in sustained attention and attentional switching between TD children and children with ASD, and in regression analyses, none of these EF skills were significantly associated with reading attainment. Finally, theory of mind (ToM)—the ability to understand others' behaviors through an adoption of their mental state (Frith & Frith, 2005)—is a core deficit of autism (Baron-Cohen, 2000) and another cognitive skill relevant to reading. Tong et al. (2020) investigated the relation between ToM and reading comprehension in Chinese children with ASD and showed that ToM partially explains differences in performance in reading comprehension tasks, especially those require inference, mentalizing, and evaluation.

Thus, the empirical findings on the relations between cognitive skills and reading skills among children with ASD remain largely mixed. According to dual-process theory (Evans & Stanovich, 2013), task performance is accomplished by two different processing systems: autonomous processes and controlled processes. Studies show that there is an increasing number of children with ASD experiencing reading difficulties and greater heterogeneity in reading performance within this population (Solari et al., 2019; Westerveld et al., 2017), indicating that reading tasks are quite cognitively demanding for children with ASD. In addition, more than 60% of children with ASD demonstrate difficulties in reading comprehension during their school years (Nation et al., 2006; Ricketts, 2013), which might be explained by the hypothesis that children with ASD have a specific deficit in "theory of mind" or "executive functioning". Thus, it is necessary to gain a better understanding for the degree to which basic and advanced cognitive skills are related to reading abilities as well as the factors that influence these relations. This meta-analysis systematically analyzes several moderators that potentially explain variations in the relations between cognitive skills and reading abilities of children with ASD. The moderators include types of cognitive skills (i.e., IQ, visual skills, EFs, and ToM) and types of reading (i.e., word decoding and reading comprehension). Understanding these relations and their influencing factors are important not only for the theoretical framework of how cognitive skills influence reading development of children with ASD, but also for educators, policy makers and parents in implementing more targeted intervention strategies.

Linguistic correlates

As for linguistic skills relevant to reading, the role of phonological awareness in reading abilities in children with ASD has been widely examined, but studies yield discrepant results. Dynia et al. (2017) found that phonological awareness emerged as the only statistically significant predictor of later decoding of non-words for children with ASD, but other research testing real-word decoding found phonological awareness to be independent of word recognition accuracy in school-aged children with ASD (Gabig, 2010). Oral language is another well researched linguistic skill with a nuanced relationship with reading in children with ASD. The literature on oral language distinguishes oral language as two separate skills: receptive language and expressive language. While receptive language has been shown to predict children with ASD's reading in the first year of school (Westerveld et. al, 2018), expressive language may be more influential in children with ASD's reading success, as expressive language emerges as stronger predictor of early, concurrent, and long-term reading in young children with ASD (Davidson & Ellis Weismer, 2014; St Clair et al., 2010).

Other linguistic skills that appear to correlate with reading in children with ASD include rapid automatic naming (RAN), syntax, and semantics. RAN is a reliable concurrent and longitudinal predictor of children's reading skills (Kirby et al., 2010; Lervåg & Hulme, 2009; Westerveld et al., 2018), and speed and articulation in naming can account for reading fluency (Li et al., 2009). Syntax is associated with comprehension (Cronin, 2008, 2014; Whyte et al., 2014; Zhou et al., 2017), and knowledge about and manipulation of syntax enhances the abilities of children with ASD to comprehend predicate and reflexive sentence structure (Fortunato-Tavares et al., 2015). Semantics is related to both decoding and comprehension (Cronin, 2008, 2014), and is difficult for children with ASD, as they will generate semantically infelicitous answers when attempting to explain compound words (Kambanaros et al., 2019).

As discussed previously, decoding and language comprehension are two core predictive factors of reading comprehension according to the framework of SVR (Gough & Tunmer, 1986). Peng et al.'s (2021) meta-analysis of TD children revealed that meta-linguistic skills (e.g., phonological awareness, RAN, orthographic awareness) made direct and unique contributions to decoding but did not make direct contributions to reading comprehension beyond decoding and language comprehension. In contrast, meta-analyses on children with ASD suggested that linguistic skills like semantic knowledge and syntax can explain a substantial amount of variance within reading comprehension (Brown et al., 2013; Sorenson Duncan et al., 2021). Due to the discrepancy between how TD children and children with ASD use linguistic skills to read, as well as the inconsistent findings about specific linguistic skills we have previously discussed, the present study investigates several moderators that may explain variation in the relations between linguistic skills and reading abilities of children with ASD. These moderators include types of linguistic skills (i.e., phonological awareness, oral language, RAN, semantics, and syntax) and types of reading (i.e., word decoding and reading comprehension). A systematic analysis like ours can provide a more accurate estimate of the correlations between cognitive skills, linguistic skills, and reading abilities among children with ASD, which ultimately enables us to paint a more complete picture of the extent to which cognitive and linguistic skills predict reading development in children with ASD.

The present research

Due to the heterogeneity in linguistic and cognitive skills of individuals with ASD and the varied literature on the relevance of these skills for reading in ASD, this study aims to systematically examine children with ASD's reading abilities by summarizing the cognitive and linguistic correlates of their reading development across orthographies. First, the current study determines the relations between cognitive and linguistic skills and reading abilities in children with ASD, as well as these relations' moderators. Second, this study examines unique correlations using a path model and constrains both paths to reading in order to determine the larger of the two. We hypothesize that, for children with ASD, both cognitive and linguistic skills will explain unique variance in word decoding and reading comprehension. Moreover, we hypothesize that domain-general cognitive skills may play a more important role in children with ASD's reading due to their delayed linguistic skills, compared to TD children. This meta-analysis of the correlates of reading in children with ASD will provide novel insight into the fundamental factors of general reading and language development, and in turn, inform early intervention.

Method

Literature search

We identified articles for this meta-analysis in two ways. First, we searched for literature in Education Resources Information Center (ERIC), MEDLINE, PsycArticles, and PsycInfo, from the earliest possible start date through December 2020. Second, we searched unpublished literature through Dissertation and Masters Abstract indexes in ProQuest. Titles, abstracts, and keywords were searched for using the following terms: ("Autism" or "ASD" or "autistic") AND ("children") AND ("letter sound knowledge" or "phonological awareness" or "RAN" or "oral language" or "receptive language" or "expressive language" or "grammatical" or "semantic" or "syntax" or "morphological" or "orthographic" or "executive function" or "working memory" or "inhibition" or "updating" or "switching" or "processing speed" or "visual skill" or "IQ" or "theory of mind") AND ("character recognition" or "decoding" or "word reading" or "comprehension"). The initial search yielded 2304 studies. Three authors of this study then reviewed all studies by titles and abstracts. After excluding the 2185 irrelevant articles, the remaining 119 articles were closely reviewed using the following criteria.

First, studies needed to include a sample of children with ASD. Second, studies needed to include at least one task measuring reading and at least one task measuring cognitive or linguistic skills. Reading measures were defined as tasks that tapped into one of the following skills: character recognition, decoding, word reading, and reading comprehension. Cognitive measures were defined as tasks that tapped into one of the following skills: intelligence, theory of mind, visual skill, processing speed, working memory, updating, inhibition, and switching. Linguistic measures were defined as tasks that tapped into one of the following skills: letter sound knowledge, phonological awareness, RAN, oral language, receptive language, expressive language, grammatical skill, semantic skill, syntax, morphological skill, and orthographic skill. Third, studies needed to report at least one correlation (*r*) between any measure of reading and any measure of cognitive or linguistic skills.

Coding procedure

Studies were coded according to the characteristics, samples, and tasks used to measure different types of reading, cognitive and linguistic skills. The number of participants was coded for each correlation, which was used to weight each effect size (so that correlations obtained from larger samples would be given more weight in our analysis than those obtained from smaller samples). For the coding of correlation matrices, we first constructed a correlation matrix template with variables of interest, including reading (decoding and reading comprehension), cognitive skills, and linguistic skills. We then obtained correlations from the reviewed studies to fill in the correlation matrix template for each independent sample. For a correlation matrix from an independent sample, sometimes there are multiple correlations between a pair of variables due to multiple assessments. We averaged those correlations between two variables with multiple assessments.

Variables were discussed until a consensus was reached between the first and the last authors. The second and the last authors used this coding system to independently code half of the included studies (i.e., each coder coded different studies) and then checked the remaining half that the other author had previously coded. The first and the last authors coded the correlation matrices independently. The interrater reliability among the two coders was higher than 0.95 for all variables of interests in this study. Any disagreements were resolved by consulting the original article or through discussion.

Analytic strategies

The effect size index used for all outcome measures was Pearson's *r*, the correlation between reading with cognitive and linguistic skills. We considered all eligible effect sizes in each study. That is, a study could contribute multiple effect sizes as long as the sample for each effect size was independent. For studies that reported multiple effect sizes from the same sample, we accounted for statistical dependencies using the random-effects robust standard error estimation technique developed by Hedges et al. (2010). This analysis allowed for clustered data (i.e., effect sizes nested within samples) by correcting the study standard errors to consider the correlations between effect sizes from the same sample.

Based on Borenstein et al.'s (2005) recommendations, we converted the correlation coefficients to Fisher's Z, and all analyses were performed using these transformed values. The results, such as summarized effects and their confidence intervals, were then converted back to correlation coefficients. A random-effects model was used since we hypothesized that this body of research reports a distribution of correlation coefficients with significant between-studies variance, as opposed to a group of studies that attempts to estimate one true correlation (Lipsey & Wilson, 2001). Weighted, random-effects meta-regression models using Hedges et al.'s (2010) corrections were run in R to summarize correlation coefficients and to examine potential moderators.

Specifically, we first estimated the overall weighted mean correlations of reading with cognitive and linguistic skills, respectively. Then, subgroup analyses were used to examine the relations between reading and cognitive/linguistic skills for each subgroup of each moderator. Meta-regression analyses were used to examine whether types of reading and types of cognitive and linguistic skills moderated the relations between reading and cognitive/linguistic skills. For the moderation analysis, all moderators were entered into the model simultaneously, and publication type (peer-reviewed and non peer-reviewed), language (English and others), child age, and ASD type (ASD and high-functioning ASD) were entered as covariates. Dummy coded variables were generated for categorical moderators in order to compare these categories (Cohen et al., 2013).

To examine whether cognitive and linguistic skills contributed uniquely to reading, we used two-stage MASEM (Cheung, 2014; Cheung & Chan, 2005) to estimate the path from cognitive and linguistic skills to word decoding and the path from cognitive and linguistic skills to reading comprehension, using the "metaSEM" package in R (Cheung, 2015). The two-stage MASEM combines meta-analytic techniques and structural equation modeling within a unified framework. Specifically, stage one computes the pooled correlation matrix from primary studies, and stage two fits the pooled correlation matrix to estimate a hypothesized structural equation model (Cheung, 2014; Cheung & Chan, 2005). In stage one, we pooled and estimated the correlation among cognitive skills, linguistic skills, and reading (either word decoding or reading comprehension). Our major objective was to examine the unique contribution of each cognitive and linguistic skill on reading among ASD children, however, there were only 13 studies simultaneously reporting the correlations of cognitive and linguistic skills with reading. We finally could only conduct the SEM analysis using the overall cognitive skills as a whole and the overall linguistic skills as a whole due to the power issues. Then, in stage two, we investigated the unique contributions of cognitive and linguistic skills to reading (either word decoding or reading comprehension), in which reading was regressed on both cognitive and linguistic skills. The regression weights of cognitive skills with reading and of linguistic skills with reading were estimated. In our analyses, all tested models were only identified, since the number of observed variables was identical to the number of parameters, and model fit statistics could not be estimated.

Publication bias

Publication bias was examined using the method of Egger et al. (1997) and funnel plots. We did not find significant publication bias based on Egger et al.'s (1997) publication bias statistics for the correlation between reading and linguistic skills or between reading and cognitive skills. The standard errors of correlations did not significantly predict correlations among studies βs = .98–1.40, $ps > .18$. We did not notice significant outlier or asymmetry using funnel plots.

Results

Based on our inclusion criteria, as shown in Fig. 1, a total of 93 studies were excluded for the reasons: (1) not having an ASD sample ($n=4$); (2) not having a measure of reading and a measure of cognitive/linguistic skills. ($n=36$); (3) not reporting at least one correlation between reading and cognitive/linguistic skills ($n=53$). And 26 studies involving 27 independent samples, 1,323 participants, and 331 correlations between cognitive/linguistic skills and reading among children with ASD were included for the final analyses. Due to the highly heterogeneous characteristics of children with ASD, in this meta-analysis, the age range of all the included studies was 1.92- to 18.92-year-old. Descriptive information for 26 studies included in the present meta-analysis was summarized in Table 1. And Table 2 shows the detailed correlations between reading and cognitive and linguistic skills, the size of the relation between cognitive skills and reading (including both decoding and comprehension) was $r=.39$, 95% CI [.31, .46], $\tau^2=.04$, and $r=.51$, 95% CI [.45, .57], $\tau^2=.04$, for linguistic skills and reading. After controlling for covariates and other moderators (including age, language type, publication type, sample type, and reading measures), the difference between cognitive-reading and linguistic-reading correlations was not significant,

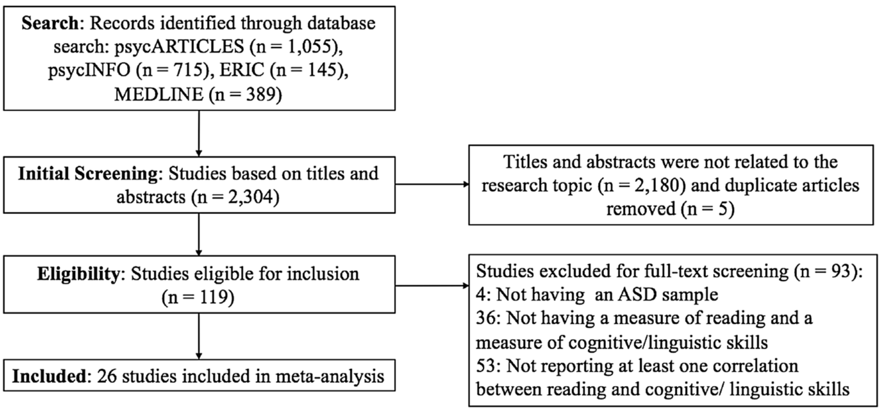

Fig. 1 Flow diagram of the inclusion of studies

Table 1 Descriptive information for the studies included in the present meta-analysis

Study	Language	Age Mean (*SD* or Range)	Clinical status of the sample	Reading measures	Cognitive measures	Language/Linguistic measures
Assouline et al. (2012)	English	127.00 (38.28)	High functioning ASD	Woodcock-Johnson-III Tests of Achievement	Beery-Buktanica Test of Visual Motor Integration; Wechsler Intelligence Scales for Children-IV; The Wechsler Adult Intelligence Test	[a]
Cardillo et al. (2021)	Italian	160.40 (44.18)	High functioning ASD	Metaphors task; Inference task	Nepsy-II battery; Reading the Mind in the Eye Test-Children's Version; E-Prime updating task	[a]
Cardoso-Martins et al. (2015)	Portuguese	137.00 (46.80)	ASD	Teste de Desempenho Escolar "Test of School Performance"; Peabody Picture Vocabulary Test-III	[a]	Pseudoword reading task; Peabody Picture Vocabulary Test-III
Cronin (2014)	English	116.40 (85.32–164.40)	High functioning ASD	Woodcock Reading Mastery Tests-Revised-Normative Update	[a]	Test of Word Reading Efficiency; Woodcock Reading Mastery Tests-Revised-Normative Update; Peabody Picture Vocabulary Test-IV; Clinical Evaluation of Language Fundamentals-IV; Oral and Written Language Scales

Table 1 (continued)

Study	Language	Age Mean (*SD* or Range)	Clinical status of the sample	Reading measures	Cognitive measures	Language/Linguistic measures
Davidson (2016)	English	129.84 (17.04)	High functioning ASD	Woodcock-Johnson Reading Mastery Test-III	Flanker task; Go/No-Go task; N-back task; Corsi Blocks task	Peabody Picture Vocabulary Test-IV; The Test of Oral Language Development, Intermediate Version, Fourth Edition
Davidson and Ellis Weismer (2014)	English	30.84 (4.16)	ASD	Test of Early Reading Ability-III	Mullen Early Scales of Learning	Test of Early Reading Ability-III; The Preschool Language Scale-IV
Davidson et al. (2018)	English	134.52 (17.76)	High Functioning ASD	The Woodcock Reading Mastery Test-III	N-back task	Woodcock Reading Mastery Test-III; Peabody Picture Vocabulary Test-IV; Test of Oral Language Development, Intermediate Version, Fourth Edition
Gabig (2010)	English	77.00 (8.59)	High functioning ASD	Woodcock Reading Mastery Test-Revised	Differential Ability Scale	Comprehensive Test of Phonological Processing; Peabody Picture Vocabulary Test-III; Test of Language Development-Primary
Henderson et al. (2014)	English	147.48 (30.12)	ASD	British ability scales-II; Neale Analysis of Reading Ability-II	[a]	British Picture Vocabulary Scales-II; Graded Nonword Reading Test
Huang et al. (2015)	Chinese	122.16 (33.12)	High functioning ASD	Figurative language task	Wechsler Intelligence Scale-III	Peabody Picture Vocabulary Test-Revised

Table 1 (continued)

Study	Language	Age Mean (*SD* or Range)	Clinical status of the sample	Reading measures	Cognitive measures	Language/Linguistic measures
Jacobs and Richdale (2013)	English	NA	High functioning ASD	Woodcock Reading Mastery Test-Revised; Neale Analysis of Reading-III	Wechsler Abbreviated Scale of Intelligence-IV; Test of Visual-Perceptual Skills (non-motor)-Revised; Attention and Memory Battery of the Leiter-R	Clinical Evaluation of Language Fundamentals-III; Comprehensive Test of Phonological Processing; Peabody Picture Vocabulary Test-III; Expressive Vocabulary Test
Knight et al. (2019)	English	68.00 (48.00–84.00)	ASD	Woodcock-Johnson III Tests of Achievement	[a]	Woodcock-Johnson III Tests of Achievement
Knight (2016)	English	NA	ASD	Gray Oral Reading Tests-V; Woodcock Johnson Tests of Achievement-III	[a]	Comprehensive Assessment of Spoken Language; Woodcock Johnson Tests of Achievement-III
May et al. (2013)	English	118.77 (20.02)	High functioning ASD	Wechsler Individual Achievement Test-II-Australian version	Wechsler Preschool and Primary School Intelligence-III; Wechsler Intelligence Scales for Children-IV; Auditory Processing Test; The Visearch task (a computerized visual search task); The Visearch dual-target task; The Vigilan task (a computerized vigilance task)	[a]

Table 1 (continued)

Study	Language	Age Mean (*SD* or Range)	Clinical status of the sample	Reading measures	Cognitive measures	Language/Linguistic measures
May et al. (2015)	English	115.40 (18.80)	High functioning ASD	Wechsler Individual Achievement Test-II-Australian version	Wechsler Intelligence Scale for Children-IV; Auditory Processing Test; Wilding Attention Tasks	[a]
Mayes and Calhoun (2008)	English	98.40 (24.00)	High functioning ASD	Wechsler Individual Achievement Test-II	Wechsler Intelligence Scale for Children-IV	[a]
McIntyre et al. (2018)	English	150.00 (25.56)	High functioning ASD	Gray Oral Reading Tests-V; Test of Word Reading Efficiency-II	Wechsler Abbreviated Scales of Intelligence-II; Happé's Strange Stories task; Silent Films task	Wechsler Individual Achievement Test-III; Wide Range Assessment of Memory and Learning-II
Nally et al. (2018)	English	97.20 (37.20–207.60)	ASD	Wechsler Individual Achievement Test-II; Neale Analysis of Reading Ability-II	[a]	Expressive One-Word Picture Vocabulary Test-IV; Preschool Language Scale-IV; Dynamic Indicators of Basic Early Literacy Skills-VI; Wechsler Individual Achievement Test-II
Tong et al. (2020)	Chinese	96.48 (7.08)	ASD	Kong Test of Specific Learning Difficulties in Reading and Writing for Primary School Students-II; Six passages (narrative and expository) task	Wechsler Abbreviated Scale of Intelligence-II; A multi-component measure of Theory of Mind task battery; Backward digit span task	Picture naming task; Vocabulary definition task

Table 1 (continued)

Study	Language	Age Mean (*SD* or Range)	Clinical status of the sample	Reading measures	Cognitive measures	Language/Linguistic measures
Weissinger (2014)	English	NA (108–168)	ASD	Stanford Diagnostic Reading Test-IV; Test of Word Reading Efficiency; Woodcock Reading Mastery Tests-Revised	Tower Test of the Delis-Kaplan Executive Function System; Happé's Strange Stories Test; Sentence Span Test	Peabody Picture Vocabulary Test Vocabulary-IV; Woodcock Reading Mastery Tests-Revised
Westerveld et al. (2018)	English	57.60 (5.70)	ASD	Castles and Coltheart Test 2; York Assessment of Reading for Comprehension	Digit span task form NEPSY-II	Peabody Picture Vocabulary Test-IV; Phonological Awareness Literacy Screening for Preschoolers; Woodcock Reading Mastery Tests-Revised
Westerveld et al. (2017)	English	57.60 (6.11)	ASD	Phonological Awareness Literacy Screening for Preschoolers; The Profile of Oral Narrative Ability task	[a]	Phonological Awareness Literacy Screening for Preschoolers; Peabody Picture Vocabulary Test Vocabulary-IV; Woodcock Reading Mastery Tests-Revised
Westerveld and Roberts (2017)	English	57.30 (5.70)	ASD	The Profile of Oral Narrative Ability task	[a]	Peabody Picture Vocabulary Test Vocabulary-IV
White (2006)	English	119.27 (19.36)	High functioning ASD	Wide Range Achievement Test 3	[a]	Phonological Assessment Battery

Table 1 (continued)

Study	Language	Age Mean (*SD* or Range)	Clinical status of the sample	Reading measures	Cognitive measures	Language/Linguistic measures
Whyte et al. (2014)	English	115.50 (22.70)	High functioning ASD	An idiom comprehension task; Verbally define the meaning of the 20 idioms in the context of a short paragraph	Reading the Mind in the Eye Test-Children's Version; Strange stories task	Comprehensive Assessment of Spoken Language; Kaufman Brief Intelligence Test (2nd ed.)
Zhao et al. (2019)	Chinese	57.00 (9.00)	ASD	Chinese character recognition task; Hong Kong Cantonese Oral Language Assessment Scale	Raven's Standard Progressive Matrices; Dimensional Change Card Sorting task; Digit span task	Syllable deletion task; Pseudoword compounding task; Peabody Picture Vocabulary Test-Revised; Rapid automatized naming task

Units of age were uniformly converted into month based on the data from the studies. *NA* not available. Range = the study did not provide the mean of age but provided the range of age information

[a]No test given in this category or statistics can not be transformed to correlations

Table 2 Correlations between reading and cognitive and linguistic skills

Measures	Word decoding				Reading comprehension				Reading			
	k	*r*	95% CI	τ^2	*k*	*r*	95% CI	τ^2	*k*	*r*	95% CI	τ^2
Cognitive skills	66	.39	[.32, .44]	.02	71	.40	[.30, .50]	.05	133	.39	[.31, .46]	.04
Linguistic skills	110	.51	[.44, .56]	.04	92	.51	[.44, .57]	.03	199	.51	[.45, .57]	.04
Types of cognitive skills												
Intelligence	18	.47	[.39, .55]	.01	29	.47	[.25, .65]	.08	49	.41	[.30, .51]	.03
Theory of mind	13	.26	[.04, .47]	.00	15	.52	[.32, .69]	.04	28	.46	[.26, .62]	.03
Basic cognitive skills	2	–	–	–	3	–	–	–	7	.30	[–.19, .67]	.09
Executive functions	24	.49	[.39, .59]	.02	24	.38	[.12, .59]	.08	49	.39	[.29, .49]	.04
Types of linguistic skills												
Phonological skills	54	.65	[.55, .74]	.08	40	.51	[.38, .64]	.07	94	.53	[.46, .49]	.03
Semantic skills	43	.49	[.37, .59]	.06	43	.62	[.49, .73]	.10	86	.50	[.42, .58]	.06
Syntax skills	10	.41	[.01, .71]	.07	9	–	–	–	19	.53	[.29, .71]	.06

k = number of effect sizes; *CI* confidence interval, τ^2 = Between-study Sampling Variance

–Not sufficient effect sizes

$\beta = .12$, $SE = .06$, $t = 2.03$, 95% CI [.00, .25], $p = .06$. Next, we examined the relation between cognitive/linguistic skills and reading for the subcategory of each moderator, and whether the type of reading, type of cognitive skill, or type of linguistic skill affected the correlations between cognitive/linguistic skills and reading.

Moderation effects of reading skills

With respect to the relation between cognitive skills and reading among children with ASD, there were 66 correlations involving word decoding, and 71 correlations involving language comprehension. The average correlation between cognitive skills and word decoding was significant, $r = .39$, 95% CI [.32, .44], $\tau^2 = .02$, and the average correlation between cognitive skills and reading comprehension was also significant, $r = .40$, 95% CI [.30, .50], $\tau^2 = .05$. As Table 3 shows, after controlling for covariates and other moderators (including age, language type, publication type, sample type, and cognitive skills), no significant difference was found between the correlations, $\beta = -.08$, $SE = .08$, $t = -1.02$, 95% CI [–.24, .09], $p = .33$. The average correlations of linguistic skills with word decoding, $r = .51$, 95% CI [.44, .56], $\tau^2 = .04$, and with reading comprehension, $r = .51$, 95% CI [.44, .57], $\tau^2 = .03$, were significant. As Table 4 shows, after controlling for covariates and other moderators (including age, language type, publication type,

Table 3 Moderation analysis on the correlations between cognitive skills and reading

Moderators	β	*SE*	*t*	95% CI	*p*
Age	.01	.02	.20	[–.05, .06]	.85
Language					
English vs. others	.24	.07	3.54	[.07, .41]	.01
Publication type					
Peer-reviewed vs. Non peer-reviewed	–.06	.10	–.64	[–.43, .31]	.58
Sample type					
ASD vs. High functioning ASD	.11	.14	.77	[–.24, .45]	.47
Types of reading					
Decoding vs. Reading comprehension	–.08	.08	–1.02	[–.24, .09]	.33
Decoding vs. Composite	–.02	.09	–.21	[–.24, .20]	.84
Reading comprehension vs. Composite	–.06	.10	–.57	[–.29, .18]	.59
Types of cognitive skills					
Intelligence vs. Theory of mind	–.12	.13	–.88	[–.44, .20]	.41
Intelligence vs. Basic cognitive skills	.16	.21	.77	[–.67, 1.00]	.52
Intelligence vs. Executive function	.01	.06	.18	[–.13, .15]	.86
Theory of mind vs. Basic cognitive skills	.28	.24	1.16	[–.40, .95]	.31
Theory of mind vs. Executive function	.10	.13	.78	[–.22, .43]	.46
Basic cognitive skills vs. Executive function	–.17	.20	–.88	[–.82, .48]	.45

Table 4 Moderation analysis on the correlations between linguistic skills and reading

Moderators	β	*SE*	*t*	95% CI	*p*
Age	.02	.02	1.61	[–.01, .06]	.15
Language					
English vs. others	.16	.13	1.29	[.16, .49]	.25
Publication type					
Peer-reviewed vs. Non peer-reviewed	–.06	.09	–.71	[–.34, .22]	.53
Sample type					
ASD vs. High functioning ASD	.06	.12	.47	[–.21, .32]	.65
Types of reading					
Decoding vs. Reading comprehension	–.04	.06	–.71	[–.17, .09]	.49
Types of linguistic skills					
Phonological skills vs. Semantic skills	.03	.07	.36	[–.12, .17]	.72
Phonological skills vs. Syntax skills	–.00	.12	–.01	[–.28, .28]	.99
Semantic skills vs. Syntax skills	–.03	.11	–.25	[–.29, .24]	.81

sample type, and linguistic skills), no significant difference was found between the correlation, $\beta = -.04$, $SE = .06$, $t = -.71$, 95% CI [− .17, .09], $p = .49$.

Moderation effects of cognitive skills

With respect to the relation between cognitive skills and reading among children with ASD, there were 49 correlations involving intelligence, 28 correlations involving theory of mind, 7 correlations involving basic cognitive skills (visual skills and processing speed were combined), and 49 correlations involving executive function. The average correlation between reading (which included word decoding and reading comprehension) the following cognitive skills were significant: intelligence, $r = .41$, 95% CI [.30, .51], $\tau^2 = .03$; theory of mind, $r = .46$, 95% CI [.26, .62], $\tau^2 = .03$; and executive function, $r = .39$, 95% CI [.29, .49], $\tau^2 = .04$. However, the correlation between reading and basic cognitive skills was not significant, $r = .30$, 95% CI [–.19, .67], $\tau^2 = .09$. As Table 3 shows, after controlling for covariates and other moderators (including age, language type, publication type, sample type, and reading measures), no significant differences were found in all comparisons.

Moderation effects of linguistic skills

With respect to the relation between linguistic skills and reading among children with ASD, there were 94 correlations involving phonological skills, 86 correlations involving semantic skills, 19 correlations involving syntax skills. The average correlation between reading (which included word decoding and reading comprehension) and each of the three linguistic skills was significant: phonological skills, $r = .53$, 95% CI [.46, .59], $\tau^2 = .03$, semantic skills, $r = .50$, 95% CI [.42, .58], $\tau^2 = .06$, and syntax skills, $r = .53$, 95% CI [.29, .71], $\tau^2 = .06$. As Table 4 shows, after controlling for covariates and other moderators (including age, language type, publication type, sample type, and reading measures), no significant differences were found in all comparisons.

Unique contribution of cognitive and linguistic skills to reading

We used two-stage MASEM to examine the unique contribution of cognitive and linguistic skills on reading in children with ASD. After correlation matrices were extracted from studies including correlations among cognitive skills, linguistic skills, and reading, we ended with 13 independent samples with 515 ASD participants. We found that cognitive skills contributed to reading when linguistic skills were controlled ($\beta = .32$, 95% CI [.22, .42], $p < .001$), and linguistic skills also contributed to reading when cognitive skills were partialled out ($\beta = .24$, 95% CI [.15, .35], $p < .001$).

Next, we examined the unique contribution of cognitive and linguistic skills on word decoding. After correlation matrices were extracted from studies including correlations among cognitive skills, linguistic skills, and word decoding, we ended with 10 independent samples with 345 ASD participants. We found that cognitive skills contributed to word decoding after controlling for linguistic skills ($\beta = .29$, 95% CI [.17, .41], $p < .001$), and linguistic skills also contributed to word decoding when cognitive skills were controlled for ($\beta = .21$, 95% CI [.09, .32], $p < .001$).

Finally, we examined the unique contribution of cognitive and linguistic skills on reading comprehension. After correlation matrices were extracted from studies including correlations among cognitive skills, linguistic skills, and reading comprehension, we ended with 12 independent samples with 501 ASD participants. We found that cognitive skills contributed to reading comprehension after controlling for linguistic skills ($\beta = .34$, 95% CI [.23, .45], $p < .001$), and linguistic skills also contributed to reading comprehension when cognitive skills were controlled for ($\beta = .25$, 95% CI [.11, .39], $p < .001$).

Discussion

This meta-analysis provided evidence of the cognitive and linguistic correlates of reading in children with autism. We found that both cognitive and linguistic skills contributed to reading across various orthographies in ASD populations. Both cognitive skills and linguistic skills showed comparable relations to reading, supporting the compensatory mechanism. Sample type, types of reading, types of cognitive skills, and types of linguistic skills did not moderate these relations. Below we discussed these findings in details.

The correlations of cognitive and linguistic skills with word decoding and reading comprehension

In finding that cognitive and linguistic skills contributed to reading abilities and that the degree of their contributions was similar, we asserted that basic and advanced cognitive skills and reading-related linguistics factors are equally imperative for learning to read. Further, both decoding and comprehension showed comparable correlations with cognitive and linguistic skills.

Within the cognitive domain, we found that intelligence, executive function, and ToM are significant predictors of reading in children with ASD. These findings echo previous literature, as May et al. (2013) also found that full-scale IQ explained a significant amount of variance in word reading attainment in individuals with ASD. Another study by Lin and Chiang (2014) showed that when IQ was controlled for, there was no longer a significant difference in language comprehension between children with ASD and those with Asperger's Syndrome, suggesting that IQ may be responsible for variation in language comprehension abilities amongst those on the autism spectrum. The large role that executive function has in reading ability is consistent with the Executive Dysfunction Theory of autism, which asserts that the executive function deficits (e.g., deficits in inhibition, attentional switching, and working memory) are responsible for symptoms in individuals with ASD (Pennington & Ozonoff, 1996) and may extend to the autists' impairments in language, since problems in reading comprehension may be caused by poor working memory or strategic planning (Locascio et al., 2010). Further, ToM plays an important function in reading, as impairments in ToM have been postulated as a major reason for social communicative deficits of autism (Baron-Cohen, 2000). These deficits set autism apart from other mental conditions with comorbid symptoms (e.g., ADHD which is also characterized by poor executive functioning, academic achievement, and reading skills) and notably, uniquely predict reading difficulties in children with high-functioning ASD, compared to ADHD and TD groups (McIntyre et al., 2017a, 2017b). Oberman and Ramachandran (2007) offered an explanation for this close relationship between ToM and language comprehension: language comprehension tasks requiring ToM (e.g., interpreting metaphorical language) make use of the mirror neuron system, which allows for the embodiment of the abstract language being used and which is compromised in individuals with ASD. ToM may also influence children with ASD's reading in an indirect way (Sigman & Ungerer, 1984): the other cognitive deficits seen in children with ASD (e.g., deficits in executive functioning or visual processing) are "secondary" to social deficits. That is, development of these other cognitive skills requires highly functioning social cognitive skills like ToM, and thus, it is deficits in ToM that constrain the development of other cognitive skills important for reading development.

As for the linguistic domain, we identified phonological, semantic, and syntactic skills as significant predictors of reading ability. Like TD children, children with ASD use phonological awareness in reading and to a degree that is more than that of children with other disabilities (Dynia et al., 2017). Moreover, phonological awareness may have an indirect effect on children with ASD's reading comprehension through its role in vocabulary and verbal memory (Engen & Høien, 2002). However, children with autism may also rely on other statistical learning strategies (e.g., perceiving visual similarities across whole words) in reading process (Cardoso-Martins & Da Silva, 2010). For semantic skills, children with ASD's knowledge about concepts, vocabulary and word frameworks is so imperative that limited integration of these various pieces of knowledge leads to the emergence of differing comprehension profiles (Carnahan & Williamson, 2013; Williamson et al., 2012). Additionally, semantic knowledge is particularly important for expressive vocabulary development, which further predicts decoding and reading comprehension in children with ASD (Davidson & Ellis Weismer, 2014; Wise et al., 2007; Young & Killen, 2002). For syntactic skills, Jacobs and Richdale (2013) observed that syntax predicts reading comprehension for both TD children and children with high-functioning ASD. Furthermore, in an intervention study of anaphoric cueing, emphasizing pronouns' functions and relations to other words within their respective sentences and paragraphs was effective in improving children with high-functioning ASD's reading comprehension (Feng & Peng, 2019). Finally, at the interface of these various linguistic skills, children with ASD struggle with integrating syntax with semantics and pragmatics (Kambanaros et al., 2019). Consistent with these findings, our meta-analytic results indicate that linguistic skills including phonological awareness, semantic and syntactic skills, as well as the integration of these skills, are critical for reading among children with ASD.

The unique roles of cognitive and linguistic skills in reading

Meta-analytic structural equation modeling demonstrated that cognitive skills and linguistic skills uniquely predicted either decoding or reading comprehension skills in children with ASD. This finding stands out in contrast to similar meta-analyses conducted on typically-developing children: Peng et al. (2022) found that while cognitive skills could explain the variance in reading abilities in typically developing children, cognitive skills did not directly influence reading comprehension, after controlling for decoding and language comprehension. Peng et al. (2022) also suggested linguistic skills largely explained the cognitive differences between TD and population with reading difficulties (RD). Our present finding suggests the population with ASD is different from the population with RD in that the population with ASD exhibits both cognitive and language deficits, children with ASD are more likely to suffer from difficulty in reading and their cognitive and language deficits seemed equally important for reading. While for TD and populations with RD, linguistic skills play a more important role in their reading development.

Since our findings showed that in children with ASD, cognitive and linguistic skills play an equally crucial role in reading development, we tentatively draw two conclusions. First, because we controlled for cognitive skills and still found a significant effect of linguistic skills, we suggest that linguistic skills play a unique and direct role in both decoding and reading comprehension rather than simply regulating reading comprehension through decoding and language comprehension. Second, we have reason to believe that cognitive skills play an important role in reading, especially reading comprehension, for children with ASD, and this may compensate for their deficits in linguistic skills. This can be further understood through the theoretical perspective of neuroconstructivism: growth or constrains in one developmental domain may influence the developmental mechanism in other important domains. For example, Fisher et al. (2005) found that children with ASD rely more on language to understand ToM tasks than do typically developing children. Conversely, the additional burden of language delay in children with ASD may lead to relying more on cognitive skills in their reading development. Since ASD involves core deficits in the social cognitive and linguistic domains, cognitive skills may compensate for linguistic limitations and support children with ASD in developing their reading, both in decoding and reading comprehension.

Limitations and future directions

Several limitations are considered in the interpretation of our findings and form the motivation for future research directions. First, in order to understand the specific deficits in reading comprehension among this population, we originally aimed to explore how the relationship of cognitive and linguistic skills with each component of SVR (word decoding and language comprehension) varied across different moderators, and whether these effects on reading varied by subgroups of ASD. However, after selecting our reviewed studies, we did not find enough data on the effects of cognitive and linguistic correlates on decoding and comprehension separately, making it difficult to consider each of these skills in the model. Thus, our findings should be further validated with both cognitive and linguistic skills when more data is available in decoding and reading comprehension development in children with ASD. Second, we used two-stage MASEM in our analysis, which is unable to estimate the between-study heterogeneities given that the model is fitted on the pooled correlation matrix but not directly on the observed correlations as the one-stage MASEM. These issues would be further investigated with more studies in the future. Third, in this meta-analysis, we have examined the correlates of reading in the population with ASD as a whole, without partitioning out various population subgroups, such as children who perform poorly in all reading and language skills, children with hyperlexia, and children who have reading skills commensurate with typically developing children (McIntyre et al., 2017a, 2017b). Partitioning out subgroups in future studies will allow us to understand how correlates of reading may differ based on strengths and weaknesses within particular profiles of reading ability, which are sometimes associated with distinct processing mechanisms (Macdonald et al., 2021).

Conclusion

Despite these limitations, our study is the first meta-structural analysis that has systematically investigated the cognitive and linguistic correlates of reading abilities among children with ASD across orthographies. Our findings have several important implications for reading development and intervention in the population with ASD.

Theoretically speaking, our findings indicate that both cognitive and linguistic skills equally predict children with ASD's word decoding and reading comprehension and suggest a compensatory mechanism of cognitive and linguistic skills for learning to read. Practically speaking, the cognitive and linguistic skills we have identified as correlates of reading can serve as useful and accurate diagnostic markers for future reading success in young children with ASD (Anderson et al., 2007). Furthermore, heterogeneity in reading abilities within the population with ASD may reflect varying sensitivities to different degrees and types of support in language learning environments (Pickles et al., 2014), urging educators, parents, and policy makers to utilize targeted early intervention strategies that make use of these cognitive and linguistic skills to improve children with ASD's decoding and comprehension skills.

Acknowledgements This study was supported by National Natural Science Foundation of China Grant (31900771; 32000761) and the Humanities and Social Science project of the Ministry of Education of China (No. 20YJC880095).

Declarations

Conflict of interest We have no known conflict of interest to disclose.

References

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders* (5th ed.). https://doi.org/10.1176/appi.books.9780890425596

Anderson, D. K., Lord, C., Risi, S., DiLavore, P. S., Shulman, C., Thurm, A., Welch, K., & Pickles, A. (2007). Patterns of growth in verbal abilities among children with autism spectrum disorder. *Journal of Consulting and Clinical Psychology, 75*(4), 594–604. https://doi.org/10.1037/0022-006X.75.4.594

Assouline, S. G., Foley Nicpon, M., & Dockery, L. (2012). Predicting the academic achievement of gifted students with autism spectrum disorder. *Journal of Autism and Developmental Disorders, 42*(9), 1781–1789. https://doi.org/10.1007/s10803-011-1403-x

Baron-Cohen, S. (2000). Theory of mind and autism: A fifteen year review. In S. Baron-Cohen, H. Tager-Flusberg, & D. J. Cohen (Eds.), *Understanding other minds: Perspectives from developmental cognitive neuroscience* (pp. 3–20). Oxford University Press.

Borenstein, M., Hedges, L. V., Higgins, J. P. T., & Rothstein, H. R. (2005). *Comprehensive meta-analysis (Version 2)*. Biostat.

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

Bullen, J. C., Zajic, M. C., McIntyre, N., Solari, E., & Mundy, P. (2022). Patterns of math and reading achievement in children and adolescents with autism spectrum disorder. *Research in Autism Spectrum Disorders, 92*, 101933. https://doi.org/10.1016/j.rasd.2022.101933

Cardillo, R., Mammarella, I. C., Demurie, E., Giofrè, D., & Roeyers, H. (2021). Pragmatic language in children and adolescents with autism spectrum disorder: Do theory of mind and executive functions have a mediating role? *Autism Research, 14*(5), 932–945. https://doi.org/10.1002/aur.2423

Cardoso-Martins, C., & Da Silva, J. R. (2010). Cognitive and language correlates of hyperlexia: Evidence from children with autism spectrum disorders. *Reading and Writing, 23*(2), 129–145. https://doi.org/10.1007/s11145-008-9154-6

Cardoso-Martins, C., Gonçalves, D. T., de Magalhães, C. G., & da Silva, J. R. (2015). Word reading and spelling ability in school-age children and adolescents with autism spectrum disorders: Evidence

from brazilian portuguese. *Psychology & Neuroscience, 8*(4), 479–487. https://doi.org/10.1037/pne0000029
Carnahan, C. R., & Williamson, P. S. (2013). Does compare-contrast text structure help students with autism spectrum disorder comprehend science text? *Exceptional Children, 79*(3), 347–363. https://doi.org/10.1177/001440291307900302
Cheung, M.W.-L. (2014). Fixed- and random-effects meta-analytic structural equation modeling: Examples and analyses in R. *Behavior Research Methods, 46*(1), 29–40. https://doi.org/10.3758/s13428-013-0361-y
Cheung, M.W.-L. (2015). metaSEM: An R package for meta-analysis using structural equation modeling. *Frontiers in Psychology, 5*, 1521. https://doi.org/10.3389/fpsyg.2014.01521
Cheung, M.W.-L., & Chan, W. (2005). Meta-analytic structural equation modeling: A two-stage approach. *Psychological Methods, 10*(1), 40–64. https://doi.org/10.1037/1082-989X.10.1.40
Cohen, J., Cohen, P., West, S. G., & Aiken, L. S. (2013). *Applied multiple regression/correlation analysis for the behavioral sciences*. Routledge.
Cronin, K. A. (2008). *Reading skills of children with autism: What role does oral language play in decoding skills and reading comprehension?* [Unpublished doctoral dissertation]. University of California, Riverside
Cronin, K. A. (2014). The relationship among oral language, decoding skills, and reading comprehension in children with autism. *Exceptionality, 22*(3), 141–157. https://doi.org/10.1080/09362835.2013.865531
*Davidson, M. M. (2016). *Reading for meaning: Reading comprehension skills in ASD and the role of oral language, central coherence, and executive function* [Unpublished doctoral dissertation]. The University of Wisconsin-Madison.
Davidson, M. M., & Ellis Weismer, S. (2014). Characterization and prediction of early reading abilities in children on the autism spectrum. *Journal of Autism and Developmental Disorders, 44*(4), 828–845. https://doi.org/10.1007/s10803-013-1936-2
Davidson, M. M., Kaushanskaya, M., & Susan, E. W. (2018). Reading comprehension in children with and without ASD: The role of word reading, oral language, and working memory. *Journal of Autism and Developmental Disorders, 48*(10), 3524–3541. https://doi.org/10.1007/s10803-018-3617-7
Dong, Y., Peng, S. N., Sun, Y. K., Wu, S. X. Y., & Wang, W. S. (2020). Reading comprehension and metalinguistic knowledge in Chinese readers: A meta-analysis. *Frontiers in Psychology, 10*, 3037. https://doi.org/10.3389/fpsyg.2019.03037
Dynia, J. M., Brock, M. E., Justice, L. M., & Kaderavek, J. N. (2017). Predictors of decoding for children with autism spectrum disorder in comparison to their peers. *Research in Autism Spectrum Disorders, 37*, 41–48. https://doi.org/10.1016/j.rasd.2017.02.003
Egger, M., Smith, G. D., Schneider, M., & Minder, C. (1997). Bias in meta-analysis detected by a simple, graphical test. *Bmj-British Medical Journal, 315*(7109), 629–634. https://doi.org/10.1136/bmj.315.7109.629
Engen, L., & Høien, T. (2002). Phonological skills and reading comprehension. *Reading and Writing, 15*(7), 613–631. https://doi.org/10.1023/A:1020958105218
Evans, J. S. B. T., & Stanovich, K. E. (2013). Dual-process theories of higher cognition: Advancing the debate. *Perspectives on Psychological Science, 8*(3), 223–241. https://doi.org/10.1177/1745691612460685
Feng, Y., & Peng, S. (2019). The effect of anaphoric cueing instruction on improving reading comprehension of students with high-functioning autism. *Chinese Journal of Special Education, 12*, 40–46.
Fisher, N., Happé, F., & Dunn, J. (2005). The relationship between vocabulary, grammar, and false belief task performance in children with autistic spectrum disorders and children with moderate learning difficulties. *Journal of Child Psychology and Psychiatry, 46*(4), 409–419. https://doi.org/10.1111/j.1469-7610.2004.00371.x
Florit, E., & Cain, K. (2011). The simple view of reading: Is it valid for different types of alphabetic orthographies? *Educational Psychology Review, 23*(4), 553–576. https://doi.org/10.1007/s10648-011-9175-6
Follmer, D. J. (2018). Executive function and reading comprehension: A meta-analytic review. *Educational Psychologist, 53*(1), 42–60. https://doi.org/10.1080/00461520.2017.1309295
Fortunato-Tavares, T., Andrade, C. R. F., Befi-Lopes, D., Limongi, S. O., Fernandes, F. D. M., & Schwartz, R. G. (2015). Syntactic comprehension and working memory in children with specific language impairment, autism or Down syndrome. *Clinical Linguistics & Phonetics, 29*(7), 499–522. https://doi.org/10.3109/02699206.2015.1027831

Frith, C., & Frith, U. (2005). Theory of mind. *Current Biology, 15*(17), R644–R645. https://doi.org/10.1016/j.cub.2005.08.041

Gabig, C. S. (2010). Phonological awareness and word recognition in reading by children with autism. *Communication Disorders Quarterly, 31*(2), 67–85. https://doi.org/10.1177/1525740108328410

Georgiou, G. K., Das, J. P., & Hayward, D. (2009). Revisiting the "simple view of reading" in a group of children with poor reading comprehension. *Journal of Learning Disabilities, 42*(1), 76–84. https://doi.org/10.1177/0022219408326210

Gough, P. B., & Tunmer, W. E. (1986). Decoding, reading, and reading disability. *Remedial & Special Education, 7*(1), 6–10. https://doi.org/10.1177/074193258600700104

Hedges, L. V., Tipton, E., & Johnson, M. C. (2010). Robust variance estimation in meta-regression with dependent effect size estimates. *Research Synthesis Methods, 1*(1), 39–65. https://doi.org/10.1002/jrsm.5

Henderson, L. M., Clarke, P. J., & Snowling, M. J. (2014). Reading comprehension impairments in autism spectrum disorders. *L'année Psychologique, 114*(4), 779–797. https://doi.org/10.4074/S0003503314004084

Huang, S., Oi, M., & Taguchi, A. (2015). Comprehension of figurative language in taiwanese children with autism: The role of theory of mind and receptive vocabulary. *Clinical Linguistics & Phonetics, 29*(8–10), 764–775. https://doi.org/10.3109/02699206.2015.1027833

Hung, C. O., & Loh, E. K. (2021). Examining the contribution of cognitive flexibility to metalinguistic skills and reading comprehension. *Educational Psychology, 41*(6), 712–729. https://doi.org/10.1080/01443410.2020.1734187

Jacob, R., & Parkinson, J. (2015). The potential for school-based interventions that target executive function to improve academic achievement: A review. *Review of Educational Research, 85*(4), 512–552. https://doi.org/10.3102/0034654314561338

Jacobs, D. W., & Richdale, A. L. (2013). Predicting literacy in children with a high-functioning autism spectrum disorder. *Research in Developmental Disabilities, 34*(8), 2379–2390. https://doi.org/10.1016/j.ridd.2013.04.007

Kambanaros, M., Christou, N., & Grohmann, K. K. (2019). Interpretation of compound words by greek-speaking children with autism spectrum disorder plus language impairment (ASD-LI). *Clinical Linguistics & Phonetics, 33*(1–2), 135–174. https://doi.org/10.1080/02699206.2018.1495766

Kasirer, A., & Mashal, N. (2014). Verbal creativity in autism: Comprehension and generation of metaphoric language in high-functioning autism spectrum disorder and typical development. *Frontiers in Human Neuroscience, 8*, 615. https://doi.org/10.3389/fnhum.2014.00615

Kirby, J. R., Georgiou, G. K., Martinussen, R., & Parrila, R. (2010). Naming speed and reading: From prediction to instruction. *Reading Research Quarterly, 45*(3), 341–362. https://doi.org/10.1598/RRQ.45.3.4

Knight, E., Blacher, J., & Eisenhower, A. (2019). Predicting reading comprehension in young children with autism spectrum disorder. *School Psychology, 34*(2), 168–177. https://doi.org/10.1037/spq0000277

Knight, E. M. (2016). *Development of reading, language, and social skills in young children with ASD* [Unpublished doctoral dissertation]. University of California, Riverside.

Lanter, E., & Watson, L. R. (2008). Promoting literacy in students with ASD: The basics for the SLP. *Language, Speech, and Hearing Services in Schools, 39*(1), 33–43. https://doi.org/10.1044/0161-1461(2008/004)

Layton, T. L., & Hao, G. (2017). Academic skills in high-functioning and low-functioning Chinese children with autism. *Journal of Intellectual Disability—Diagnosis and Treatment, 5*(1), 7–17. https://doi.org/10.6000/2292-2598.2017.05.01.2

Lervåg, A., & Hulme, C. (2009). Rapid automatized naming (RAN) taps a mechanism that places constraints on the development of early reading fluency. *Psychological Science, 20*(8), 1040–1048. https://doi.org/10.1111/j.1467-9280.2009.02405.x

Li, J. J., Cutting, L. E., Ryan, M., Zilioli, M., Denckla, M. B., & Mahone, E. M. (2009). Response variability in rapid automatized naming predicts reading comprehension. *Journal of Clinical and Experimental Neuropsychology, 31*(7), 877–888. https://doi.org/10.1080/13803390802646973

Lin, Y., & Chiang, H. (2014). Language comprehension of children with Asperger's disorder and children with autistic disorder. *Research in Autism Spectrum Disorders, 8*(7), 767–774. https://doi.org/10.1016/j.rasd.2014.03.018

Lipsey, M. W., & Wilson, D. B. (2001). *Practical meta-analysis*. SAGE Publications.

Locascio, G., Mahone, E. M., Eason, S. H., & Cutting, L. E. (2010). Executive dysfunction among children with reading comprehension deficits. *Journal of Learning Disabilities, 43*(5), 441–454. https://doi.org/10.1177/0022219409355476

McBride-Chang, C., & Kail, R. V. (2002). Cross-cultural similarities in the predictors of reading acquisition. *Child Development, 73*(5), 1392–1407. https://doi.org/10.1111/1467-8624.00479

Macdonald, D., Luk, G., & Quintin, E. (2021). Early word reading of preschoolers with ASD, both with and without hyperlexia, compared to typically developing preschoolers. *Journal of Autism and Developmental Disorders, 51*(5), 1598–1612. https://doi.org/10.1007/s10803-020-04628-8

May, T., Rinehart, N., Wilding, J., & Cornish, K. (2013). The role of attention in the academic attainment of children with autism spectrum disorder. *Journal of Autism and Developmental Disorders, 43*(9), 2147–2158. https://doi.org/10.1007/s10803-013-1766-2

May, T., Rinehart, N. J., Wilding, J., & Cornish, K. (2015). Attention and basic literacy and numeracy in children with Autism Spectrum Disorder: A one-year follow-up study. *Research in Autism Spectrum Disorders, 9*, 193–201. https://doi.org/10.1016/j.rasd.2014.10.010

Mayes, S. D., & Calhoun, S. L. (2008). WISC-IV and WIAT-II profiles in children with high-functioning autism. *Journal of Autism and Developmental Disorders, 38*(3), 428–439. https://doi.org/10.1007/s10803-007-0410-4

McIntyre, N. S., Oswald, T. M., Solari, E. J., Zajic, M. C., Lerro, L. E., Hughes, C., Devine, R. T., & Mundy, P. C. (2018). Social cognition and reading comprehension in children and adolescents with autism spectrum disorders or typical development. *Research in Autism Spectrum Disorders, 54*, 9–20. https://doi.org/10.1016/j.rasd.2018.06.004

McIntyre, N. S., Solari, E. J., Gonzales, J. E., Solomon, M., Lerro, L. E., Novotny, S., Oswald, T. M., & Mundy, P. C. (2017a). The scope and nature of reading comprehension impairments in school-aged children with higher-functioning autism spectrum disorder. *Journal of Autism and Developmental Disorders, 47*(9), 2838–2860. https://doi.org/10.1007/s10803-017-3209-y

McIntyre, N. S., Solari, E. J., Grimm, R. P., Lerro, L. E., Gonzales, J. E., & Mundy, P. C. (2017b). A comprehensive examination of reading heterogeneity in students with high functioning autism: Distinct reading profiles and their relation to autism symptom severity. *Journal of Autism and Developmental Disorders, 47*(4), 1086–1101. https://doi.org/10.1007/s10803-017-3029-0

Miyake, A., & Friedman, N. P. (2012). The nature and organization of individual differences in executive functions: Four general conclusions. *Current Directions in Psychological Science, 21*(1), 8–14. https://doi.org/10.1177/0963721411429458

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., & Howerter, A. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology, 41*(1), 49–100. https://doi.org/10.1006/cogp.1999.0734

Muter, V., Hulme, C., Snowling, M. J., & Stevenson, J. (2004). Phonemes, rimes, vocabulary, and grammatical skills as foundations of early reading development: Evidence from a longitudinal study. *Developmental Psychology, 40*(5), 665–681. https://doi.org/10.1037/0012-1649.40.5.665

Nally, A., Healy, O., Holloway, J., & Lydon, H. (2018). An analysis of reading abilities in children with autism spectrum disorders. *Research in Autism Spectrum Disorders, 47*, 14–25. https://doi.org/10.1016/j.rasd.2017.12.002

Nation, K., Clarke, P., Wright, B., & Williams, C. (2006). Patterns of reading ability in children with autism spectrum disorder. *Journal of Autism and Developmental Disorders, 36*(7), 911–919. https://doi.org/10.1007/s10803-006-0130-1

Oberman, L. M., & Ramachandran, V. S. (2007). The simulating social mind: The role of the mirror neuron system and simulation in the social and communicative deficits of autism spectrum disorders. *Psychological Bulletin, 133*(2), 310–327. https://doi.org/10.1037/0033-2909.133.2.310

Ostrolenk, A., Forgeot d'Arc, B., Jelenic, P., Samson, F., & Mottron, L. (2017). Hyperlexia: Systematic review, neurocognitive modelling, and outcome. *Neuroscience and Biobehavioral Reviews, 79*, 134–149. https://doi.org/10.1016/j.neubiorev.2017.04.029

Peng, P., Barnes, M., Wang, C., Wang, W., Li, S., Swanson, H. L., Dardick, W., & Tao, S. (2018). A meta-analysis on the relation between reading and working memory. *Psychological Bulletin, 144*(1), 48–76. https://doi.org/10.1037/bul0000124

Peng, P., Lee, K., Luo, J., Li, S., Joshi, R. M., & Tao, S. (2021). Simple view of reading in chinese: A one-stage meta-analytic structural equation modeling. *Review of Educational Research, 91*(1), 3–33. https://doi.org/10.3102/0034654320964198

Peng, P., Namkung, J. M., Fuchs, D., Fuchs, L. S., Patton, S., Yen, L., Compton, D. L., Zhang, W., Miller, A., & Hamlett, C. (2016). A longitudinal study on predictors of early calculation development

among young children at risk for learning difficulties. *Journal of Experimental Child Psychology, 152*, 221–241. https://doi.org/10.1016/j.jecp.2016.07.017
Peng, P., Zhang, Z., Wang, W., Lee, K. J., Wang, T. F., Wang, C. C., Luo, J., & Lin, J. Z. (2022). A meta-analytic review of cognition and reading difficulties: Individual differences, moderation, and language mediation mechanisms. *Psychological Bulletin*. https://doi.org/10.1037/bul0000361
Pennington, B. F., & Ozonoff, S. (1996). Executive functions and developmental psychopathology. *Journal of Child Psychology and Psychiatry, 37*(1), 51–87. https://doi.org/10.1111/j.1469-7610.1996.tb01380.x
Pickles, A., Anderson, D. K., & Lord, C. (2014). Heterogeneity and plasticity in the development of language: A 17-year follow-up of children referred early for possible autism. *Journal of Child Psychology and Psychiatry, 55*(12), 1354–1362. https://doi.org/10.1111/jcpp.12269
Quinn, J. M., & Wagner, R. K. (2018). Using meta-analytic structural equation modeling to study developmental change in relations between language and literacy. *Child Development, 89*(6), 1956–1969. https://doi.org/10.1111/cdev.13049
Ricketts, J., Jones, C. R. G., Happé, F., & Charman, T. (2013). Reading comprehension in autism spectrum disorders: The role of oral language and social functioning. *Journal of Autism and Developmental Disorders, 43*(4), 807–816. https://doi.org/10.1007/s10803-012-1619-4
Sigman, M., & Ungerer, J. A. (1984). Cognitive and language skills in autistic, mentally retarded, and normal children. *Developmental Psychology, 20*(2), 293–302. https://doi.org/10.1037/0012-1649.20.2.293
Solari, E. J., Grimm, R. P., McIntyre, N. S., Zajic, M., & Mundy, P. C. (2019). Longitudinal stability of reading profiles in individuals with higher functioning autism. *Autism, 23*(8), 1911–1926. https://doi.org/10.1177/1362361318812423
Sorenson Duncan, T., Karkada, M., Deacon, S. H., & Smith, I. M. (2021). Building meaning: Meta-analysis of component skills supporting reading comprehension in children with autism spectrum disorder. *Autism Research, 14*(5), 840–858. https://doi.org/10.1002/aur.2483
St Clair, M. C., Durkin, K., Conti-Ramsden, G., & Pickles, A. (2010). Growth of reading skills in children with a history of specific language impairment: The role of autistic symptomatology and language-related abilities. *British Journal of Developmental Psychology, 28*(1), 109–131. https://doi.org/10.1348/026151009x480158
Tipton, L. A., Blacher, J. B., & Eisenhower, A. S. (2017). Young children with ASD: Parent strategies for interaction during adapted book reading activity. *Remedial and Special Education, 38*(3), 171–180. https://doi.org/10.1177/0741932516677831
Tong, S. X., Wong, R. W. Y., Kwan, J. L. Y., & Arciuli, J. (2020). Theory of mind as a mediator of reading comprehension differences between chinese school-age children with autism and typically developing peers. *Scientific Studies of Reading, 24*(4), 292–306. https://doi.org/10.1080/10888438.2019.1666133
Vanegas, S. B., & Davidson, D. (2015). Investigating distinct and related contributions of Weak Central Coherence, Executive Dysfunction, and Systemizing theories to the cognitive profiles of children with Autism Spectrum Disorders and typically developing children. *Research in Autism Spectrum Disorders, 11*, 77–92. https://doi.org/10.1016/j.rasd.2014.12.005
*Weissinger, K. M. (2014). *Factors associated with individual differences in reading comprehension for typically-developing students and for a pilot sample of students diagnosed with autism spectrum disorder* [Unpublished doctoral dissertation]. University of Rhode Island.
Westerveld, M. F., Paynter, J., O'Leary, K., & Trembath, D. (2018). Preschool predictors of reading ability in the first year of schooling in children with ASD. *Autism Research, 11*(10), 1332–1344. https://doi.org/10.1002/aur.1999
Westerveld, M. F., Paynter, J., Trembath, D., Webster, A. A., Hodge, A. M., & Roberts, J. (2017). The emergent literacy skills of preschool children with autism spectrum disorder. *Journal of Autism and Developmental Disorders, 47*(2), 424–438. https://doi.org/10.1007/s10803-016-2964-5
Westerveld, M. F., & Roberts, J. M. A. (2017). The oral narrative comprehension and production abilities of verbal preschoolers on the autism spectrum. *Language, Speech, and Hearing Services in Schools, 48*(4), 260–272. https://doi.org/10.1044/2017_LSHSS-17-0003
White, S., Frith, U., Milne, E., Rosen, S., Swettenham, J., & Ramus, F. (2006). A double dissociation between sensorimotor impairments and reading disability: A comparison of autistic and dyslexic children. *Cognitive Neuropsychology, 23*(5), 748–761. https://doi.org/10.1080/02643290500438607

Whyte, E. M., Nelson, K. E., & Scherf, K. S. (2014). Idiom, syntax, and advanced theory of mind abilities in children with autism spectrum disorders. *Journal of Speech, Language, and Hearing Research, 57*(1), 120–130. https://doi.org/10.1044/1092-4388(2013/12-0308)

Williamson, P., Carnahan, C. R., & Jacobs, J. A. (2012). Reading comprehension profiles of high-functioning students on the autism spectrum: A grounded theory. *Exceptional Children, 78*(4), 449–469. https://doi.org/10.1177/001440291207800404

Wise, J. C., Sevcil, R. A., Morris, R. D., Lovett, M. W., & Wolf, M. (2007). The relationship among receptive and expressive vocabulary, listening comprehension, pre-reading skills, word identification skills, and reading comprehension by children with reading abilities. *Journal of Speech, Language, and Hearing Research, 50*(4), 1093–1109. https://doi.org/10.1044/1092-4388(2007/076)

Young, G. A., & Killen, D. H. (2002). Receptive and expressive language skills of children with five years of experience using a cochlear implant. *Annals of Otology, Rhinology & Laryngology, 111*(9), 802–810. https://doi.org/10.1177/000348940211100908

Zhao, J., Chen, S., Tong, X., & Li, Y. (2019). Advantage in character recognition among chinese preschool children with autism spectrum disorder. *Journal of Autism and Developmental Disorders, 49*(12), 4929–4940. https://doi.org/10.1007/s10803-019-04202-x

Zhou, P., Crain, S., Gao, L., & Jia, M. (2017). The use of linguistic cues in sentence comprehension by mandarin-speaking children with high-functioning autism. *Journal of Autism and Developmental Disorders, 47*(1), 17–32. https://doi.org/10.1007/s10803-016-2912-4

Authors and Affiliations

Ying Wang[1] · Zhu Lan[1] · Isabella Duan[2] · Peng Peng[3] · Wei Wang[4] · Tengfei Wang[5]

[1] Department of Psychology, Tsinghua University, Beijing, China

[2] Program in Human Biology, Stanford University, Stanford, USA

[3] Department of Special Education, College of Education, The University of Texas at Austin, Austin, USA

[4] The Graduate Center, City University of New York, CUNY, 365 Fifth Avenue, New York, NY 10016, USA

[5] Department of Psychology and Behavioral Sciences, Zhejiang University, Hangzhou, China