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ORIGINAL PAPER

The Contribution of Perceptual Reasoning Skills to Phonological Awareness for School Age Autistic Children

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Abstract
This study aimed to investigate the phonological awareness (PA) skills of school age autistic children (age range = 6–12) in two parts: (1) comparing their performance on a PA task to non-autistic children with groups matched on chronological age, verbal and non-verbal cognitive skills, and (2) exploring the role of cognitive skills and autism characteristics on PA skills. Results revealed that the groups did not differ in their PA skills (study 1) and that perceptual reasoning skills are associated with the PA skills of autistic participants (study 2). Results highlight the role of non-verbal cognitive skills in literacy development for autistic children and suggest that their perceptual reasoning abilities likely contribute a great deal when learning to read.

Keywords Phonological awareness · Autism spectrum disorder · Early literacy · Perceptual reasoning skills

Reading is a crucial skill to acquire as it leads to enhanced future learning opportunities, academic achievement, adaptive skills, social skills, and occupational attainment (Nally et al., 2018; Westerveld et al., 2018). Several necessary precursors essential to future reading achievement (i.e., emergent literacy skills) have been identified in the literature including alphabet knowledge, print-concept knowledge, rapid naming, and working memory (National Early Literacy Panel [NELP], 2008; Ring & Black, 2018). Phonological awareness (PA) is considered one of the strongest emergent literacy predictors with a moderately strong correlation with word decoding ($r = .40$) (NELP, 2008) for non-autistic children (Blachman et al., 1999; Dynia et al., 2017), signifying that it is a necessary precursor essential to future reading success (Whitehurst & Lonigan, 1998). As such, PA is the emergent literacy skill of focus throughout this study.

Phonological awareness is a metalinguistic skill that represents the ability to analyse and manipulate the sound structures of spoken language (Hudson et al., 2017; Scarborough & Brady, 2002; Schuele & Boudreau, 2008). The manipulation and analysis of phonological sound structures of oral language can be conducted at several levels, namely at the syllable, subsyllabic (i.e., the division of syllables into onsets and rimes), and phoneme (i.e., the smallest unit of speech, /k/, /a/, and /t/ in the word cat) levels (Moritz et al., 2013; Scarborough & Brady, 2002). Research shows that the typical development of PA skills follows a common pattern, beginning at an early age (e.g., syllable awareness develops around age 3) and growing in complexity throughout the late preschool (e.g., onset and rime awareness develop around age 4) and school age years (e.g., segmenting words into individual phonemes) (Goswami, 2002; Moritz et al., 2013; Scarborough & Brady, 2002). A child's understanding of the phonological structure of spoken words can be displayed and assessed in various ways. Scarborough and Brady (2002) describe detailed PA assessment methods (see Table 1).

Developing reading precursor skills, such as PA, is critical given the emphasis society places on the use of literacy in academics and daily life (Browder et al., 2009). Numerous studies over the last four decades have established that PA

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Table 1 Examples of Phonological Awareness Assessment Methods as Described in Scarborough and Brady (2002)

PA Assessment Methods	Example
Rhyming	Which of these words rhymes with *cat*: *seal, hat, five*? *Hat*
Segmentation	Say a little bit of *snake*. /s/,
Categorization	*door*…*pan*…*duck*…Which one doesn't belong? *Pan*
Identity	Tell me the last sound in *fish. /sh/*
Synthesis/blending	*car*…*tune*…What do you get when you say them together? *Cartoon*
Manipulation	Say *winter* without the *ter* part. *Win*

plays a prominent role in reading development (Catts, 1989; Catts et al., 1999; Kirby et al., 2003; Milankov et al., 2021; NELP, 2008; Torgesen et al., 1994), consistently finding that difficulties with PA are one of the most distinguishing features that characterize children with a developmental reading disability (also known as dyslexia) (Stanovich, 1988; Stone & Brady, 1995; Wagner & Torgesen, 1987). More recently, research showed that deficits in PA were present in around 73% of a sample of 279 children with a reading disability (Morris et al., 2012) and in 69% of a sample of 218 children with a language impairment (Justice et al., 2015). Children with deficits in PA have difficulty manipulating the sound structure of words (Morris et al., 2012), therefore, they have trouble segmenting individual or groups of letters into phonemes and blending them to make words (Wagner & Torgesen, 1987). In turn, difficulties with PA can impact a child's ability to develop necessary reading skills (Layes et al., 2020).

Given the important role of PA in reading achievement, the purpose of the current study is to compare the PA skills of school age autistic children to non-autistic children and to explore the relationship between PA skills and cognitive and autism characteristics to better understand the development of literacy skills of autistic children. The literature investigating the PA skills of autistic children has mostly included preschool age children and continued investigation is warranted in this field as findings vary widely across studies.

Phonological Awareness Skills and Autism

Investigations into the reading profiles of autistic children have revealed considerable diversity in reading profiles. A number of children on the autism spectrum experience challenges in reading comprehension (Davidson & Ellis Weismer, 2014; Henderson et al., 2014; Nation et al., 2006), decoding (Nation et al., 2006), and word reading abilities (Westerveld et al., 2018). Meanwhile, between 6 and 20% of autistic children present with hyperlexia (Ostrolenk et al., 2017), a strength in word decoding and recognition alongside difficulties with reading comprehension skills and verbal abilities (Silberberg & Silberberg, 1967). In essence, a review of the literature suggests a heterogeneous reading profile among children on the autism spectrum ranging from difficulties to enhanced skills.

Many factors play a role in literacy development, as such, the multiple deficit model framework proposed by Pennington (2006) posits that behavioural symptoms (such as reading success/challenges) within developmental disorders cannot be explained by a single cause, but rather by the interplay of multiple genetic and environmental protective and risk factors (Pennington, 2006; Van Bergen et al., 2014). For instance, the development of reading skills for autistic children could be impacted by multiple protective/risk factors including (1) autism characteristics (i.e., restricted interests, differences in social-communication skills), (2) language skills, (3) cognitive skills, and (4) co-occurring conditions (e.g., Dynia et al., 2014; Fleury & Lease, 2018; Nally et al., 2018; Westerveld et al., 2020).

Phonological Awareness Skills of Preschool Autistic Children

Phonological awareness skills are a significant predictor for reading achievement of preschool aged autistic children (Dynia et al., 2017). The literature reports mixed findings on the development of PA skills of preschool autistic children with some studies reporting PA as an area of challenge (Dynia et al., 2019; Westerveld et al., 2016), while others reporting PA as a relative strength (Macdonald et al., 2020; Westerveld et al., 2020). However, mixed findings appear to be the result of group matching, such that there are few if any differences between groups matched for verbal and nonverbal cognitive skills; preschool children on the autism spectrum show comparable PA skills to non-autistic children when verbal skills (Dynia et al., 2014; Westerveld et al., 2020) and non-verbal skills (Westerveld et al., 2020) are accounted for.

Phonological Awareness Skills of School Age Autistic Children

There is a limited number of studies that have investigated PA in school age autistic children and found impairments in PA skills within this age group (Nally et al., 2018; Smith Gabig, 2010); although caution should be taken when interpreting these results given the absence of group matching on language and cognitive skills. Similar to findings from the preschool literature, school age autistic children showed lower performance on a PA task compared to non-autistic children when groups were not matched for cognitive or language skills (Smith Gabig, 2010). In addition, school age autistic children between the ages of 6–17 years old show difficulty in PA skills, with 67% of the sample obtaining floor level scores on the PA task (Nally et al. 2018).

The Role of Cognitive Skills and Autism Characteristics on the Phonological Awareness Skills of Autistic Children

Linguistic abilities are considered an important underpinning in reading development, as the association between verbal skills and literacy skills has been well documented for non-autistic children (e.g., Catts et al., 1999; Cornwall, 1992; Macdonald et al., 2020; McArthur et al., 2000; Roth et al., 2002). However, this may not be the case for autistic children. Evidence of a common developmental pathway exists within the cognitive profile of autistic children, showing discrepantly higher non-verbal/perceptual skills compared to verbal skills (Ankenman et al., 2014; Charman et al., 2011; Courchesne et al., 2015; Joseph et al., 2002; Nader et al., 2015; Soulières et al., 2011). The marked strength for non-verbal/perceptual skills over verbal skills may be the results of the distinct cognitive styles of autistic persons. For instance, the Enhanced Perceptual Functioning model (EPF; Mottron et al., 2001, 2006, 2009) posits that autistic cognitive profiles can be characterized by superior representations of locally oriented and featural information and enhanced activation of perceptual brain areas during task performance (e.g., visuospatial, language, working memory tasks). Similarly, the Trigger-Threshold-Target model (TTT; Mottron et al., 2014) of autism suggests that cognitive enhancement, where perceptual materials are preferentially processed over social materials, is due to brain reorganization triggered by a series of genetic mutations. Together, the EPF and TTT models highlight how persons on the autism spectrum perceive and experience the world differently and account for the relative strength in visual and auditory processing documented in the literature, such as superior visual search skills (Kaldy et al., 2011), musical memory and melodic perception (Heaton, 2003; Stanutz et al., 2014), and pitch frequency distinction (Bonnel et al., 2010).

The EPF and TTT models describe the cognitive profiles of persons on the autism spectrum. As such, academic skill development, including the development of emergent literacy skills, can also be considered within the framework of the EPF and TTT models. For example, the EPF and TTT models applied to PA skills would posit that when presented with a PA task, autistic children may show greater reliance on lower-level perceptual processes (e.g., detection, discrimination, categorization) over higher-order cognitive processes (e.g., memory, attention) when reasoning and problem solving (Mottron et al., 2001). For example, persons on the autism spectrum show increased activity in perceptual (sensory) regions of the brain and reduced activity in the prefrontal region (involved in reasoning) during matrix reasoning tasks compared to age-matched controls, while obtaining similar behavioral results (Soulières et al., 2009). Persons on the autism spectrum also show increased reliance on visual-spatial abilities, even in higher-order problem solving tasks, again with similar behavioural results as non-autistic persons (Sahyoun et al., 2010; Soulières et al., 2009). It may also be the case that autistic children may show comparable behavioural performance on academic tasks as non-autistic children while using an alternative approach (i.e., a perceptual approach) to literacy acquisition. Therefore, investigating if PA skills are related to verbal skills, as in the case of non-autistic children, or other skills (i.e., non-verbal skills) due to the distinct cognitive styles of autistic persons, is needed to elucidate correlates of literacy development for autistic children.

Indeed, various factors may play an important role in PA development of autistic children such as autism characteristics, language skills, and cognitive skills (e.g., Dynia et al., 2014; Fleury & Lease, 2018; Nally et al., 2018; Smith Gabig, 2010; Westerveld et al., 2020). Autistic children show comparable performance on PA tasks to non-autistic children when accounting for verbal skills (Dynia et al., 2014; Westerveld et al., 2020) and non-verbal skills (Westerveld et al., 2020). Furthermore, verbal skills (Nally et al., 2018), non-verbal skills (Jokel et al., 2020) and general cognitive skills (Fleury & Lease, 2018) are associated with PA. Specifically, non-verbal (visual-spatial/perceptual reasoning) cognitive skills are a predictor for oral language abilities among autistic children (Wodka et al., 2013) and may even account for the heterogeneity in language profiles (Kjelgaard & Tager-Flusberg, 2001).

In addition, some studies show a relationship between autism characteristics and oral language skills such that greater social impairment is related to delayed acquisition of oral language (Wodka et al., 2013). However, social skills are not a significant predictor of PA skills (Dynia et al., 2019), and repetitive behaviours/sensory interests do not seem related to oral language skills (Wodka et al., 2013) of autistic children. Overall, it is pertinent to continue to investigate the impact of autism characteristics and verbal and non-verbal cognitive skills on the PA skills of autistic children to understand which factors influence their learning.

The overall aim of this study is to extend prior research on the PA skills of preschool children to school age autistic children. Gaining insight into the development of PA skills of school age autistic children is relevant given that difficulties in PA skills can persist into later years (Nally et al., 2018).

Furthermore, PA encompasses a range of skills that increase in complexity, ranging from shallow-level knowledge (e.g., dividing words into syllables) to deep-level knowledge (e.g., segmenting words into individual phonemes), which is developed during the school age years (Goswami, 2002; Moritz et al., 2013; Scarborough & Brady, 2002; Schuele & Boudreau, 2008). In addition, we will examine the relationship between PA skills and cognitive and autism characteristics to understand how autistic children best learn in the context of literacy development. This objective is informed by the neurodiversity movement, which posits that a natural range of diversity occurs in human neurodevelopment (Pellicano & Houting, 2022) while recognizing that neurocognitive differences encompass strengths as well as weaknesses, which may present challenges for the individual's functioning within their environment (Leadbitter et al., 2021). Thus, findings could help to improve academic outcomes for autistic children by providing insight into possible mechanisms underlying phonological awareness development for school age children who present with a wide range of support needs (Davidson & Ellis Weismer, 2014; Wodka et al., 2013), while considering autistic developmental trajectories and natural developmental processes to inform targeted strength-based interventions to palliate areas of challenge (Leadbitter et al., 2021).

Study Objectives and Hypotheses

Study 1

The objective of the first study is to compare the PA skills of school age autistic children to non-autistic children, using a PA task commonly used in clinical practice and recommended for use with autistic children. Based on findings from previous investigations on PA, mainly in preschool age autistic children showing comparable PA skills to non-autistic children when accounting for language (Dynia et al., 2014; Westerveld et al., 2020) and non-verbal cognitive skills (Westerveld et al., 2020), we hypothesized that there would be no difference in performance on the PA task between school age autistic children compared to non-autisitc children. Study 1 includes a preliminary exploration of the relationship between cognitive skills, autism characteristics, and PA skills of autistic and non-autistic children, which is explored in greater depth in study 2.

Study 2

Given the uneven cognitive profile of autistic children, the link between non-verbal skills and PA skills (Jokel et al., 2020), and the mixed findings reported across behavioural studies regarding the role of general autism characteristics and oral language on PA skills (e.g., Dynia et al., 2019 vs. Wodka et al., 2013), the objective of the second study is to explore the relationship between verbal and non-verbal cognitive skills and autism characteristics (social communication/interaction and repetitive behaviours/restricted interests) and PA skills of autistic children across a wide spectrum of cognitive skills.

Study 1

Methodology

Participants in the current study represent a subset of participants from a larger study where behavioural and neurophysiological measures were collected for autistic and non-autistic children who participated in a Summer Social Science Research camp in Burnaby, British Columbia, Canada. Ethical approval was granted by the Office of Research Ethics at the University.

Participants

A total of 32 participants ($n = 9$ females) between the ages of 6 and 12 ($M = 9$, $SD = 1.64$) including 18 autistic and 14 non-autistic participants were included in study 1. Exclusion criteria included individuals with a co-occurring intellectual disability (IQ < 70). Participant characteristics of the autistic and non-autistic groups are reported in Table 2. Independent *t*-tests were used to investigate if the autistic and non-autistic groups differed on the experimental measure of PA skills, and on group characteristics of chronological age, autism characteristics and verbal and non-verbal cognitive skills. Univariate effects were evaluated at a Bonferroni corrected alpha level of 0.008 (0.05/6). The autistic and non-autistic groups were matched on chronological age, the Wechsler Abbreviated Scale of Intelligence, 2nd Edition (WASI-II; Wechsler, 2011) Vocabulary and Matrix Reasoning subtests, but differed in terms of autism characteristics.

Measures and Group Characteristics

Autism Inclusionary Criteria. Children in the autistic group received a standardized clinical diagnosis of autism spectrum disorder from a qualified pediatrician, psychologist, or psychiatrist associated with the provincial government funded autism assessment network, or through a qualified private clinician. All diagnoses were based on the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV-5; APA, 2013) using the Autism Diagnostic Interview–Revised (ADI-R; Rutter et al. 2003), and Autism

Table 2 Study 1 Participant Characteristics of Autistic and Non-Autistic Groups

Variables	Autistic Group ($N = 18$, 2 females)			Non-Autistic Group ($N = 14$, 7 females)				
	M	*SD*	Range	*M*	*SD*	Range	*p*	*d*
Age	9.78	1.71	6–12	8.97	1.49	6–11	0.17	0.51
SRS-2	72	8	58–87	49	9	39–69	<0.01*	2.7
AQ	33	5	24–41	15	6	5–30	<0.01*	3.3
WASI-II VC	100	12	79–143	102	8	88–128	0.63	0.20
WASI-II MR	106	8	85–131	114	12	85–140	0.21	0.80
NEPSY-II PA	11	3	4–17	11	2	7–15	0.96	0

Note. Means (*M*), standard deviations (*SD*), age (in years), Social Responsiveness Scale, 2nd edition (SRS-2) total t-scores, Autism-Spectrum Quotient (AQ) total score, Wechsler Abbreviated Scale of Intelligence, 2nd Edition (WASI-II), Vocabulary (VC), Matrix reasoning (MR), WASI-II VC and MR presented in standard scores. NEPSY-II Phonological Processing subtest (PA). Second last column denotes a *t*-test (p) comparing group differences in means for each variable, and last column denotes Cohen's *d* effect size. *Bonferroni corrected alpha level of 0.008 (0.05/6)

Diagnostic Observation Schedule (ADOS; Lord et al. 1999). A clinical autism assessment report or a Ministry of Child and Family Development autism funding eligibility form, which requires a clinical autism assessment, was provided by the parents to confirm diagnosis. In addition, autism characteristics were measured through parent report on two parent questionnaires; the Social Responsiveness Scale – 2 (SRS-2; Constantino & Gruber, 2012) and the Autism-Spectrum Quotient screener questionnaire (AQ; Baron-Cohen et al., 2001). A total score of ≥32 on the AQ and a t-score ≥60 on the SRS-2 were used as cut-off scores indicative of autism characteristics. The SRS-2 and AQ questionnaires were administered to both the parents of autistic and non-autistic children.

Two participants with a prior diagnosis of autism from a clinician met criteria on either the SRS-2 or the AQ, but not both, obtaining scores slightly below clinical cut-off scores on either one of these questionnaires. All analyses were repeated excluding the 2 participants in the autism group to assess whether the pattern of results differed for analyses conduced with and without these 2 participants. Given that the pattern of results did not differ with and without these 2 participants and that we obtained evidence of diagnosis of autism by a clinician, these participants were retained in the autism group. All other 16 autistic participants scored in the elevated range for autism on the SRS-2 or the AQ. All non-autistic participants ($n = 14$) scored below the clinical cut-off score of 32 on the AQ, indicating few signs of autism. All but 2 non-autistic participants obtained scores below the clinical cut-off t-score of 60 on the SRS-2. Analyses were repeated excluding these 2 non-autistic participants and patterns of results did not differ. Thus, these 2 participants were retained in the non-autistic group.

Study Exclusion. The original sample comprised 48 participants; however, 13 participants were excluded due to incomplete data, extreme scores (outliers identified through assessment of boxplots) and being in the process of an autism assessment (unable to assign them to either group), and 3 participants in the non-autistic group were removed from the study as they obtained scores indicative of autism characteristics on both autism screening questionnaires. The final sample included in the analyses consisted of 32 children ($n = 9$ females) including 18 autistic children and 14 non-autistic children.

Co-Occurring Conditions. Twelve participants in the autistic group presented with one or more co-occurring conditions other than autism spectrum disorder which included attention-deficit-hyperactivity disorder ($n = 7$), specific learning disorder ($n = 1$), and anxiety ($n = 7$). Two participants in the non-autistic group presented with an anxiety disorder. All participants did not have a history of a hearing impairment, as per parental report. All participants were able to complete the measures in this study.

Autism Characteristics. There was a statistically significant difference with a large effect size in autism characteristics between groups on the SRS-2, $t(30) = -7.49$, $p = <0.01$, $d = 2.7$, and the AQ, $t(30) = -8.84$, $p = <0.01$, $d = 3.3$, with the autistic group having statistically significant higher scores, indicating more autism traits, than the non-autistic group (see Table 2).

Age and Sex. There was no statistically significant difference in chronological age between the autistic and non-autistic groups, $t(30) = -1.41$, $p = .17$, $d = 0.51$. Chi-square analyses revealed statistically significant sex difference between the autistic and non-autistic groups. The autistic group was primarily composed of males ($N = 16$, 88%) and the non-autistic group was equally composed of males and females ($N = 7$, 50%). The discrepancy in sex distribution within our sample reflects the fact that autism is more commonly identified in males than in females at a ratio of 4:1 (CDC, 2018). The male-preponderance in autism prevalence has been attributed to several factors including diagnostic measures using primarily male samples without offering sex specific norms (Medda et al., 2019) and differences in female autistic profiles (i.e., increased ability to mask autistic traits, also known as camouflaging) (Lai et al., 2017).

Cognitive Skills. The Wechsler Abbreviated Scale of Intelligence, 2nd Edition (WASI-II; Wechsler, 2011) was used as a fast and reliable measure of cognitive skills including verbal (Vocabulary subtest) and non-verbal skills, specifically, perceptual reasoning skills[1] (Matrix Reasoning subtest). Total raw scores are transformed into t-scores, and we converted those into standard scores where the mean is 100 and the standard deviation is 15. There was no statistically significant difference in verbal skills, $t(30) = 0.483$, $p = .63$, $d = 0.2$., and non-verbal cognitive skills, $t(30) = 1.29$, $p = .95$, $d = 0.8$., between the autistic and non-autistic groups. Levene's test revealed that perceptual reasoning skills violated the assumption of homogeneity of variance and was therefore interpreted using the equal variances not assumed test statistic.

Phonological Awareness

Given the heterogeneity of cognitive, receptive, and expressive language profiles of autistic children, we used the NEPSY-II's Phonological Processing subtest (Korman et al., 2007) to measure PA because it minimizes the participant's use of expressive language. In addition, the NEPSY-II has been specifically studied for autistic children and children with an intellectual disability and is able to identify challenges in phonological awareness for these populations (Brooks et al., 2009).

The Phonological Processing subtest of the NEPSY-II (Korman et al., 2007) can be administered to participants from 3 to 16 years of age. The Phonological Processing subtest is comprised of non-verbal items (receptive), measuring word segment recognition, which require participants to identify words from word segments by pointing to pictures (e.g., the participant is asked to choose between 3 pictures to match "do-g"). This subtest also included verbal items (expressive), measuring phonological segmentation, that assess the ability to manipulate sounds and syllables in spoken words. These items ask participants to repeat a word and then to create a new word by omitting or substituting a syllable or phoneme (e.g., "coat", now say it again but don't say /k/, "oat"). Higher scores on the NEPSY-II Phonological Processing subtest indicate stronger PA skills. Raw scores are transformed into standardized scores, where the mean is 10 and the standard deviation is 3.

[1] The term "non-verbal" cognitive skills is used to refer to the specific non-verbal skill of perceptual reasoning, as measured by the Matrix Reasoning subtest of the WASI-II (Wechsler, 2011). As such, the terms "non-verbal cognitive skills" and "perceptual reasoning skills" may be used interchangeably.

Table 3 Correlations Between Phonological Awareness (PA) Skills, Cognitive Skills and Autism Characteristics within the Autistic and Non-Autistic Groups

	NEPSY-II PA (PA) correlation with:		
	WASI-II VC (Verbal)	WASI-II MR (Non-verbal)	SRS-2
Autistic Group	0.391	0.615*	−0.116
Non-Autistic Group	0.333	0.403	−0.427

Note. NEPSY-II Phonological Processing subtest (PA), Wechsler Abbreviated Scale of Intelligence, 2nd Edition (WASI-II), Vocabulary (VC), Matrix reasoning (MR), Social Responsiveness Scale, 2nd edition (SRS-2) total t-scores. *Bonferroni corrected alpha level of 0.017 (0.05/3)

Results

Participants in the autistic group performed similarly ($M = 10.56$, $SD = 3.28$) to the participants in the non-autistic group ($M = 10.5$, $SD = 1.99$) on the PA measure; there was not a statistically significant difference in PA skills between groups, $t(30) = -0.056$, $p = .96$, $d = 0, -0.06$, BCa 95% CI [-2.09, 1.98] (Table 2). These results revealed that the autistic and non-autistic groups did not differ in their PA skills.

The Relationship Between Cognitive Skills, Autism Characteristics and PA Skills

Autistic Group. Spearman correlation analyses were used to investigate the relationship between PA skills and verbal and non-verbal cognitive skills and autism characteristics (i.e., SRS-2 total t-score) (Table 3). Results revealed a statistically significant positive and moderate correlation, with Bonferroni correction for multiple comparisons applied, between PA and perceptual reasoning skills, $r_s = 0.615$, $p < .01$, within the autism group. Autistic children with higher perceptual reasoning skills had better performance on the PA task compared to those with lower perceptual reasoning skills. There was no relationship between PA skills and either verbal cognitive skills or autism characteristics, within the autism group.

Non-Autistic Group. Spearman correlation analyses did not reveal a relationship between PA skills and either verbal, non-verbal skills, or autism characteristics, within the non-autistic group.

Discussion

The aim of study 1 was to compare the PA skills of school age autistic children to non-autistic children, using a PA task commonly used in clinical practice and recommended to use with autistic children. Specifically, this study aimed to extend prior research on the PA skills of preschool children to school age autistic children matched with non-autistic

Table 4 Study 2 Autistic Participant Characteristics

Variables	*n*	*M*	*SD*	Range
Age	35	9.6	1.54	6–12
SRS-2 Total	35	72	9	55–87
SRS-2 RRB	35	71	9	58–90
SRS-2 SCI	35	71	9	54–89
AQ Total	18	33	5	24–41
SCQ Total	20	19	6	2–27
ADOS-2[1]	11	9	1	7–10
WASI-II VC	35	90	15	55–143
WASI-II MR	35	95	12	63–132
NEPSY-II PA	35	8	4	1–17

Note. Means (M), standard deviations (SD), age (in years), Social Responsiveness Scale, 2nd edition (SRS-2) total t-scores, Restricted Interests and Repetitive Behaviour or Autistic Mannerisms (RRB), Social Communication and Interaction (SCI), Autism-Spectrum Quotient (AQ) total score, Social Communication Questionnaire (SCQ) raw scores, Autism Diagnostic Observation Schedule, 2nd Edition (ADOS-2) comparison score, Wechsler Abbreviated Scale of Intelligence, 2nd Edition (WASI-II), Vocabulary (VC), Matrix reasoning (MR), WASI VC and MR presented in standard scores. NEPSY-II Phonological Processing subtest (PA). 1. The ADOS-2 was administered last in a separate session, which 11 participants were able to complete before COVID-19 lock down. The autism characteristics of participants that did not complete an ADOS-2 were validated through screening questionnaires (e.g., SCQ, SRS-2, AQ).

peers. We hypothesized that autistic and non-autistic children would not differ in their scores on the PA task. Results supported our hypothesis and found that the autistic and non-autistic groups had similar performance on the PA task. Study 1 provided a preliminary investigation of the relationship between cognitive skills, autism characteristics and PA skills of autistic children and non-autistic children. Findings revealed a positive relationship between perceptual reasoning skills and PA skills for autistic children. No relationship was found between verbal or non-verbal cognitive skills and PA skills for non-autistic children.

Given the cognitive profile of autistic children in study 1, results seem most applicable to autistic children requiring a low level of support, who often complete school in mainstream education. As such, findings from study 1 may be limited to children with low support needs and may not generalize to those with high support needs, who often complete school in specialized education. Thus, we investigate the relationship between PA, cognitive skills, and autism characteristics in study 2, which includes participants with low and high support needs across the spectrum.

Study 2

Methodology

The participant sample in study 2 includes the autistic participants from study 1 ($n = 18$) combined with an additional 21 autistic participants recruited separately, for a total of 35 participants. The 21 additional autistic participants were recruited at an elementary school in Montreal, Quebec, Canada for autistic children and children with other neurodevelopmental conditions. While study 1 excluded participants with a co-occurring intellectual disability (IQ < 70), study 2 includes participants with a wide range of cognitive skills in order to be representative of the heterogeneity of cognitive profiles across the spectrum. Ethical approval was granted by the University's Research Ethics Board. Informed consent was obtained from parents and teachers, and assent was obtained from child participants.

Participants

A total of 35 autistic participants ($n = 4$ females) between the ages of 6 and 12 years old ($M = 9.6$, $SD = 1.54$) were included in study 2. Participant characteristics are reported in Table 4. All variables fell within conventional limits of normality (i.e., skewness and kurtosis absolute value smaller than 1.96) (Field, 2013).

Measures

The measures used in study 2 overlap with those used in study 1. The Phonological Processing subtest of the NEPSY-II (Korman et al., 2007) was used to measure phonological awareness skills, The Wechsler Abbreviated Scale of Intelligence, 2nd Edition (WASI-II; Wechsler, 2011) was used to measure cognitive skills including verbal (Vocabulary subtest) and non-verbal/perceptual reasoning skills (Matrix Reasoning subtest), and the Social Responsiveness Scale – 2 (SRS-2; Constantino & Gruber, 2012) and Autism-Spectrum Quotient screener questionnaire (AQ; Baron-Cohen et al., 2001) were used to measure autism characteristics. Two additional measures were used to measure autism characteritics in a subset of participants in study 2; the Autism Diagnostic Observation Schedule, 2nd Edition (ADOS-2; Lord et al., 2012) and the Social Communication Questionnaire (SCQ; Rutter et al., 2003).

The ADOS-2 is a semi structured, standardized assessment of communication, social interaction, play, and restricted and repetitive behaviours. Autism criterion is met by obtaining a comparison score in the moderate to high range and a classification of autism spectrum/autism.

Table 5 Correlations Between Phonological Awareness (PA) Skills, Cognitive Skills and Autism Characteristics

Variable	PA	Verbal	Non-verbal	RRB	SCI
NEPSY-II PA (PA)	-	0.725†	0.837†	– 0.392*	0.041
WASI-II VC (Verbal)		-	0.734†	– 0.153	0.130
WASI-II MR (Non-verbal)			-	– 0.292	0.223
SRS-2 RRB (RRB)				-	0.444**
SRS-2 SCI (SCI)					-

Note. NEPSY-II Phonological Processing subtest (PA), Wechsler Abbreviated Scale of Intelligence, 2nd Edition (WASI-II), Vocabulary (VC), Matrix reasoning (MR), Social Responsiveness Scale, 2nd edition (SRS-2) total t-scores, Restricted Interests and Repetitive Behaviour or Autistic Mannerisms (RRB), Social Communication and Interaction (SCI). *Significant without Bonferroni correction, $p < .05$. **Significant without Bonferroni correction, $p < .01$. †Significant with Bonferroni corrected alpha level of 0.005 (0.05/10)

The SCQ-Lifetime (focus on the child's entire developmental history) version of the screening questionnaire was used for parent and the SCQ-Current version for teachers. Parental report scores were used in analyses and teacher report was used in cases where parental report was not obtained.

Autism Characteristics and Study Exclusion. All participants had a prior diagnosis of autism from a clinician (e.g., pediatrician, psychiatrist, psychologist) or had a Québec Education Ministry code indicating that the participant had been identified as autistic by a clinician (Lazoff et al., 2010). Autism characteristics were measured through additional screening questionnaires (i.e., SRS-2, Constantino & Gruber, 2012; AQ, Baron-Cohen et al., 2001; SCQ, Rutter et al., 2003) and a standardized assessment instruments (i.e., ADOS-2, Lord et al., 2012). Participants who obtained scores below the cut-off score of 60 on the SRS-2 scored above the clinical cut-off on either AQ (32), SCQ (15), or met criteria for a clinical diagnosis on the ADOS-2.

The original sample for study 2 comprised of 39 participants; however, 2 participants were excluded due to incomplete data and 2 participants were excluded because they did not meet criteria on either the SRS-2 or the AQ, obtaining scores slightly below cut-off scores on these questionnaires, and SCQ and ADOS-2 scores were not available for those participants. The final sample included in the analyses consisted of 35 autistic children ($n = 4$ females).

Co-Occurring Conditions. Seventeen participants presented with one or more co-occurring conditions other than autism which included attention-deficit-hyperactivity disorder ($n = 10$), global developmental delay ($n = 2$), specific learning disorder ($n = 2$), intellectual disability ($n = 1$), and anxiety ($n = 7$). All participants did not have a history of a

Table 6 Regression Analysis Predicting Phonological Awareness from Autism Characteristics, Verbal and Non-Verbal Cognitive Skills

Predictor	Phonological Awareness				
	B	**SE B**	**β**	***t***	***p***
WASI-II VC (Verbal)	0.08	0.04	0.26	1.91	0.066
WASI-II MR (Non-verbal)	0.23	0.06	0.62	4.23	<0.001
SRS-2 RRB (RRB)	– 0.07	0.05	– 0.14	-1.23	0.227
SRS-2 SCI (SCI)	– 0.03	0.05	– 0.07	– 0.62	0.538

Note. Unstandardized beta (B), standard error for unstandardized beta (SE B), standardized beta (β), Wechsler Abbreviated Scale of Intelligence, 2nd Edition (WASI-II) Vocabulary (VC), Matrix Reasoning (MR), Social Responsiveness Scale, 2nd edition (SRS-2) total t-scores, Restricted Interests and Repetitive Behaviour or Autistic Mannerisms (RRB), Social Communication and Interaction (SCI).

hearing impairment, as per parental report. All participants in the sample were able to complete the measures.

Results

Pearson correlation analyses were used to investigate the relationship between PA skills and verbal and non-verbal/perceptual reasoning cognitive skills and autism characteristics (i.e., restricted interests/repetitive behaviours [RRB], and social communication and interactions [SCI]) (Table 5). Results revealed a statistically significant positive and large correlation between PA and verbal, $r = .725$, $p < .001$, and perceptual reasoning, $r = .837$, $p < .001$, cognitive skills with Bonferonni correction for multiple comparisons applied. In addition, there was a negative moderate correlation between the RRB subscale of autism characteristics and PA skills, $r = -.392$, $p = .02$. However, the relationship between the RRB subscale and PA skills was not significant when Bonferonni correction was applied. There was no relationship between the SCI subscale of autism characteristics and PA skills.

Predictors of Phonological Awareness Skills

We performed a regression analysis in order to assess the predictive impact of cognitive skills (verbal and non-verbal) and autism characteristics (RRB and SCI) on PA skills of autistic children, where PA skills was considered as the dependent variable (Table 6). Results revealed a significant overall regression model, $F(4, 30) = 23.63$, $p = <0.01$, $R^2_{adj} = 0.73$. The adjusted R^2 value suggests that 73% of the variance in PA skills is attributed to verbal and non-verbal cognitive skills, RRB, and SCI. Of the four predictors, perceptual reasoning skills was the only significant predictor of PA skills, $\beta = 0.62$, $t = 4.23$, $p = <0.001$, for autistic participants; suggesting that an increase of 1 (standard score) on the PA task is associated with an increase of 0.23 (standard score) on the WASI-II Matrix Reasoning task.

Discussion

The aim of study 2 was to examine the contribution of verbal and non-verbal cognitive skills and autism characteristics to the PA skills of children with low and high support needs across the autism spectrum. Children with a wide range of support needs, including broad levels of cognitive skills and autism characteristics, were included in study 2 in order to assess whether the findings of study 1 that apply mainly to children in mainstream education settings generalize to children in specialized education as well.

In the development of non-autistic children, reading is considered a language-based skill (Catts et al., 1999; McArthur et al., 2000; Roth et al., 2002). However, many autistic children experience the world differently and show a strength for non-verbal/perceptual skills (e.g., visual and auditory processing) over verbal skills (Ankenman et al., 2014; Charman et al., 2011), which is also highlighted by the EPF (Mottron et al., 2001, 2006, 2009) and TTT (Mottron et al., 2014) theoretical models. Therefore, we investigated if PA skills were related to verbal skills, as in the case of non-autistic children (e.g., Roth et al., 2002), or other skills (i.e., perceptual reasoning skills) due to the distinct cognitive styles of autistic persons. Findings from the current study showed that perceptual reasoning skills, but not verbal skills or autism characteristics, are associated with PA skills of autistic children. Results highlight the central role of non-verbal cognitive skills in literacy development for autistic children and suggest that their enhanced perceptual processing abilities likely contribute a great deal when learning to read.

General Discussion

The current study investigated an important emergent literacy skill, phonological awareness (PA), among autistic children with a wide range of cognitive skills, autism characteristics, and co-occurring conditions, in two parts. Study 1 compared the PA skills of school age autistic children to non-autistic children, with groups matched on chronological age, verbal and non-verbal cognitive skills. Study 1 also conducted a preliminary investigation into the relationship between cognitive skills, autism characteristics and PA skills for autistic and non-autistic children. Study 2 examined the contribution of verbal and non-verbal cognitive skills and autism characteristics on performance on the PA task of children with low and high support needs across the spectrum. Including children with heterogeneous abilities in study 2 allows for findings to be as representative as possible of the developmental profiles found across the spectrum and in different educational settings.

Overall, results from study 1 and 2 can be summarized into three main findings: (i) we found that autistic children show similar PA skills to non-autistic children (study 1), (ii) the PA skills of autistic children are associated with their perceptual reasoning skills (studies 1 & 2), while the two are not correlated for non-autistic children (study 1), and (iii) we found no significant correlation between PA skills and verbal cognitive skills or autism characteristics for both autistic and non-autistic children (studies 1 & 2).

Autistic Children Show Similar PA Skills to Non-Autistic Children

The first main finding (study 1) supported our hypothesis showing that autistic and non-autistic children showed similar PA skills. School age autistic and non-autistic children did not differ in their performance on the PA task when groups were matched on chronological age, verbal and non-verbal cognitive skills. Scores obtained by both groups were within the normative average on the NEPSY-II. Results are consistent with previous studies on PA skills with preschool children that indicate no difference in PA skills between autistic children and non-autistic children when verbal and non-verbal skills are accounted for (e.g., Westerveld et al., 2020) but are not consistent with research showing that autistic children have challenges in PA skills compared to non-autistic children (Dynia et al., 2019, 2017, 2014). Our finding supports the notion that inconsistencies in the literature on PA skills of preschool autistic children appear to be the result of the lack of controlling for cognitive skills and group matching, such that there are few if any differences between groups matched for verbal and non-verbal cognitive skills.

Further, our finding showing that children in the autistic and non-autistic groups did not differ in their PA skills expands the extensive research on PA skills of preschool autistic children to school age children who have begun to receive formal literacy instruction in school. To our knowledge, only a few studies have investigated the PA skills of school age autistic children and found deficits in PA skills within this age group (e.g., Nally et al., 2018; Smith Gabig, 2010). Yet, group matching on language and cognitive skills was absent, although the autistic and non-autistic groups were matched on chronological age (Smith Gabig, 2010). Our finding suggests that differences in PA skills reported in previous studies may be related to verbal and non-verbal skills, which were not controlled for in previous studies. Overall, our results indicate that autistic and non-autistic children show similar PA skills during the school age period of development, after receiving years of formal reading instruction.

PA Skills are Associated with Perceptual Reasoning Skills of Autistic Children

The second main finding showed that PA skills are positively associated with the perceptual reasoning skills of autistic children with low (study 1) or low to high support needs (study 2), although not for non-autistic children (study 1). Autistic children with higher perceptual reasoning skills had better performance on the PA task compared to those with lower perceptual reasoning skills. Although autistic children in study 1 performed in the normative range of the NEPSY-II PA subtest (NEPSY-II: $M = 11$, $SD = 3$, range = 4–17) and autistic children in study 2 performed approximately one standard deviation below the PA subtests normative range (NEPSY-II: $M = 8$, $SD = 4$, range = 1–17), the association between PA and perceptual reasoning skills remained for autistic children despite their higher level of support needs (with study 2 including children with a wider range of support needs). Results did not reveal an association between PA and perceptual reasoning skills for non-autistic children.

Given that the autistic and non-autistic groups did not differ in their PA skills, the second main finding suggests that perceptual reasoning skills play a greater role in literacy development for autistic children as compared to non-autistic children. The Enhanced Perceptual Functioning (EPF; Mottron et al., 2001, 2006, 2009) and the Trigger-Threshold-Target (TTT; Mottron et al., 2014) models of autistic cognitive profiles account for the relative strength in non-verbal/perceptual skills (visual and auditory) as compared to verbal skills for persons on the autism spectrum, which has been well documented in the literature (Ankenman et al., 2014; Charman et al., 2011; Courchesne et al., 2015; Joseph et al., 2002; Nader et al., 2015; Soulières et al., 2011). Taken together, enhanced perceptual processing could be contributing to literacy skill acquisition of autistic children. Results from the current study could suggest that although autistic school age children show similar PA skills to non-autistic children, their PA skills are more influenced by perceptual skills than by verbal skills or that PA and verbal skills are not as closely related for autistic children as is the case for non-autistic children. Thus, autistic children may be using more of a perceptual approach to reading acquisition than non-autistic children.

Our finding leads us to question the trajectory of reading development for autistic children, particularly when considering the diversity of reading profiles across the spectrum ranging from marked difficulties to enhanced skills, as in the context of hyperlexia (i.e., a special strength in word decoding/recognition accompanied by difficulties with reading comprehension and with verbal skills) (Silberberg & Silberberg, 1967). For instance, preschool age autistic children with hyperlexia demonstrate advanced word reading skills compared to autistic children without hyperlexia and non-autistic children, but do not significantly differ in terms of PA skills (Macdonald et al., 2020), suggesting that preschool autistic children who present with a hyperlexic profile may employ a non-phonological alternative approach when learning to read (Macdonald et al., 2020), which our findings would suggest to be a perceptual approach to reading acquisition.

No Significant Relationship Between PA Skills and Verbal Skills or Autism Characteristics for Autistic and Non-Autistic Children

The third main finding revealed no statistically significant relationship between PA skills and verbal cognitive skills or autism characteristics for autistic and non-autistic children (studies 1 & 2). Although PA and verbal cognitive skills were significantly correlated for autistic children in study 2 (and not in study 1), further investigation revealed that verbal skills were not a significant predictor for PA skills of autistic children when non-verbal cognitive skills were also included in a regression model (study 2). This finding further illustrates the importance of perceptual reasoning skills over verbal skills for autistic children when it comes to learning to read.

Our finding of no significant association between PA and verbal skills for non-autistic children is not consistent with findings that show a link between reading skills and oral language in the development of non-autistic children. Yet, previous studies showing that PA and verbal/language skills are closely related for non-autistic children mostly focus on the preschool age period (e.g., Catts et al., 1999; Macdonald et al., 2020; Roth et al., 2002), with few studies investigating the link between these two for older children. Thus, it is possible that the chronological age of the participants included in this study (children between 6 and 12 years old) could explain the lack of a significant association between PA and verbal skills within the non-autistic group, such that a significant association between the two is no longer present in the school age years. The association between PA and verbal skills may decrease later in development given that PA is a highly teachable skill (Lundberg et al., 2012) and older children have had more experience with formal instruction and training. Thus, older children may rely less on verbal skills when completing PA tasks compared to preschool children. In addition, the result showing no significant association between PA and verbal skills for non-autistic children could also potentially be explained by the nature of the task used to measure PA (NEPSY-II Phonological Processing subtest). The PA task contains receptive (early items) and expressive (later items) questions which increase in difficulty. The expressive items require the child to manipulate sounds and syllables in spoken words, a reasoning skill that requires mental reasoning, a process that is arguably more akin with abilities required for the Matrix Reasoning task (i.e., visual-spatial/perceptual reasoning) compared to the Vocabulary task (i.e., word knowledge) on the WASI-II (although PA and non-verbal skills were also not correlated for the non-autistic group). Lastly, the lack of association between PA and verbal skills may also be explained by the limitations in the current study such as a small sample size and the fact that non-autistic children included in study 1 had strong verbal cognitive scores (standard score range = 88–128), with few participants falling below the low average range.

Similar to previous studies investigating the association between PA skills and autism characteristics (e.g., Dynia et al., 2019; Macdonald et al., 2020; Wodka et al., 2013), the current study did not find an association between PA skills and autism characteristics across the repetitive behaviour (RRB) and social communication (SCI) domains within the autistic and non-autistic groups. Whereas a negative correlation between PA skills and the RRB subscale of autism characteristics was found in study 2, the correlation was no longer significant when Bonferroni correction for multiple comparisons was applied. Additionally, RRB was not a significant predictor for PA skills of autistic children when further analysis was conducted using a regression. Further, our results are not consistent with findings from Nally et al. (2018) showing that more autism characteristics predicted increased reading deficits. Instead, we found that perceptual reasoning skills seem to play a more important role than autism characteristics in literacy skills development.

Limitations and Future Directions

Despite our findings showing similar PA skills for autistic and non-autistic children, and an association between perceptual reasoning skills and PA for autistic children, the current study has several limitations. For instance, the generalization of the current findings could be strengthened with a larger sample size of participants included across the studies. Sample size is often a challenge when conducting research with specific populations, including autistic children, as such, exploring the relationship between perceptual reasoning skills and early literacy skills with a larger sample could be a valuable avenue for prospective research to explore. It must also be noted that the task used to measure PA skills in the current study was untimed, which may have had an impact of performance compared to if a timed PA task was used. Thus, it would be informative for future studies investigating the PA skills of autistic children compared to non-autistic children to utilize both timed and untimed PA tasks to establish if the additional demands of a timed task impact results.

Based on the multiple deficit model (Pennington, 2006), it is possible that high perceptual reasoning skills act as a protective factor to literacy development for autistic children. Thus, prospective studies should also include measures of reading and writing achievement to explore the role of perceptual reasoning on PA skills, reading, and writing for autistic children. Similarly, the current study did not measure the presence of hyperlexia within our sample of participants which limits our understanding of distinct reading profiles, although our findings suggest that this alternative approach to reading may capitalize on strengths for perceptual processing that are more closely related to non-verbal than verbal cognitive skills. Future studies examining the reading profiles of school age autistic children should include measures of reading skills, such as reading comprehension and word reading, to clarify the presence of hyperlexia in order to elucidate the trajectory of reading development for older autistic children following formal reading instruction. In addition, according to the multiple deficit model (Pennington, 2006), the development of reading skills for autistic children could be impacted by many factors including the presence of co-occurring conditions. It is important to acknowledge that many participants within the present sample of autistic participants also had a previous diagnosis of ADHD, which may have an impact on the current findings. However, findings may also provide an accurate representation of emergent literacy skills of autistic children given the high prevalence of co-occurring conditions with autism (e.g., Brookman-Frazee et al., 2018; Ibrahim, 2020).

Next steps in this line of research could also include assessing the relationship between PA skills and basic reading and reading comprehension skills of autistic children, while accounting for cognitive skills (e.g., perceptual reasoning skills). This investigation could provide insight into the applicability of the prominent reading development theory, the Simple View of Reading (i.e., reading comprehension is attained when decoding and listening comprehension are developed; SVR, Gough & Tunmer, 1986), for the development of reading skills of autistic children. Indeed, our finding that PA and perceptual reasoning are correlated for autistic children, but not for non-autistic children, may indicate that autistic children may rely on an alternate, possibly perceptual, approach to reading acquisition as would be suggested by the EPF theory. It may thus also be the case that the SVR theory may only partially explain reading acquisition of autistic children.

Implications

Our findings provide insight into the mechanisms underlying an important aspect of literacy development (i.e., phonological awareness) in school age autistic children who present with a wide range of support needs, cognitive profiles, autism characteristics and co-occurring conditions. Our finding that autistic children show similar PA skills to non-autistic children and showing the importance of perceptual reasoning skills in literacy development for autistic children align within the neurodiversity framework, which emphasizes the importance of considering the environment goodness-of-fit and individual developmental trajectories when creating and implementing intervention programs (Leadbitter et al., 2021). Through highlighting the contribution of perceptual reasoning skills to literacy development, results support the use of strength-based approaches to reading instruction for autistic children such as using non-verbal aids like accompanying visual or auditory stimuli (i.e., music, pictures). Using non-verbal aids during reading instruction could also be useful for all children in the classroom regardless of a diagnosis. In addition, results support the use of literacy instruction tools that encourage the use of perceptual processing mechanisms such as detection, discrimination, and categorization tasks.

While the task used to measure perceptual processing included in this study primarily involved visual processing skills, it is important to recognize that not all autistic children will benefit from visual approaches to reading interventions given the heterogeneity of profiles across the spectrum. Findings support the need for further research on multimedia (e.g., combination of text, graphics, audio, and video) reading interventions for autistic children that incorporate the individual's relative perceptual learning strengths.

Conclusion

This study contributes to a better understanding of the development of PA skills in school age autistic children with a wide range of support needs, cognitive profiles, and autism characteristics. Results reveal that autistic children show comparable PA skills to that of non-autistic children (matched on chronological age, verbal and non-verbal cognitive skills) and highlight the contribution of perceptual reasoning skills to PA skills of autistic children. This study expands the existing research with preschool age autistic children to school age autistic children. Overall, findings hold important educational implications for autistic children and help inform instructional interventions targeting literacy skills by suggesting a need for approaches that capitalize on the strength in perceptual processing while relying less on verbal skills when teaching autistic children to read.

Declarations

Conflict of Interest The authors do not have any conflict of interest to disclose.

References

American Psychiatric Association. (2013). *Diagnostic and statistical Manual of Mental Disorders (DSM-5®)*. American Psychiatric Pub.

Ankenman, K., Elgin, J., Sullivan, K., Vincent, L., & Bernier, R. (2014). Nonverbal and verbal cognitive discrepancy profiles in autism spectrum disorders: influence of age and gender. *American Journal on Intellectual and Developmental Disabilities*, *119*(1), 84–99. https://doi.org/10.1352/1944-7558-119.1.84.

Baron-Cohen, S., Wheelwright, S., Skinner, R., Martin, J., & Clubley, E. (2001). The autism-spectrum quotient (AQ): evidence from asperger syndrome/high-functioning autism, malesand females, scientists and mathematicians. *Journal of autism and developmental disorders*, *31*(1), 5–17. https://doi.org/10.1023/A:1005653411471.

Blachman, B. A., Tangel, D. M., Wynne, E., Black, R., & Mcgraw, C. K. (1999). Developing phonological awareness and word recognition skills: a two-year intervention with low- income, inner-city children. *Reading and Writing*, *11*(3), 239–273. https://doi.org/10.1023/A:1008050403932.

Bonnel, A., McAdams, S., Smith, B., Berthiaume, C., Bertone, A., Ciocca, V., Burack, J. A., & Mottron, L. (2010). Enhanced pure-tone pitch discrimination among persons with autism but not Asperger syndrome. *Neuropsychologia*, *48*(9), 2465–2475. https://doi.org/10.1016/j.neuropsychologia.2010.04.020.

Brookman-Frazee, L., Stadnick, N., Chlebowski, C., Baker-Ericzén, M., & Ganger, W. (2018). Characterizing psychiatric comorbidity in children with autism spectrum disorder receiving publicly funded mental health services. *Autism*, *22*(8), 938–952. https://doi.org/10.1177/1362361317712650.

Brooks, B. L., Sherman, E. M. S., & Strauss, E. (2009). NEPSY-II: A Developmental Neuropsychological Assessment, Second Edition. *Child Neuropsychology*, *16*(1), 80– 101. https://doi.org/10.1080/09297040903146966

Browder, D., Gibbs, S., Ahlgrim-Delzell, L., Courtade, G. R., Mraz, M., & Flowers, C. (2009). Literacy for students with severe developmental disabilities: what should we teach and what should we hope to achieve? *Remedial and Special Education*, *30*(5), 269–282. https://doi.org/10.1177/0741932508315054.

Catts, H. W. (1989). Defining dyslexia as a developmental language disorder. *Annals of dyslexia*, *39*(1), 50.

Catts, H. W., Fey, M. E., Zhang, X., & Tomblin, J. B. (1999). Language basis of reading and reading disabilities: evidence from a longitudinal investigation. *Scientific Studies of Reading*, *3*(4), 331–361. https://doi.org/10.1207/s1532799xssr0304_2.

Center for Disease Control and Prevention (2018). Autism Spectrum Disorder: Data and Statistics. *National Center on Birth Defects and Developmental Disabilities*. Retrieved from https://www.cdc.gov/ncbddd/autism/data.html

Charman, T., Pickles, A., Simonoff, E., Chandler, S., Loucas, T., & Baird, G. (2011). IQ in children with autism spectrum disorders: data from the Special needs and Autism Project (SNAP).

Psychological medicine, *41*(3), 619–627. https://doi.org/10.1017/S0033291710000991.
Constantino, J. N., & Gruber, C. P. (2012). *Social responsiveness Scale–Second Edition (SRS-2)*. Torrance, CA: Western Psychological Services.
Cornwall, A. (1992). The relationship of phonological awareness, rapid naming, and verbal memory to severe reading and spelling disability. *Journal of Learning Disabilities*, *25*(8), 532–538. https://doi.org/10.1177/002221949202500808.
Courchesne, V., Meilleur, A. A. S., Poulin-Lord, M. P., Dawson, M., & Soulières, I. (2015). Autistic children at risk of being underestimated: school-based pilot study of a strength-informed assessment. *Molecular Autism*, *6*(1), 1–10. https://doi.org/10.1186/s13229-015-0006-3.
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.
Dynia, J. M., Bean, A., Justice, L. M., & Kaderavek, J. N. (2019). Phonological awareness emergence in preschool children with autism spectrum disorder. *Autism & Developmental Language Impairments*, *4*, 239694151882245. https://doi.org/10.1177/2396941518822453.
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.
Dynia, J. M., Lawton, K., Logan, J. A. R., & Justice, L. M. (2014). Comparing emergent- literacy skills and home-literacy environment of children with autism and their peers. *Topics in Early Childhood Special Education*, *34*(3), 142–153. https://doi.org/10.1177/0271121414536784.
Field, A. P. (2013). *Discovering statistics using IBM SPSS statistics: and sex and drugs and rock 'n' roll* (4th ed.). Los Angeles: Sage.
Fleury, V. P., & Lease, E. M. (2018). Early indication of reading difficulty? A descriptive analysis of emergent literacy skills in children with autism spectrum disorder. *Topics in Early Childhood Special Education*, *38*(2), 82–93. https://doi.org/10.1177/0271121417751626.
Goswami, U. (2002). Phonology, reading development, and dyslexia: a cross-linguistic perspective. *Annals of Dyslexia*, *52*(1), 139–163. https://doi.org/10.1007/s11881-002-0010-0.
Gough, P. B., & Tunmer, W. E. (1986). Decoding, reading, and reading disability. *Remedial and special education*, *7*(1), 6–10. https://doi.org/10.1177/074193258600700104.
Heaton, P. (2003). Pitch memory, labelling and disembedding in autism. *Journal of Child Psychology and Psychiatry*, *44*(4), 543–551. https://doi.org/10.1111/1469-7610.00143.
Henderson, L. M., Clarke, P. J., & Snowling, M. J. (2014). Reading comprehension impairments in Autism Spectrum Disorders. *L'Année Psychologique*, *114*(04), 779–797. https://doi.org/10.4074/S0003503314004084.
Hudson, R. F., Sanders, E. A., Greenway, R., Xie, S., Smith, M., Gasamis, C., Martini, J., Schwartz, I., & Hackett, J. (2017). Effects of emergent literacy interventions for preschoolers with autism spectrum disorder. *Exceptional Children*, *84*(1), 55–75. https://doi.org/10.1177/0014402917705855.
Ibrahim, I. (2020). Specific learning disorder in children with autism spectrum disorder: current issues and future implications. *Advances in Neurodevelopmental Disorders*, *4*(2), 103–112. https://doi.org/10.1007/s41252-019-00141-x.
Jokel, A., Armstrong, E., Gabis, L., & Segal, O. (2020). Associations and dissociations among phonological processing skills, language skills and nonverbal cognition in individuals with autism spectrum disorder. *Folia Phoniatrica et Logopaedica*, 1–11. https://doi.org/10.1159/000505744.
Joseph, R. M., Tager-Flusberg, H., & Lord, C. (2002). Cognitive profiles and social-communicative functioning in children with autism spectrum disorder. *Journal of Child Psychology and Psychiatry*, *43*(6), 807–821. https://doi.org/10.1111/1469-7610.00092.
Justice, L., Logan, J., Kaderavek, J., Schmitt, M. B., Tompkins, V., & Bartlett, C. (2015). Empirically based profiles of the early literacy skills of children with language impairment in early childhood special education. *Journal of Learning Disabilities*, *48*(5), 482–494. https://doi.org/10.1177/0022219413510179.
Kaldy, Z., Kraper, C., Carter, A. S., & Blaser, E. (2011). Toddlers with autism spectrum disorder are more successful at visual search than typically developing toddlers. *Developmental science*, *14*(5), 980–988. https://doi.org/10.1111/j.1467-7687.2011.01053.x.
Kirby, J. R., Parrila, R. K., & Pfeiffer, S. L. (2003). Naming speed and phonological awareness as predictors of reading development. *Journal of Educational Psychology*, *95*(3), 453. https://doi.org/10.1037/0022-0663.95.3.453.
Kjelgaard, M. M., & Tager-Flusberg, H. (2001). An investigation of language impairment in autism: implications for genetic subgroups. *Language and Cognitive Processes*, *16*(2–3), 287–308. https://doi.org/10.1080/01690960042000058.
Korman, M., Kirk, U., & Kemp, S. (2007). *NEPSY-II: a developmental neuropsychological assessment* (2nd ed.). San Diego: Harcourt.
Lai, M. C., Lombardo, M. V., Ruigrok, A. N., Chakrabarti, B., Auyeung, B., Szatmari, P., Happé, F., & Baron-Cohen, S. (2017). Quantifying and exploring camouflaging in men and women with autism. *Autism*, *21*(6), 690–702. https://doi.org/10.1177/1362361316671012.
Layes, S., Guendouz, M., Lalonde, R., & Rebai, M. (2020). Combined phonological awareness and print knowledge training improves reading accuracy and comprehension in children with reading disabilities. *International Journal of Disability Development and Education*, 1–15. https://doi.org/10.1080/1034912X.2020.1779914.
Lazoff, T., Zhong, L., Piperni, T., & Fombonne, E. (2010). Prevalence of pervasive developmental disorders among children at the English Montreal School Board. *The Canadian Journal of Psychiatry*, *55*(11), 715–720. https://doi.org/10.1177/070674371005501105.
Leadbitter, K., Buckle, K. L., Ellis, C., & Dekker, M. (2021). Autistic self-advocacy and the neurodiversity movement: implications for autism early intervention research and practice. *Frontiers in Psychology*, 782. https://doi.org/10.3389/fpsyg.2021.635690.
Lord, C., Rutter, M., DiLavore, P. C., Risi, S., Gotham, K., & Bishop, S. (2012). Autism Diagnostic Observation Schedule, Second Edition. Torrence, CA: Western Psychological Services.
Lord, C., Rutter, M., DiLavore, P. C., & Risi, S. (1999). *Autism Diagnostic Observation Schedule-WPS (ADOS-WPS)*. Los Angeles: Western Psychological Services.
Lundberg, I., Larsman, P., & Strid, A. (2012). Development of phonological awareness during the preschool year: the influence of gender and socio-economic status. *Reading and writing*, *25*(2), 305–320. https://doi.org/10.1007/s11145-010-9269-4.
Macdonald, D., Luk, G., & Quintin, E. M. (2020). Early word reading of preschoolers with ASD, both with and without hyperlexia, compared to typically developing preschoolers.Journal of autism and developmental disorders,1–15.
McArthur, G. M., Hogben, J. H., Edwards, V. T., Heath, S. M., & Mengler, E. D. (2000). On the "specifics" of specific reading disability and specific language impairment. *The Journal of Child Psychology and Psychiatry and Allied Disciplines*, *41*(7), 869–874. https://doi.org/10.1111/1469-7610.00674.
Medda, J. E., Cholemkery, H., & Freitag, C. M. (2019). Sensitivity and specificity of the ADOS-2 algorithm in a large german sample. *Journal of Autism and Developmental Disorders*, *49*(2), 750–761. https://doi.org/10.1007/s10803-018-3750-3.

Milankov, V., Golubović, S., Krstić, T., & Golubović, Š. (2021). Phonological awareness as the foundation of reading acquisition in students reading in transparent orthography. *International Journal of Environmental Research and Public Health*, *18*(10), 5440. https://doi.org/10.3390/ijerph18105440.

Moritz, C., Yampolsky, S., Papadelis, G., Thomson, J., & Wolf, M. (2013). Links between early rhythm skills, musical training, and phonological awareness. *Reading and Writing*, *26*(5), 739–769. https://doi.org/10.1007/s11145-012-9389-0.

Morris, R. D., Lovett, M. W., Wolf, M., Sevcik, R. A., Steinbach, K. A., Frijters, J. C., & Shapiro, M. B. (2012). Multiple-component remediation for developmental reading disabilities: IQ, socioeconomic status, and race as factors in remedial outcome. *Journal of Learning Disabilities*, *45*(2), 99–127. https://doi.org/10.1177/0022219409355472.

Mottron, L., Belleville, S., Rouleau, G. A., & Collignon, O. (2014). Linking neocortical, cognitive, and genetic variability in autism with alterations of brain plasticity: the trigger-threshold-target model. *Neuroscience & Biobehavioral Reviews*, *47*, 735–752. https://doi.org/10.1016/j.neubiorev.2014.07.012.

Mottron, L., & Burack, J. A. (2001). Enhanced perceptual functioning in the development of autism. In J. A. Burack, T. Charman, N. Yirmiya, & P. R. Zelazo (Eds.), *The development of autism: perspectives from theory and research* (pp. 131–148). Lawrence Erlbaum Associates Publishers.

Mottron, L., Dawson, M., & Soulières, I. (2009). Enhanced perception in savant syndrome: patterns, structure and creativity. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*(1522), 1385–1391. https://doi.org/10.1098/rstb.2008.0333.

Mottron, L., Dawson, M., Soulières, I., Hubert, B., & Burack, J. (2006). Enhanced perceptual functioning in autism: an update, and eight principles of autistic perception. *Journal of Autism and Developmental Disorders*, *36*(1), 27–43. https://doi.org/10.1007/s1080.

Nader, A. M., Jelenic, P., & Soulières, I. (2015). Discrepancy between WISC-III and WISC-IV cognitive profile in autism spectrum: what does it reveal about autistic cognition? *PloS one*, *10*(12), e0144645. https://doi.org/10.1371/journal.pone.0144645.

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.

National Early Literacy Panel. (2008). *Developing early literacy*. Washington, D.C: National Institute for Literacy.

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.

Pellicano, E., & den Houting, J. (2022). Annual Research Review: shifting from 'normal science'to neurodiversity in autism science. *Journal of Child Psychology and Psychiatry*, *63*(4), 381–396. https://doi.org/10.1111/jcpp.13534.

Pennington, B. F. (2006). From single to multiple deficit models of developmental disorders. *Cognition*, *101*(2), 385–413. https://doi.org/10.1016/j.cognition.2006.04.008.

Ring, J., & Black, J. L. (2018). The multiple deficit model of dyslexia: what does it mean for identification and intervention? *Annals of dyslexia*, *68*(2), 104–125. https://doi.org/10.1007/s11881-018-0157-y.

Roth, F. P., Speece, D. L., & Cooper, D. H. (2002). A longitudinal analysis of the connection between oral language and early reading. *The Journal of Educational Research*, *95*(5), 259–272. https://doi.org/10.1080/00220670209596600.

Rutter, M., Bailey, A., & Lord, C. (2003). *The Social Communication Questionnaire*. Los Angeles: Western Psychological Services.

Rutter, M., Le Couteur, A., & Lord, C. (2003). *ADI-R. Autism Diagnostic interview revised. Manual*. Los Angeles: Western Psychological Services.

Sahyoun, C. P., Belliveau, J. W., Soulières, I., Schwartz, S., & Mody, M. (2010). Neuroimaging of the functional and structural networks underlying visuospatial vs. linguistic reasoning in high-functioning autism. *Neuropsychologia*, *48*(1), 86–95. https://doi.org/10.1016/j.neuropsychologia.2009.08.013.

Scarborough, H. S., & Brady, S. A. (2002). Toward a common terminology for talking about speech and reading: a glossary of the "phon" words and some related terms. *Journal of Literacy Research*, *34*(3), 299–336. https://doi.org/10.1207/s15548430jlr3403_3.

Schuele, C. M., & Boudreau, D. (2008). Phonological awareness intervention: beyond the basics. *Language Speech and Hearing Services in Schools*, *39*(1), 3–20. https://doi.org/10.1044/0161-1461(2008/002).

Silberberg, N. E., & Silberberg, M. C. (1967). Hyperlexia: specific-word recognition skills in young children. *Exceptional Children*, *34*, 41–42. https://doi.org/10.1177/001440296703400106.

Smith Gabig, C. (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.

Soulières, I., Dawson, M., Gernsbacher, M. A., & Mottron, L. (2011). The level and nature of autistic intelligence II: what about Asperger syndrome? *PloS one*, *6*(9), e25372. https://doi.org/10.1371/journal.pone.0025372.

Soulières, I., Dawson, M., Samson, F., Barbeau, E. B., Sahyoun, C. P., Strangman, G. E., & Mottron, L. (2009). Enhanced visual processing contributes to matrix reasoning in autism. *Human brain mapping*, *30*(12), 4082–4107. https://doi.org/10.1002/hbm.20831.

Stanovich, K. E. (1988). Explaining the differences between the dyslexic and the garden-variety poor reader: the phonological-core variable-difference model. *Journal of Learning Disabilities*, *21*(10), 590–604. https://doi.org/10.1177/002221948802101003.

Stanutz, S., Wapnick, J., & Burack, J. A. (2014). Pitch discrimination and melodic memory in children with autism spectrum disorders. *Autism*, *18*(2), 137–147. https://doi.org/10.1177/1362361312462905.

Stone, B., & Brady, S. (1995). Evidence for phonological processing deficits in less-skilled readers. *Annals of Dyslexia*, *45*(1), 51–78. https://doi.org/10.1007/BF02648212.

Torgesen, J. K., Wagner, R. K., & Rashotte, C. A. (1994). Longitudinal studies of phonological processing and reading. *Journal of Learning Disabilities*, *27*(5), 276–286. https://doi.org/10.1177/002221949402700503.

Van Bergen, E., van der Leij, A., & de Jong, P. F. (2014). The intergenerational multiple deficit model and the case of dyslexia. *Frontiers in human neuroscience*, 346. https://doi.org/10.3389/fnhum.2014.00346.

Wagner, R. K., & Torgesen, J. K. (1987). The nature of phonological processing and its causal role in the acquisition of reading skills. *Psychological bulletin*, *101*(2), 192. https://doi.org/10.1037/0033-2909.101.2.192.

Wechsler, D. (2011). *Wechsler Abbreviated Scale of Intelligence, Second Edition (WASI-II)*. San Antonio, TX: NCS, Pearson.

Westerveld, M. F., Paynter, J., Brignell, A., & Reilly, S. (2020). No differences in code- related emergent literacy skills in well-matched 4-Year-old children with and without ASD. *Journal of Autism and Developmental Disorders*, *50*(8), 3060–3065. https://doi.org/10.1007/s10803-020-04407-5.

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., Trembath, D., Shellshear, L., & Paynter, J. (2016). A systematic review of the literature on emergent literacy skills of preschool children with autism spectrum disorder. *The Journal of Special Education*, *50*(1), 37–48. https://doi.org/10.1177/0022466915613593.

Whitehurst, G. J., & Lonigan, C. J. (1998). Child development and emergent literacy. *Child development*, *69*(3), 848–872. https://doi.org/10.1111/j.1467-8624.1998.tb06247.x.

Wodka, E. L., Mathy, P., & Kalb, L. (2013). Predictors of phrase and fluent speech in children with autism and severe language delay. *Pediatrics*, *131*(4), 1128–1134. https://doi.org/10.1542/peds.2012-2221.

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