

Profile of hyperlexia: Reconciling conflicts through a systematic review and meta-analysis

Shuai Zhang*, R. Malatesha Joshi

Department of Teaching, Learning, and Culture, Texas A & M University, TAMU 4232, College Station, TX, 77845, United States



ARTICLE INFO

Keywords:

Decoding
Hyperlexia
Listening comprehension
Reading comprehension

ABSTRACT

It is believed that children with poor decoding skills and adequate listening comprehension skills exhibit a dyslexia-type syndrome. However, there is no consensus relating to the other problem that arises: children who have exceptional decoding but poor listening comprehension. Sometimes, these children have been labeled as “individuals exhibiting hyperlexia.” There is no clear understanding of the following aspects of hyperlexia: a) population criteria (e.g., typically vs. atypically developing children), b) specific criteria (e.g., precocity, definition of “good decoding”) on their associations with reading, and c) the applicability of reading theories to hyperlexia (e.g., phonemic awareness is critical in decoding; both decoding and listening comprehension contribute to reading comprehension). Therefore, we conducted a systematic and meta-analytic review to explore these questions. We found that despite good decoding and verbal short-term memory skills, individuals with hyperlexia exhibit poor listening, verbal working memory, and reading comprehension skills. Also, all but three studies identified hyperlexics from atypical developing populations; however, criteria to define “good decoding” varied and the onset of precocious decoding behavior was not consistently reported. Our meta-regression analysis suggests that decoding still predicted the performance of reading comprehension after controlling for listening comprehension, suggesting that the variations of defining “good decoding” led to different reading comprehension profiles (e.g., mild vs. severe reading comprehension deficit). Further, listening comprehension but not decoding is related to phonemic awareness, which may be due to the difficulty of understanding phonemic awareness tasks. However, it may also suggest that the current decoding theory is not applied to hyperlexia. Future suggestions for hyperlexia research are provided.

1. Introduction

Silberberg and Silberberg (1967) were the first to coin the term ‘hyperlexia’ based on 20 children who showed precocity in their decoding, even though their verbal functioning ability was lower than typically developing children, which would affect listening, reading comprehension and other academic skills. This finding revealed that decoding ability could develop normally even in children with developmental disorders. Therefore, originally the term “hyperlexia” only referred to those readers with low IQ but precocious decoding skills.

Later in 1968, to quantify the criterion of identifying individuals with hyperlexia (i.e., hyperlexics), Silberberg and Silberberg further specified that only children with a decoding score of 1–1.5 years above their corresponding grade level could be identified as

* Corresponding author.

E-mail addresses: szhang1989@tamu.edu (S. Zhang), mjoshi@tamu.edu (R.M. Joshi).

<https://doi.org/10.1016/j.jneuroling.2018.08.001>

Received 12 October 2017; Received in revised form 4 August 2018; Accepted 5 August 2018

Available online 15 August 2018

0911-6044/ © 2018 Elsevier Ltd. All rights reserved.

hyperlexics. However, grade levels, as ordinal data, do not provide detailed and precise information. Also, this single criterion does not justify how to describe hyperlexics' comprehension skills. Since then, some studies on hyperlexia have been published, but the identification criteria debate has not ceased.

Needleman's (1982) criteria include the diagnosis of developmental disorders and the precocity of decoding as well as better decoding than IQ levels. This definition is more comprehensive and clearer, which may be the reason why it is more accepted compared to Silberberg and Silberberg (1968) definition (Snowling & Frith, 1986). However, some of these data (e.g., precocity of reading) may be difficult to collect in empirical studies, and the understanding of "developmental disorder" varied across hyperlexia research. Later, reading process was simplified to the product of decoding and listening comprehension, which is known as the *Simple View of Reading* (SVR; Gough & Tunmer, 1986). In the SVR model, hyperlexia can be defined as having "good decoding but poor listening and (as the product) poor reading comprehension skills." The SVR's view on hyperlexia does not specify that the hyperlexics need to show atypically developing syndromes (e.g., Autism Spectrum Disorder [ASD]), and it also has received support from researchers (e.g., Catts, Hogan, & Fey, 2003; Hoover & Gough, 1990; Joshi & Aaron, 2000; Singh et al., 2017). Meanwhile, other researchers still applied Needleman's (1982) criteria while identifying hyperlexia (e.g., Burd & Kerbeshian, 1985; Healy, 1982; Wong, Weekes, Iao, To, & Su, 2013).

Using Needleman's criteria, Burd, Kerbeshian, and Fisher (1985) found that 6.6% ASD children in the state of North Dakota, U.S. had hyperlexia. If this ratio is still valid, then the scarcity of hyperlexia research is not reasonable. One evidence is that the keyword of "hyperlexia" searched on the Education Resource Information Center (ERIC) database yielded only eight published research studies from 2008 to 2017, while the keyword search of "dyslexia" produced 1153 studies during the same time.

We propose that reconciling the conflicts is an urgent need for the productivity and quality of hyperlexia research. Therefore, the current research aims to synthesize findings from the past 37 years. Our study is motivated by three aims: a) understand hyperlexia-type reading and clarify the population criteria, b) understand if it is plausible to eliminate some criteria (e.g., precocity and IQ) so the future research design can be simplified, and c) understand if the reading theories (e.g., the SVR) are applicable to hyperlexia. Lastly, we hope to provide suggestions for future research.

2. Literature review

We begin by reviewing prevalent reading theories to introduce how reading and reading disorders are defined. The SVR model (Gough & Tunmer, 1986) proposes that decoding and listening comprehension are essential components of reading comprehension, and the role of decoding and listening comprehension in reading comprehension should be formulated as:

$$\text{Reading comprehension (RC)} = \text{Decoding (D)} \times \text{Listening Comprehension (LC)}$$

In the SVR model, as shown above, decoding and listening comprehension can develop independently of one another, but the multiplication sign "x" indicates that reading comprehension is the product of decoding and listening comprehension. If decoding is poor, but listening comprehension is good, reading comprehension will be poor, and this explanation has been used to define *dyslexia* in the SVR model. However, if listening comprehension is poor, but decoding is good, the reading comprehension will still be poor, and this is how the SVR defines *hyperlexia* (Hoover & Gough, 1990).

The SVR model also defines the construct of each reading component. Decoding is to sound out nonwords and real words (Florit & Cain, 2011), and popular decoding measurements are real word reading accuracy, nonword reading accuracy, and word or nonword reading fluency (speed and accuracy; Braze et al., 2016; Florit & Cain, 2011; Gough, Hoover, & Peterson, 1996; Tunmer & Chapman, 2012). Listening comprehension is the ability to understand *spoken* language. It can be assessed through receptive vocabulary (e.g., listen to a word and identify the corresponding picture), expressive vocabulary (e.g., listen to a word and give an oral definition), as well as receptive or expressive sentence- and discourse-level tests (Hoover & Gough, 1990; Tunmer & Chapman, 2012). Reading comprehension as the product of decoding and listening comprehension is to sound out and understand *written* texts (Gough & Tunmer, 1986). Therefore, it can be assessed by word, sentence and passage reading comprehension (Braze et al., 2016; Carver, 1998; Floyd, Meisinger, Gregg, & Keit, 2012).

2.1. Decoding and dyslexia

How children achieve decoding has been well understood. For example, Share's *self-teaching hypothesis* (Share, 1995, 2008) states that during early literacy development, children learn to apply grapheme-to-phoneme correspondence (GPC; or orthographic-phonological mapping) rules for the sake of attaching sounds to letters of an unfamiliar word; gradually, when children are proficient at these rules, they decode fluently (i.e., fast and accurate; Share, 2008). The *Triangle model of reading* (Harm & Seidenberg, 2004; Seidenberg & McClelland, 1989) further states that semantic-phonological mapping can also assist in decoding real words. For example, when children remember the meaning of a word, the word's meaning can also be triggered to assist decoding. Therefore, both orthographic-phonological and semantic-phonological mapping are critical when students learn to decode. Research has shown that children apply different mapping strategies based on word familiarity or spelling regularity of the words. Semantic-phonological mapping is applied when words are familiar or are not spelled based on letter-sound correspondence (i.e., irregular words), and orthographic-phonological mapping is used when words are regularly spelled but may not be familiar to students (Bishop & Snowling, 2004; Ehri, 1992; Uhry, 2011).

With a clear understanding of how decoding is learned, when investigating reading disorders, researchers tend to focus on decoding problems (Bishop & Snowling, 2004). Although there were debates on why dyslexics show poor decoding (Elliott & Grigorenko, 2014; Goswami, 2015; Vidyasagar & Pammer, 2010), more research studies support the core deficit of dyslexia is phonemic awareness. Phonemic awareness is defined as the ability to *manipulate* individual sounds in spoken language and is the best predictor of decoding among the phonological processing skills (Ehri et al., 2001; Hulme et al., 2002; National Reading Panel [NRP, 2000]; Ziegler & Goswami, 2005). Studies based on brain functions in dyslexia further show that the poor phonemic processing skills originate from the reduced activation in the left temporal-parietal cortex and are independent of verbal IQ levels (Maisog, Einbinder, Flowers, Turkeltaub, & Eden, 2008; Tanaka et al., 2011). This cortex can be re-activated when training of phonemic awareness strategies is implemented (Temple et al., 2003). At the present time, dyslexia research focuses more on the correlates of dyslexia such as whether their attention, math or memory skills are also poor (Siegel, 2006; Tunmer & Greaney, 2010). On the other hand, hyperlexia is still in the definition debate phase and may have harmed the productivity and understanding of this reading disorder.

2.2. Population criteria of hyperlexia

The reason for the scarcity of hyperlexia research maybe due to the different perceptions of “poor listening comprehension.” For example, “poor listening comprehension” can result from low IQ in typically developing populations, but typically developing children may also have poor listening comprehension that is due to poor vocabulary or syntactic skills. To clarify, in this paper, “typically developing populations” are people who have no developmental disorder, and no IQ, social or behavioral deficits; “atypically developing populations” refers to the groups that have ASD, Specific Language Impairments (SLI), or other types of developmental, neurological, or behavioral disorders.

Although the SVR does not specify population criteria, researchers have validated the SVR in a wide range of groups, including typically developing, ASD, SLI, and Down Syndrome, and non-English speaking populations (Catts, Adlof, & Weismer, 2006; Florit & Cain, 2011; Ricketts, Jones, Happé, & Charman, 2013; Roch & Levorato, 2009). Therefore, the SVR's definition may suggest that hyperlexia can be identified from any population. However, Needleman (1982) suggested that hyperlexia should be identified in atypically developing populations. Needleman's criteria included: “a) Occurs in developmental disordered population, b) early manifestation (of decoding; age 2–5 years), c) (Decoding) emerges suddenly and is self-generated and d) (Decoding) is in advance of cognitive or other language abilities” (p. 475). Therefore, reporting atypically developing syndromes such as developmental disorder or showing precocious decoding is necessary. Empirical research that used the SVR definition may suggest that any individual who meets the criteria of “good decoding and poor comprehension” could be identified as having hyperlexia, but those who used Needleman's criteria may only identify hyperlexia from atypically developing populations. Hence, the first clarification that needs to be made is population criteria: If hyperlexia is defined in typically developing populations, hyperlexia research should focus on investigating the core deficit (perhaps vocabulary) that caused poor listening comprehension and provide remediation strategies. If hyperlexia occurs in atypically developing populations only, the issue maybe complicated but the comorbidity of poor listening comprehension and developmental disorders should be the area of focus.

2.3. Atypically developing syndromes

Even though some researchers may agree with Needleman's (1982) criteria, in empirical research, there are significant difficulties in collecting data to meet all the criteria. For example, to investigate precocity of reading, one has to interview parents or guardians (Richman & Wood, 2002). Moreover, the criterion “(Decoding) is in advance of cognitive or other language abilities” would require at least two diagnostic assessments—decoding and IQ tests to determine if the level of decoding is higher than the IQ. Aaron (1989) identified invariant (consistently reported) and variant (often but not consistently reported) syndromes from hyperlexia studies, and the double discrepancy (i.e., high decoding but low comprehension ability) plus precocious reading behaviors are consistent identification criteria for hyperlexia whereas not all studies include ASD or other atypically developing features as identifiers. Later, researchers tried to explain the reasons for hyperlexia and atypically developing syndrome comorbidities (e.g., ASD), but their findings did not reach a consensus.

2.3.1. ASD and hyperlexia

With the findings in which ASD showed similar reading profiles as hyperlexics, some researchers equated ASD and hyperlexic groups in reading research. For example, a meta-analysis of ASD studies conducted by Brown, Oram-Cardy, and Johnson (2013) included studies of hyperlexics, alluding that the two groups had a similar reading profile.

Brain research studies have also shown comorbidity of ASD and hyperlexia. Samson, Mottron, Soulieres, and Zeffiro (2012) conducted an activation likelihood estimation (ALE) meta-analysis on ASD readers and found that their visual processing-related regions were more active than typically developing peers. Further, Turkeltaub et al. (2004) scanned the brain of a 9-year-old boy with hyperlexia (with ASD) and found that his phonological and visual processing brain regions were both hyperactive. According to Seidenberg and McClelland (1989), children must first visually process the letter patterns of words to attach sounds to these words (also see Lachmann, Khera, Srinivasan, & Van Leeuwen, 2012). Therefore, perhaps the exceptional visual skills helped hyperlexics process the letter patterns, and then the exceptional phonological processing abilities further helped the hyperlexics rapidly and accurately attach sounds to these letters (Sparks, 2004).

The above studies suggested that both visual and phonological processing are necessary in decoding, and this view is supported in research on typically developing readers (Berninger, Abbott, Nagy, & Carlisle, 2017; Lachmann et al., 2012). Also, individuals with

hyperlexia (good visual and phonological processing) may have better decoding skills than ASD children (good visual processing only). Research on hyperlexics supports this view (e.g., Burd, Fisher, Knowlton, & Kerbeshian, 1987; Cardoso-Martins & Da Silva, 2010; Enoch-Holman, 2004; Newman et al., 2007), and tends to separate ASD with hyperlexia (i.e., ASD + HPL) from ASD without hyperlexia (ASD-HPL). Meanwhile, these researchers believe that hyperlexia is highly associated with ASD syndromes (Ostrolenk, d’Arc, Jelenic, Samson, & Mottron, 2017). However, the reasons for the comorbidity of ASD and hyperlexia are unknown, such as why the social interaction disabilities (ASD characteristics) and the exceptional decoding skills (hyperlexia characteristics) are associated with each other.

2.3.2. Other atypically developing syndromes and hyperlexia

Nonetheless, Snowling and Frith (1986) argued that hyperlexia “is not a syndrome-specific phenomenon” (p. 410). Some hyperlexia cases were reported in Attention Deficit/Hyperactivity Disorder (ADHD), Turner’s syndrome, 22q11.2 deletion syndrome, or Specific Language Impairment (SLI) groups (Temple & Carney, 1996; Tobia, Brigstocke, Hulme, & Snowling, 2018; Åsberg Johnels, Gillberg, & Kopp, 2017). It should be noted that the ADHD participants in Åsberg Johnels et al. (2017) showed poorer social interaction skills and more communication errors than the ADHD participants without hyperlexia, and these deficits are also characteristics of ASD. As no evidence has shown that ADHD syndromes are associated with visual or phonological skills (Helenius, Laasonen, Hokkanen, Paetau, & Niemivirta, 2011), hyperlexia may still be related to ASD, as shown in Åsberg Johnels et al.’s (2017) study.

However, Cohen, Hall, and Riccio (1997) identified hyperlexics from children with SLI (delay of language development), and these children showed no social interaction deficits. Cohen et al. (1997) explained that some children with SLI may have good decoding skills because of their exceptional visual memory skills, but this explanation has not been explored further. Other hyperlexics from Turner’s syndrome (Temple & Carney, 1996) and Dysmorphic Facial characteristics (Santoro, Healey, & McGinley, 2016) groups also did not show ASD characteristics. Santoro et al.’s (2016) case even had poor visual memory, which is different from the cases in Cohen et al.’s (1997) study. These research studies may suggest that social interaction or visual memory alone is not a causal factor of hyperlexia.

2.3.3. Precocity and “giftedness”

Samson, Mottron, Soulières, and Zeffiro (2012) concluded that precocious decoding is also related to atypical hyperactivities in phonological processing brain regions. Perhaps precocious decoding is also not specific to ASD, as it has also been observed in SLI and Periventricular Leukomalacia (PVL) groups that had no ASD features (Cohen et al., 1997; Richman & Wood, 2002; Yokochi, 2000).

It may not be appropriate to label hyperlexics as “gifted children.” This is because gifted children often have IQ scores over 130 (Winner, 1997, p. 1071) while many individuals with hyperlexia have IQ scores below 70 (e.g., Cobrinik, 1982; Jones et al., 2009; Needleman, 1982; Sparks, 2004; Worthy & Invernizzi, 1995). Therefore, precocious decoding may be just one feature of some developmental disorders such as ASD. Healy (1982) coined the term “savant” to describe hyperlexics’ precocious and good decoding despite poor IQ and comprehension. However, the impact of precocity of reading on later reading development has not been studied.

2.4. Definition of “good decoding”

Different from precocity, developmental disorders, and IQ, “good decoding” as a basic feature of hyperlexia cannot be challenged. Needleman’s (1982) criteria may provide general guidelines and qualitative descriptors but do not give quantification on how much “higher” decoding should be compared to IQ. To make this issue more complex, some researchers (e.g., Cardoso-Martins & Da Silva, 2010; Grigorenko et al., 2003) did not compare decoding with IQ but adopted other ways to define “good decoding.” In this section, we summarize some prevalent quantification criteria of “good decoding”.

2.4.1. Decoding compared to self-IQ level

Cohen et al. (1997) as well as Grigorenko et al. (2003) identified hyperlexics through comparison between decoding and self-IQ as Needleman (1982) had recommended. Nevertheless, researchers may quantify the discrepancy differently. Cohen et al. (1997) suggested that hyperlexics should have a decoding score of 1 *SD* higher than nonverbal IQ while Grigorenko et al. (2003) proposed 2 *SD*. Instead of statistical comparisons, Welsh, Pennington, and Rogers (1987) mathematically calculated the discrepancy. Welsh and colleagues computed the reading quotient (RQ) by dividing the decoding age equivalent score by the participants’ IQ age score, and if the quotient was over 1.2, the participants were identified as hyperlexics. However, this method has not received wide support.

The above-mentioned IQs are reported as full scale IQs; however, full scale IQ scores are based on verbal and performance (nonverbal) IQ scores (i.e., VIQ and PIQ; Wechsler Intelligence Scale for Children [WISC, Wechsler, 2003]), which further complicates the role of IQ in hyperlexia. For example, Richman and Wood (2002) identified two subgroups of hyperlexics: a) the VIQ-decoding discrepancy group that had poor VIQ but good PIQ and decoding skills, and b) the PIQ-decoding discrepancy group that had poor PIQ, but good VIQ and decoding skills. Although VIQ and listening comprehension often have similar tests (e.g., expressive vocabulary) and thus VIQ should have an impact on reading comprehension based on the SVR, the role of PIQ skills (e.g., visual-spatial processing) in reading has not been understood well.

2.4.2. Decoding compared to typically developing children

Studies that fall into this category typically have included typically developing individuals as control groups. Richman and Kitchell (1981) identified individuals with hyperlexia by comparing decoding scores between the hyperlexics and typically

developing children; specifically, given the precocity and the developmental disorder(s), if the participants' decoding skills were significantly better than those of typically developing children, the former would be identified as hyperlexics. Lin (2014) specified the gap to 1 standard deviation (*SD*), which means the hyperlexics should have a decoding score of 1 *SD* above that of typically developing peers. Cardoso-Martins and Da Silva (2010) and Naples (2009) suggested that “average” decoding skills could meet the criterion of “good decoding skills.” Therefore, hyperlexics in these two studies have decoding skills matched with those of typically developing children (given the precocity of decoding and atypical developing syndromes). Little is yet known about how “better decoding” and “matched decoding” will produce any difference on other reading profiles of hyperlexics.

2.4.3. Decoding compared to comprehension level

Some researchers identify hyperlexics through comparisons between decoding and listening or reading comprehension skills (e.g., Abnett, 2013; Ng & Chia, 2014). These studies tend to align with the SVR, but some studies may identify listening and reading comprehension as a composite “comprehension” construct but not differentiate them. Also aligned with the SVR is that these studies tend to lack information about developmental disorders and precocity information, which means they may have recruited typically developing children. One problem of these studies is that the term “poor comprehender” has been used in recent years to refer to a “good decoder but poor comprehender” as well (Nation, 1999). Research has not reached a consensus as to whether a difference should exist between the two terms, but recent studies tend to identify “poor comprehenders” from typically developing populations (Spencer & Wagner, 2018).

3. Impact of criteria debate and the current research

3.1. Contradictory research findings

Definition debates on population criteria (typically vs. atypically developing), variations on specific syndromes (e.g., type of disorder, precocious decoding) and different quantification criteria of decoding may have caused research to generate different or even conflicting answers. For example, Turkeltaub et al.'s (2004) case of hyperlexia (with ASD and precocious decoding) demonstrated exceptional IQs (VIQ = 121, PIQ = 130, Full IQ [FIQ] = 127) and the participant's listening comprehension was advanced (age equivalent score = 19 vs. chronological age = 9). This participant may have used comprehension skills to assist word decoding, as predicted by the *Triangle model of reading* (Harm & Seidenberg, 2004). By contrast, the participants in Ng and Chia's (2014) study (mean chronological age = 9) had lower VIQ scores (mean VIQ = 79.67) than Turkeltaub et al.'s case and had no ASD or precocious decoding reports. Also, Ng and Chia further implemented reading comprehension interventions to the hyperlexics and found them effective, but Turkeltaub et al.'s case did not even have a reading comprehension problem. Therefore, the two studies may have identified different groups as a result of definition conflicts. We suggest that if a common understanding of hyperlexia cannot be reached, researchers will continue to define hyperlexia in various ways and then explore their research questions. As a result, these research findings will still be hard to converge and thus interfere with our understanding of hyperlexia.

3.2. Lack of research on reading-related skills

Perhaps because of the definition debates, hyperlexia research that has investigated phonemic awareness, verbal memory, and non-English languages is scarce. Although researchers well understood that phonemic awareness is the best predictor of decoding in typically developing children, research that has attempted to understand if hyperlexics rely on phonemic awareness to decode is limited. It seems intuitive to believe that phonemic awareness of hyperlexics is exceptional given their good decoding skills; however, some studies have found that hyperlexics' phonemic awareness performance was poor (Cardoso-Martins & Da Silva, 2010; Newman et al., 2007; Sparks, 2004), but Joshi, Padakannaya, and Nishanimath (2010) and Kennedy (2003) found that hyperlexics maintained good phonemic awareness. Newman et al. (2007) believe that hyperlexics' phonemic awareness skills were intact, and the problem was the understanding of phonemic awareness tasks. Sparks (2004) proposed that phonemic awareness of hyperlexics were indeed poor, as “manipulations” skills may have touched on the domain of comprehension. Interestingly, “poor comprehenders” (identified in typically developing children) did not seem to exhibit poor phonemic awareness (Hogan, Adlof, & Alonzo, 2014; Nation, Snowling, & Clarke, 2007; Ricketts, Bishop, & Nation, 2008; Stothard & Hulme, 1995). Until now, no research has synthesized findings on phonemic awareness of hyperlexics to show if this skill is poor across hyperlexics, or if poor listening comprehension has led to poor performance in phonemic awareness tasks.

Verbal memory is defined as the capacity of *storing* and *processing* oral information (Daneman & Carpenter, 1980). According to Carretti, Borella, Cornoldi, and De Beni (2009), verbal memory includes *verbal short-term memory* (e.g., recall digits in the presented order) and *verbal working memory* (e.g., recall digits in the reverse order). When asked to apply GPC rules for decoding, typically developing children with poor verbal memory may have difficulty retaining each sound in their memory long enough to be blended into a whole word. Hyperlexics may show good verbal short-term memory but poor verbal working memory, as short-term memory mainly relates to decoding but working memory also taps on comprehension domain (see Daneman & Merikle, 1996 and Peng et al., 2018, for meta-analyses). However, no research has synthesized the findings on hyperlexics' verbal memory to show if the verbal memory profile is consistent with their decoding or listening comprehension profile.

Also, most hyperlexia research has been conducted in alphabetic languages, where sounds are represented by written symbols (letter or letter clusters; Joshi & Aaron, 2006; Share, 1995, 2008). These languages vary on the degree of letter-to-sound correspondence, which may cause differences in decoding acquisition (Joshi & Aaron, 2006). In some languages such as Greek, Italian, and

Spanish, one letter or letter cluster typically has only one way of decoding. These languages are referred to as “transparent alphabetic languages” to represent their high letter-sound correspondence level. By contrast, “opaque alphabetic languages” such as English have an inconsistent letter-to-sound relationship because some of their letters or letter clusters can represent more than one sound (Ziegler & Goswami, 2005).

Hyperlexia has been reported in transparent languages (Naples, 2009; Talero-Gutierrez, 2006; Zuccarello et al., 2015; Åsberg Johnels & Miniscalco, 2014), but the majority of cases were reported in English monolinguals (Catts et al., 2003; Chia & Kee, 2013; Cohen et al., 1997; Healy, 1982; Needleman, 1982). Due to the low letter-to-sound consistency, typically developing children in English take more time to develop intact decoding skills compared to their counterparts in transparent alphabetic languages (Seymour, Aro, & Erskine, 2003; Share, 2008; Ziegler & Goswami, 2005). Despite the fact that the SVR asserts that the contribution of decoding and listening comprehension to reading comprehension is independent of one another (Catts et al., 2003; Gough & Tunmer, 1986; Hoover & Gough, 1990), the joint effect of hyperlexics' advanced decoding level and the high consistency of letter-to-sound correspondence may lead hyperlexics in transparent alphabetic language to be different from English hyperlexics on reading comprehension profiles. Non-alphabetic languages such as Chinese-Mandarin (Lin, 2014), Chinese-Cantonese (Wong et al., 2013) and Japanese (Yokochi, 2000) also reported individual cases of hyperlexia. However, these studies rarely report group-based outcomes, which may be due to the criteria debates.

3.3. Significance of the current study

To sum up, different understandings of population criteria (typically vs. atypically developing), specific syndromes (e.g., type of disorder, precocious decoding, IQ) and quantification of decoding may have impeded the development of hyperlexia research, as empirical research has no clear guideline to follow. Therefore, reconciling hyperlexia debates can help researchers to follow unified criteria so that contradictory findings can be avoided, and then researchers can proceed to understand hyperlexics' performance in phonemic awareness, verbal memory, and in languages other than English. Investigating phonemic awareness and verbal memory is critical to understanding why hyperlexics can achieve decoding, especially when many hyperlexics may show precocious decoding even though phonemic awareness has not been fully developed. If decoding and phonemic awareness are not related, current decoding theories (e.g., *Self-teaching hypothesis*, *triangle model of reading*) that propose that phonemic awareness and decoding are related may not be applied to hyperlexia. Then reading theories may need to consider hyperlexics as a special group and develop specific theories that explore their “learning to read” routes.

As stated, the role of decoding in reading comprehension has been validated in different developmental disorder groups (Cardoso-Martins & Mervis, 2018; Mervis & Cardoso-Martins, 2018; Palikara, Dockrell, & Lindsay, 2011; Ricketts et al., 2013; Roch & Levorato, 2009). As hyperlexics are often identified from these groups, their decoding skills may also predict their reading comprehension. Then, if reading comprehension is a product of decoding and listening comprehension in any population, the difference on quantifying “good decoding” may be problematic, as it may have led to different reading comprehension ability. However, before an SVR investigation on hyperlexics can be performed, we suggest that the population criteria need to be clearly defined (i.e., typically vs. atypically developing) to reduce bias. Therefore, we ask our research questions as follows.

RQ 1: What is the comprehensive reading profile of individuals with hyperlexia? How consistent are researchers in defining and identifying hyperlexia? How does each specific criterion (e.g., “good decoding,” PIQ levels) affect reading comprehension profiles?

RQ 2: How are decoding and listening comprehension related to phonemic awareness and reading comprehension profiles among individuals with hyperlexia?

4. Data source and method

The current study adopted a systematic and meta-analytic procedure. First, we investigated the case studies and group-based studies of hyperlexia. We synthesized the coding results into matrixes to observe the consistency of the criteria. Second, we filtered the qualified studies for a meta-analysis to reconcile the research conflicts. We then explored if the inconsistencies of criteria would affect reading comprehension profiles.

4.1. Systematic review procedure

Studies included in Step 1 (systematic review) met the following criteria: (a) Were published in academic journals, dissertations, conference papers, and books between 1981 and 2017; (b) have claimed the existence of hyperlexia, irrespective of what criteria were followed (e.g., Gough & Tunmer, 1986; Needleman, 1982; Silberberg & Silberberg, 1967, 1968); (c) should have reported at least one hyperlexic participant's qualitative or quantitative information of reading skills; and (d) have been published in English.

The following databases were examined to select studies: ERIC, Education Resource, EBSCO, PsycINFO and Web of Science. We also checked previous reviews on the topic of ASD and hyperlexics (Brown et al., 2013; Ostrolenk et al., 2017). We extracted articles with a keyword “hyperlexia” or “hyperlexic” either in the title or in the abstract. This search yielded 240 articles. By looking into the abstracts and contents, we found 70 articles and 74 independent studies that met our standard.

4.1.1. Coding of precocity

According to Needleman (1982), to be considered as “precocious,” one needs to show the onset of decoding skills before five years of age or younger. In other words, children with decoding precocity can read aloud words before they receive formal school instruction. We entered a “yes” to the cell under the column of “precocious decoding” if the participants showed such behavior.

4.1.2. Coding of decoding skill

We entered specific descriptions of decoding skills to the cell under the column of “decoding descriptor.” For example, the decoding skill descriptor of Tirosh and Canby (1993) was entered as “1 SD higher than VIQ.” If specific values were missing in the identification but the decoding was qualitatively described, we followed the studies’ reports and entered as “precocious only,” “matched with typically developing readers,” “higher than typically developing readers,” “higher than IQ,” “higher than comprehension (type not specified),” and “higher than reading comprehension.”

4.1.3. Coding of population

We entered the population criteria to the cell under the column of “population.” Therefore, syndromes such as ASD, ADHD, SLI, Turner’s syndrome, Periventricular leukomalacia were entered in this column.

4.1.4. Coding of IQ

We entered the values of VIQ, PIQ, and FIQ under the column “IQ.” The IQ scores were coded based on the standard scores of WISC or WAIS irrespective of their versions. These scores have a mean of 100 and standard deviation of 15. If IQ scores from WISC or WAIS were not available, other test scores such as Raven’s Progressive Matrices test were coded (we provided notes for which test scores used). However, only WISC or WAIS scores were used for subsequent analyses and calculations.

4.2. Systematic review results

Step 1 results are summarized in Table 1. The total number of individuals with hyperlexia across studies was 545. The mean age based on the available data was 10.25 years ($SD = 5.46$; range = 3.92–39 years). There were 72 females (18.27%) and 322 males (81.73%), and the remaining 151 cases had no gender information.

Among the 74 included studies, 71 studies were from atypically developing populations (95.95%). Forty-eight studies (64.86%) identified hyperlexics from ASD samples or had hyperlexics showing ASD-like syndromes. Other developmental disorders included ADHD (Cohen, Campbell, & Gelardo, 1987), Turner’s syndrome (Temple & Carney, 1996), West syndrome (Ichiba, 1990), Right Brain Tumor and Hydrocephalus (Kennedy, 2003), Periventricular Leukomalacia and Spastic Diplegia (Yokochi, 2000), Tourette syndrome (Burd & Kerbeshian, 1988), 22q 11.2 Deletion syndrome (Tobia et al., 2018), Prader-Will syndrome (Burd & Kerbeshian, 1989), Hypergraphia (Burd & Kerbeshian, 1985; Whitehouse & Harris, 1984), and FIQ disability with no other diagnoses (Snowling & Frith, 1986). Twelve studies (16.22%) identified hyperlexics from participants who had SLI (e.g., Cohen et al., 1997; Prasad & Srivastava, 1992; Richman & Wood, 2002). Only three (4.05%) studies reported hyperlexia from participants that had no reports of developmental disorders or SLI.

Also, the majority of the studies identified hyperlexics from English monolinguals ($n = 56$; 75.68%). Other language groups include Chinese-Mandarin ($n = 1$), Chinese-Cantonese ($n = 2$), Japanese ($n = 2$), Italian ($n = 3$), Russian ($n = 1$), Spanish ($n = 1$), Swedish ($n = 2$), Korean ($n = 1$), Portuguese ($n = 3$), a Kannada-English bilingual ($n = 1$) case and a Dutch-French-English trilingual ($n = 1$) case.

Further, the majority of the 74 studies reported at least one type of IQ ($n = 51$; 81.2%). The mean WISC– or WAIS– VIQ score was 80.27 ($SD = 17.19$; range = 55.00–127.00), PIQ was 83.24 ($SD = 21.22$; range = 49.00–123.50), and FIQ was 78.77 ($SD = 20.16$; range = 48.00–130.00).

In total, 49 studies (66.22%) reported precocious decoding, with only 24 of the 42 group-based studies reported this criterion. But the highest inconsistency existed on “good decoding” descriptor. These descriptors varied from simple notes (e.g., “precocious only;” “advanced decoding, poor comprehension;” “higher than typically developing readers”) to specific quantitative identifiers (e.g., “decoding was 1.27 *SD* higher than the comparison group;” “standard decoding score is 10 points higher than the reading comprehension score”). These reports can be generally classified as “matched with typically developing readers,” “more advanced than typically developing readers,” “more advanced than listening or reading comprehension level,” “more advanced than IQ level” and “more advanced than chronological age” (also see Table 1, for specifics). Therefore, although most studies have aligned their criteria with Needleman’s (1982) guideline, the largest variation occurred among decoding descriptors, as there are six types of categories.

4.3. Meta-analysis coding procedure

In Step 2 (meta-analysis), we looked for empirical studies within the 74 coded studies. Eligible studies should have included the mean, standard deviation and sample size of both typically developing (control group) and hyperlexic groups. If either the mean or standard deviation is missing, we looked for group comparing statistics such as *t* and *F* values and transformed them to effect sizes based on Lipsey and Wilson’s (2001) instructions. If control groups were not included in a study or their statistic information was incomplete, we used Brown et al.’s (2013) approach to use normative sample of a test (e.g., PPVT-R for vocabulary) to build the control group; also, sample size of the control group is set as the same with the hyperlexic group for a balanced design (see Reid, Gonzalez, Nordness, Trout, & Epstein, 2004, for the same approach). However, this method was applied only to tests that used

Table 1
Information of case studies and group-based studies identified from Step 1 (systematic review).

Study	Sample size	Age	Language	Population	Precocity	IQ scores	Decoding skill description
<i>Case Studies (n = 32)</i> Aram, Rose, and Horwitz (1984)	1 (1 M)	39 y	English	ASD	Yes	VIQ (n/a) PIQ (n/a) FIQ (60)	Advanced decoding; poor comprehension
Åsberg Johnels and Miniscalco (2014)	1 (1 M)	7 y	Swedish	ASD	n/a	VIQ (84) PIQ (108) FIQ (94)	Advanced decoding (Top 7%); poor listening comprehension
Atkin and Lorch (2006)	1 (1 M)	4 y	English	ASD	Yes	VIQ (n/a) PIQ (n/a)	Higher than predicted by CA
Burd et al. (1985)	4 (3 M 1 F)	Case 1: 7 y Case 2: n/a Case 3: n/a Case 4: n/a	English	PDD	Yes	VIQ (n/a) PIQ (n/a)	Advanced decoding; poor comprehension
Burd et al. (1987)	4 (3 M 1 F)	Case 1: 11.5 y Case 2: 8 y Case 3: 25 y Case 4: 10.5 y	English	ASD	Yes	FIQ (only reported the mean FIQ: 58) VIQ: (case 1–4: n/a, 101, 91, n/a, 84, n/a, n/a) PIQ: (case 1–4: n/a, 101, 91, n/a, 97, 101, 91, 90)	Advanced decoding; poor comprehension
Burd and Kerbeshian (1985)	1 (1 M)	11 y	English	Hypergraphia	Yes	VIQ (n/a) PIQ (n/a)	Advanced decoding; poor comprehension
Burd and Kerbeshian (1988)	2 (1 M 1 F)	7 y 2m	English	PDD and Tourette syndrome	Yes	FIQ (48)	Advanced decoding; poor comprehension
Burd and Kerbeshian (1989)	1 (1 M)	n/a	English	Prader-Willi syndrome	Yes	Case 2: (n/a) VIQ (n/a) PIQ (n/a)	Advanced decoding; poor comprehension
Cardoso-Martins, Gonçalves, and de Magalhães (2013)	1 (1 M)	3y 11m	Portuguese	ASD with echolalia	n/a	FIQ (75) n/a	Matched with TD
Cossu and Marshall (1986)	2 (2 F)	Case 1: 12y 6 m Case 2: 18y 6 m	Italian	Poor IQ	n/a	VIQ (case 1: 58; case 2: 57) PIQ (case 1: n/a; case 2: 60) FIQ (case 1: n/a, case 2: 56)	Advanced decoding; poor FIQ
Craig and Telfer (2005)	1 (1 M)	12 y	English	PDD-NOS	Yes	VIQ (n/a) PIQ (100)	Advanced
Glosser, Friedman, and Roeltgen (1996)	1 (1 M)	8 y	English	SLI	Yes	FIQ (n/a) VIQ (n/a) PIQ (n/a) FIQ (51)	Advanced; 135 standard score on WRMT-R

(continued on next page)

Table 1 (continued)

Study	Sample size	Age	Language	Population	Precocity	IQ scores	Decoding skill description
Ichiba (1990)	2 (1 M 1 F)	11 and 10 y	Japanese	West syndrome	Yes	VIQ (case 1: n/a; case 2: n/a) PIQ (case 1: n/a; case 2: n/a) FIQ (case 1: 45; case 2: 76)	Advanced decoding; poor FIQ
Jensen (2005)	1 (1 M)	n/a	English	ASD	Yes	n/a	Advanced decoding; poor FIQ
Joshi et al. (2010)	1 (1 M)	16 y	Kannada English bilingual	TD	n/a	VIQ (n/a) PIQ (50 based on Raven's Progressive Matrices test)	Advanced decoding; poor listening and reading comprehension
Kennedy (2003)	2 (2 M)	15 y 5m and 19 y 9 m	English	Right brain tumor and hydrocephalus (one case has ASD features)	n/a	FIQ (n/a) VIQ (case 1: 69; case 2: n/a) PIQ (case 1: 49; case 2: n/a) FIQ (case 1: n/a; case 2: 39)	Reading quotient higher than 1.2
Kupperman, Bligh, and Barouski (1992)	1 (1 M)	7 y	English	PDD-high functioning	Yes	VIQ (n/a) PIQ (n/a)	Precocious but poor comprehension
Lebrun, Van Endert, and Sztutowski (1988)	1 (1 F)	9 y	Dutch, French, English	Hyperactive	No precocity	FIQ (120) VIQ (n/a) PIQ (n/a) FIQ (55)	Far in advance of comprehension; matched with TD
O'Connor and Hermelin (1994)	2 (M)	5 y and 8 y	English	ASD-Asperger's syndrome	Yes	VIQ (case 1: 118; case 2: 104) PIQ (case 1: 109; case 2: 138) FIQ (n/a)	Teacher identified their good decoding skills
Oberschneider (2003)	1 (M)	4 y	English	Social abnormality	Yes	n/a	In advance of TD; good listening comprehension
Patti and Lupinetti (1993)	1 (1 F)	22 y	English	ASD	Yes	VIQ (55) PIQ (50) FIQ (49)	Higher than FIQ
Pazzaglia, Ravarelli, Balestra, Orto, and Zanetti (2012)	1 (1 M)	25 y	English	ASD	Yes, then disappeared when ASD syndrome shows	VIQ (n/a) PIQ (n/a) FIQ (55)	Advanced decoding; poor listening and reading comprehension
Pennington, Johnson, and Welsh (1987)	1 (1 M)	Time 1: 3.2 y; Time 2: 4.2 y	English	TD	Yes	VIQ (n/a) PIQ (time 1: 100; time 2: 144)	Decoding higher than IQ
Santorio et al. (2016)	1 (1 F)	13 y	English	Dysmorphic facial characteristics	Yes	FIQ (n/a) VIQ (n/a) PIQ (n/a) FIQ (72)	Advanced reading fluency; low comprehension
Siegel (1984)	1 (1 F)	6 y	English	SLI	Yes	VIQ (69) PIQ (52) FIQ (58)	In advance of listening comprehension

(continued on next page)

Table 1 (continued)

Study	Sample size	Age	Language	Population	Precocity	IQ scores	Decoding skill description
Smith and Bryson (1988)	2 (2M)	7 y 2 m	English	ASD	Yes	VIQ (n/a) PIQ (case 1: 49; case2: 62)	Advanced decoding; poor comprehension
Su, To, and Weekes (2011)	1 (1M)	8y 4 m	Cantonese	ASD	Yes	Estimated IQ was below the lowest 5% in his age	Advanced decoding; poor comprehension
Talero-Gutierrez (2006)	2 (2M)	Case 1: Time 1: 2y, Time 2: 3 y 7 m, Time 3: 9 y 7 m; Case 2: Time 1: 7 y, Time 2: 9 y 2 m, Time 3: 15 y 4 m	Spanish	ASD	Yes	FIQ described as in lower extreme	Advanced decoding; poor comprehension
Temple (1990)	1 (1M)	10 y	English	Language delay and speech difficulties	Yes	VIQ (n/a.) PIQ (n/a.) FIQ (87)	Advanced decoding; poor comprehension
Turkeltaub et al. (2004)	1 (1M)	Time 1: 5.92 y Time 2: 9.75 y	English	ASD	Yes	VIQ (127) PIQ (121) FIQ (130)	6 years higher than predicted by CA
Wong et al. (2013)	1 (1M)	8y 11 m	Cantonese	ASD	Yes	VIQ (n/a) PIQ (n/a) FIQ described as in lower extreme	Advanced decoding; poor FIQ
Worthy and Invernizzi (1995)	1 (1F)	14 y	English	Language delay and motor development disorder; good social skills	Yes	VIQ (n/a) PIQ (n/a) FIQ (47)	Advanced decoding; poor comprehension
Group Studies (n = 42) Abnett (2013)	64 (58M 8F)	n/a	English	ASD	n/a	n/a	> 90 on standard decoding scores and < 80 on standard comprehension scores
Aram (1997)	12 (12M)	Range 7 y 11 m- 13y 7 m	English	ASD	Yes	VIQ (n/a) PIQ (n/a) FIQ (80)	Advanced decoding; poor comprehension
Åsberg Johnels et al. (2017)	10 (10F)	13.1 y	Swedish	ADHD	n/a	VIQ (93.6) PIQ (93.1) FIQ (n/a)	1 SD better than (reading) comprehension
Cardoso-Martins and Da Silva (2010) Study 1	6 (6M)	6.2y	Portuguese	ASD	Yes	VIQ (n/a) PIQ (66.33) FIQ (99.4)	Matched with TD
Cardoso-Martins and Da Silva (2010) Study 2	2 (2M)	3 y 11 m (range 3 y 9 m- 3 y 11 m)	Portuguese	ASD	Yes	VIQ (81) PIQ (89.5) FIQ (83.5)	Precocious
Castles, Crichton, and Prior (2010)	2 (2M)	9 y (range 8 y-10 y)	English	ASD	n/a	VIQ (n/a) PIQ (83)	High than FIQ
Catts et al. (2003)	28 (n/a)	2 nd grade	English	TD	n/a	VIQ (n/a) PIQ (n/a) FIQ (n/a)	Good decoding, poor listening comprehension
Chia and Kee (2013)	10 (10M)	8 y 5 m (range 8 y 3 m-8 y 10 m)	English	ASD	Yes	VIQ (n/a) PIQ (n/a) FIQ (98.2)	Precocious

(continued on next page)

Table 1 (continued)

Study	Sample size	Age	Language	Population	Precocity	IQ scores	Decoding skill description
Cobrinik (1982)	9 (9M)	10.99 y (range 9 y 8 m–13 y 2 m)	English	Schizophrenia, ASD, chronic brain syndrome	Yes	VIQ (n/a) PIQ (n/a) FIQ (50.2) VIQ (69.5) PIQ (82.5) FIQ (74)	Higher than FIQ
Cohen et al. (1987)	5 (3M 2F)	6.78 y (range 5 y 7 m–9 y 4 m)	English	SLI, 3 also had ADHD	Yes	VIQ (68.5) PIQ (82) FIQ (n/a)	20 points higher than unspecified type of IQ
Cohen et al. (1997)	16 (n/a)	6.43 y (range 4.65–8.21y)	English	SLI (PDD participants excluded)	Yes	VIQ (68.5) PIQ (82) FIQ (n/a)	1 SD higher than PIQ score
DeLong, Ritch, and Burch (2002)	24 (n/a)	2–8 y	English	ASD	Yes	n/a	Precocious reading; good or excellent decoding, family history of affective disorder, poor comprehension
Enoch-Holman (2004)	6 (n/a)	9.5 (range 3 rd –5th grade)	English	ASD	Yes	VIQ (n/a) PIQ (n/a) FIQ (102.7)	Matched with TD but poor comprehension (based on teacher reports)
Fontenelle and Alarcon (1982)	8 (7M 1F)	Range 4–17 y	English	ASD	n/a	N = 4 (PIQ > VIQ) N = 3 (VIQ > PIQ) N = 1 (n/a) FIQ (range 57–118)	Advanced decoding; poor comprehension
Goldberg and Rothermel (1984)	8 (7M 1F)	9.9 y (range 5.3–17.8y)	English	ASD and ASD-like	Yes	VIQ (64.3) PIQ (78.5) FIQ (82)	Advanced decoding; poor comprehension
Grigorenko et al. (2003)	12 (11M 1F)	5.9 y	English	ASD and PDD-NOS	n/a	VIQ (n/a.) PIQ (n/a) FIQ (83.44)	2 SD higher than FIQ
Healy, Avram, Horvitz, and Kessler (1982)	12 (11M 1F)	8.19 y (range 5 y–11 y)	English	SLI and behavioral abnormalities	Yes	n/a	Advance of comprehension and FIQ
Jones et al. (2009)	14 (n/a)	15.5 y (range 14 y 8 m–16 y 9 m)	English	ASD	n/a	VIQ (77.6) PIQ (74.8) FIQ (74)	14 points better than FIQ
Lamônica, Gejão, do Prado, and Ferreira (2013)	6 (6M)	Range 4 y 4 m–5 y 2 m	English	Asperger's syndrome and general developmental delay	Yes	n/a	Advanced decoding; poor comprehension
Lee and Hwang (2015)	10 (9M 1F)	5.83 y	Korean	ASD (8 Autism and 2 Asperger)	Yes	VIQ (n/a) PIQ (n/a) FIQ (85.4)	Previous diagnose of higher than FIQ and reading comprehension
Lin (2014)	15 (13M 2F)	Range 4–6 y	Chinese	ASD	n/a	n/a	1 SD above TD
Naples (2009)	4 (4M)	7.9 y	Russian	ASD	Yes	n/a	Matched with TD
Needleman (1982)	9 (n/a)	Range 3–9 y	English	ASD with Apraxia	Yes	VIQ (n/a) PIQ (n/a) FIQ (56.8)	Higher than IQ
Newman et al. (2007)	20 (18M 2F)	10.41 y	English	5 autism 4 Asperger and 1 PDD-NOS	Yes	VIQ (n/a) PIQ (n/a) FIQ (99.4)	Decoding > comprehension and IQ
Ng and Chia (2014)	3 (3M)	8.7, 9 and 8.5 y	English	SLI	n/a	VIQ (79.67) PIQ (123.3) FIQ (100.67)	Advanced decoding; poor reading comprehension

(continued on next page)

Table 1 (continued)

Study	Sample size	Age	Language	Population	Precocity	IQ scores	Decoding skill description
Prasad and Srivastava (1992)	7 (n/a)	Range 5–10 y	English	Speech difficulty	n/a	VIQ < 70 PIQ (n/a)	Higher than TD
Richman and Kitchell (1981)	10 (8M 2F)	7.5 y (range 5.75 y–9.58 y)	English	6 speech delay; 5 telegraphic speech; 3 autisms like 2 echolalia	Yes	VIQ (92.6) PIQ (111.0) FIQ (101.6) VIQ (84.2)	2 years higher than CA
Richman and Wood (2002) (VIQ impaired)	19 (n/a)	10.69 (range 6 y–13 y)	English	Language disorder	Yes	PIQ (106.4) FIQ (97.5)	2 years higher than reading comprehension; reading level above IQ
Richman and Wood (2002) (PIQ impaired)	11 (n/a)	10.63 (range 6 y–13 y)	English	Non-verbal disorder	Yes	VIQ (108.5) PIQ (87.6) FIQ (98.3)	2 years higher than reading comprehension; reading level above IQ
Saldaña, Carreiras, and Frith (2009)	14 (12M 2F)	13.9 y	English	ASD	n/a	VIQ (72.9) PIQ (n/a) FIQ 86.1 (n/a)	First screening: decoding 10 points higher than reading comprehension on WORD test; Second screening identified reading-VIQ discrepancy group as hyperlexics
Snowling and Frith (1986) Low VIQ and ASD group	11 (n/a)	15 y 3 m	English	ASD	n/a	VIQ (described as in lower extreme) PIQ (78) FIQ (n/a)	In lower VIQ group, both ASD and non-ASD poor academic achievers are identified as hyperlexics
Snowling and Frith (1986) Low VIQ and Non-ASD Group	5 (n/a)	9 y 6 m	English	No-ASD	n/a	VIQ (described as in lower extreme) PIQ (75)	See above
Sparks (2004)	3 (2M 1F)	10.27 y	English	ASD	Yes	VIQ (61.33) PIQ (69.75) FIQ (63)	Higher than FIQ
Temple and Carney (1996)	10 (10F)	10.58 y	English	Turner syndrome	n/a	VIQ (on average) PIQ (n/a) FIQ (99.4)	Decoding > predicted by CA and IQ
Tirosh and Canby (1993)	6 (5M 1F)	Range 11–16 y	English	ASD	n/a	VIQ (65) PIQ (74) FIQ (71)	1 SD above VIQ
Tobia et al. (2018)	18 (6M 12F)	9.87 (range 6.42 y–17.33 y)	English	22q11.2 deletion syndrome 22q11.2 deletion syndrome 22q11.2 deletion syndrome 22q11.2 deletion syndrome	n/a	VIQ (86.44) PIQ (71.89) FIQ (73.94)	Higher decoding than FIQ; identified after
Wei, Christiano, Jennifer, Wagner, and Spiker (2015)	12 (10M 2F)	7.6 y	English	ASD	n/a	n/a	1.27 SD above national average of rapid naming test score but 1 SD below national average of reading comprehension
Welsh et al. (1987)	5 (5M)	7.7 y (range 4–10 y)	English	ASD; two cases with dysnomia	Yes	VIQ (80.4) PIQ (80) FIQ (79.4)	Reading quotient higher than 1.2

(continued on next page)

Table 1 (continued)

Study	Sample size	Age	Language	Population	Precocity	IQ scores	Decoding skill description
Whitehouse and Harris (1984)	20 (20 M)	Range 13–25 y	English	ASD; several co-diagnosed with hypergraphia	Yes	VIQ (73.2) PIQ (88.14) FIQ (74.1)	Higher than FIQ
Yokochi (2000)	4 (n/a)	Range 6–15 y	Japanese	Periventricular leukomalacia and spastic diplegia	Yes	n/a (PIQ described as lower than VIQ)	Precocious
Zuccarello et al. (2015) ASD average IQ group	13 (11 M 2F)	9.2 y (range 7–13.2 y)	Italian	ASD with average IQ	n/a	VIQ (89.77) PIQ (104.08) FIQ (96.08)	Advanced decoding, low reading comprehension
Zuccarello et al. (2015) ASD lower extreme IQ group	17 (15 M 2F)	9.6 y (range 7.5 y–13 y)	Italian	ASD with below average IQ	n/a	VIQ (70.06) PIQ (74.12) FIQ (68.35)	Advanced decoding, low reading comprehension

Note. Y = year; m = month; M = Male; F = Female; TD = Typical developing populations; ASD = Autism Spectrum Disorder; PDD = Pervasive Developmental Disorder; PDD-NOS = Pervasive Developmental Disorder Not Otherwise Specified; Lower extreme IQ \leq 69; n/a = did not report such information in the study; PIQ = Performance IQ; VIQ = Verbal IQ; FIQ = Full scale IQ.

Table 2
Information of final included studies in step 2— meta-analysis.

Study	Sample size of hyperlexics	Sample size of control groups	Control group selection criteria	Age of hyperlexics (in year)	Control group age (in year)	Population	Precocity	PIQ (Standard scores only)	Language type
Åsberg Johnels et al. (2017)	10 (10 F)	10 (n/a)	D: NS from H4 test RC: NS from DRWT-passage reading LC: NS from WISC-III-oral vocabulary Younger than HPL; average decoding; TD	13.10	n/a	ADHD	n/a	93.1	Transparent
Cardoso-Martins and Da Silva (2010) Study 1	6 (6 M)	6 (6 M)	Average decoding: older than HPL; TD	10.90	6.20	ASD	Yes	66.33	Transparent
Cardoso-Martins and Da Silva (2010) Study 2	2 (2 M)	21 (10 M 11 F)		3.92	6.14	ASD	Yes	n/a	Transparent
Castles et al. (2010)	2 (2 M)	27 (25 M 2 F)	TD	9.00	9.00	ASD	n/a	89.5	English
Cobrinik (1982)	9 (9 M)	10 (10 M)	TD	10.99	11.14	Mixed	Yes	n/a	English
Cohen et al. (1987)	5 (3 M 2 F)	5 (n/a)	D: NS from WRAT-Word recognition RC: NS from BAS-passage reading LC: NS from WISC-R-oral vocabulary, PPVT-R-receptive vocabulary WM: NS from WISC-R-digit span, DTLA-word and sentence memory	6.78	n/a	SLI	Yes	82.5	English
Cohen et al. (1997)	16 (n/a)	16 (n/a)	D: NS from WRAT-word recognition LC: NS from WISC-R-oral vocabulary and PPVT-R-receptive vocabulary WM: NS from KABC-digit span, DTLA-word and sentence memory	6.43	n/a	SLI	Yes	82	English
Enoch-Holman (2004)	6 (n/a)	6 (n/a)	Classmates of the HPLs, TD	9.50	n/a	ASD	Yes	n/a	English
Glosser et al. (1996)	1 (1 M)	10 (n/a)	TD, average decoding; decoding matched with hyperlexics	6.50	8.17	SLI	Yes	n/a	English
Grigorenko et al. (2003)	12 (11 M 1 F)	12 (n/a)	D: NS from K-ABC-word recognition LC: NS from EOWPVT-R-oral vocabulary, PPVT-receptive vocabulary	5.90	n/a	Mixed	n/a	n/a	English
Jones et al. (2009)	14 (n/a)	14 (n/a)	D: NS from WORD single word reading, TOWRE-word reading and nonword reading RC: NS from WORD passage reading comprehension	15.50	n/a	ASD	n/a	74.8	English
Lee and Hwang (2015)	10 (9 M 1 F)	10 (9 M 1 F)	Age and decoding matched with hyperlexia, TD	5.83	6.67	ASD	Yes	n/a	Transparent
Naples (2009)	4 (4 M)	10 (8 M 2 F)	Age and decoding matched with hyperlexics, TD	7.90	9.70	ASD	Yes	n/a	Transparent
Newman et al. (2007)	20 (18 M 2 F)	18 (14 M 4 F)	Younger than HPL, TD	10.41	9.99	ASD	Yes	n/a	English
Richman and Kitchell (1981)	10 (8 M 2 F)	50 (n/a)	Age matched with HPL; TD	7.50	7.00	Mixed	Yes	111	English
Richman and Wood (2002) Verbal impaired group	19 (n/a)	19 (n/a)	LC: NS from WISC-III, vocabulary similarity judgement, word fluency and nonverbal skill composite score WM: NS from WISC-III-digit span and sentence memory	10.69	n/a	SLI	Yes	106.4	English
Richman and Wood (2002) Nonverbal impaired group	11 (n/a)	11 (n/a)	LC: NS from WISC-III, vocabulary similarity judgement, word fluency and nonverbal skill WM: NS from WISC-III-digit span and sentence memory composite score	10.63	n/a	Nonverbal disorder	Yes	87.6	English
Saldaña et al. (2009)	14 (12 M 2 F)	12 (12 M)		13.90	13.70	ASD	n/a	n/a	English

(continued on next page)

Table 2 (continued)

Study	Sample size of hyperlexics	Sample size of control groups	Control group selection criteria	Age of hyperlexics (in year)	Control group age (in year)	Population	Precocity	PIQ (Standard scores only)	Language type
Snowling and Frith (1986)	8 (n/a)	11 (n/a)	Decoding and reading comprehension were within 10 points of the standardized population mean	15.75	10.50	Mixed	n/a	78	English
Sparks (2004)	3 (2 M 1 F)	3 (n/a)	D: NS from WRMT-R: word reading, word attack; PIAT-word reading LC: NS from WRMT-R passage listening RC: NS from WRMT-R word and passage reading; PIAT- passage reading WM: NS from WJPB backward digit recall and sentence memory PA: Decoding matched with hyperlexics' age, TD Average IQ: TD	10.27	n/a	ASD	Yes	69.75	English
Temple and Carney (1996)	10 (10 F)	20 (20 F)	Average IQ: TD	10.58	10.92	Turner's syndrome	n/a	n/a	English
Tobia et al. (2018)	18 (6M 12F)	12 (n/a)	D: NS from BAS-II-word reading; LC: NS from GCA- vocabulary tests	9.87	n/a	22q11.2 deletion syndrome	n/a	71.89	English
Wei et al. (2015)	12 (10 M 2 F)	12 (n/a)	D: NS from WJ- III letter word identification	7.60	n/a	ASD	n/a	n/a	English
Welsh et al. (1987)	5 (5 M)	12 (n/a)	RC: NS from WJ- III-passag comprehension D: NS from PIAT word	7.70	n/a	ASD	Yes	80	English
Zuccarello et al. (2015) ASD average IQ group	17 (15 M 2 F)	17 (n/a)	LC: NS from PPVT receptive vocabulary RC: NS from PPVT word reading comprehension D: NS from word and pseudo-word reading subtests from the Battery for the Assessment of Developmental Reading and Spelling Disorders	9.60	n/a	ASD	n/a	104.1	Transparent
Zuccarello et al. (2015) ASD lower extreme IQ group	13 (11 M 2 F)	13 (n/a)	RC: NS from the text reading task from the M.T. Reading Battery for Primary School D: NS from the word and pseudo-word reading subtests from the Battery for the Assessment of Developmental Reading and Spelling Disorders RC: NS from the text reading task from the M.T. Reading Battery for Primary School	9.20	n/a	ASD	n/a	74.12	Transparent

Note. M = Male; F = Female ASD = Autism Spectrum Disorder; TD = Typical developing populations; NS = Normative sample; BAS II = British Ability Scales II Test; DTLA = Detroit Test of Learning Aptitude Test; EOWPVT = Expressive One-Word Picture Vocabulary Tests; H4 test = H4 word reading test; GCA = General Conceptual Ability Test; K-ABC = Kaufman Assessment Battery for Children; PIAT = Peabody Individual Ability Test; PPVT = Peabody Picture Vocabulary Test; TOWRE = Test of Word Reading Efficiency; WISC = Wechsler Intelligence Scale for Children; WRAT = Wide Range Achievement; WRMT-R = Word Reading Mastery Test-Revised; WJ III = Woodcock Johnson III Diagnostic Reading Battery; WJPB = Woodcock-Johnson Psychoeducational Battery; WORD test = The WORD 3 Elementary Test.

standard test scores ($M = 100$; $SD = 15$). Further, to ensure interrater reliability, one trained graduate student also coded the studies. The hyperlexic group and control group information is shown in Table 2. We also re-coded the atypically developing syndromes to “ASD,” “ADHD,” “Turner's syndrome,” “SLI,” and “Mixed” (i.e., ASD, SLI or other disorders are in one study sample), which was done for the convenience of moderator analyses.

4.4. Outcome variables

We then investigated the difference between hyperlexics and typically developing readers on the following reading or reading-related skills: a) Decoding, b) listening comprehension, c) reading comprehension, d) verbal memory, and e) phonemic awareness. We acknowledge the ongoing measurement debates (e.g., whether listening comprehension should be measured by oral expression or picture matching; Tunmer & Chapman, 2012), so we also calculated the effect size of each variable in decoding, listening comprehension, verbal memory and reading comprehension to examine heterogeneities within each construct.

4.4.1. Decoding, listening comprehension and reading comprehension

In the current meta-analysis, we considered that nonword, word reading and fluency are valid measures of decoding (Georgiou, Das, & Heyward, 2009; Protopapas, Mousaki, Sideridis, Kotsolakou, & Simos, 2013). Also, both receptive (i.e., identify pictures based on the oral commands) and expressive measures (e.g., orally define a word) are treated as listening comprehension measures.

Reading comprehension is typically measured by two constructs: sentence-level (e.g., fill out a missing prepositional word to connect two clauses) and passage-level comprehension (e.g., inferential questions based on the context clues; Marzola, 2011). But other SVR validation studies also used word reading comprehension as a reading comprehension measure (Carver, 1998; Floyd, Meisinger, Gregg, & Keit, 2012). The current meta-analysis considered these measures as reading comprehension measures and reported the composite value as well as word, sentence and passage reading comprehension effects to examine any possible differences. Based on our coding, no hyperlexia study has utilized sentence reading comprehension.

4.4.2. Phonemic awareness and verbal memory

Phonemic awareness tasks include sound identification (call out a sound in a word), deletion (say a word without a sound), segmentation (say the sounds of word one by one) and blending tasks (blend sounds to form the sound of a word). Verbal memory includes verbal short-term and working memory (Carretti et al., 2009). Verbal short-term memory tasks include forward digit span and word (or nonword) repetition tasks, and verbal working memory tasks include backward digit span and sentence memory (answer a comprehension question and then recall the last word of a sentence). These tasks are categorized based on Carretti et al.'s (2009) guideline in their meta-analysis.

4.5. Model selection and effect size calculation

Random effect models are plausible in this research as the individuals with hyperlexia are identified from different populations (Borenstein, Hedges, Higgins, & Rothstein, 2009; Lipsey & Wilson, 2001). We calculated Hedges' g instead of Cohen's d for it is more tolerable to small sample sizes (Hedges, 1984; Lipsey & Wilson, 2001). R package “Metafor” (Viechtbauer, 2010) was used for all analyses.

4.6. Heterogeneity

To test for heterogeneities within each construct, we calculated Q_{within} and τ^2 statistics. The Q_{within} statistic and its associated p value can test the significance of heterogeneity across studies, and the τ^2 statistic can assess the true between-study variances (Borenstein, Hedges, Higgins, & Rothstein, 2009).

4.7. Publication bias

Three methods for detecting publication bias were adopted: Rosenthal's Fail-safe N analysis (Rosenthal, 1979), Orwin's Fail-safe N analysis (Orwin, 1983), and Duval and Tweedie's (2000) Trim and Fill analysis. The Fail-safe N analyses estimated the number of studies that were unpublished but had statistically non-significant results (i.e., $p > 0.05$ for Rosenthal's, and we set effect size < 0.10 for Orwin's).

The Trim and Fill analysis plots the distribution of effect sizes (X axis: Hedge's g ; Y axis: standard error). This analysis assumes all effect size distributions as normal, and thus will adjust the plots when non-normal distribution appears. Then the effect size would be adjusted to a larger or smaller number. In our sample, if the Trim and Fill method adjusted the effect size to a small number (confidence interval includes 0), our analysis may have missed studies that reported higher effect sizes (i.e., favoring hyperlexics; Duval & Tweedie, 2000).

4.8. Moderator effects

We selected four variables that were relevant to the definition debate of hyperlexia in moderator analyses: Precocious reading reports (reported vs. no reports), syndromes of developmental disorder or language impairment (ASD, other developmental disorders,

Table 3a
Effect sizes (Hedge's *g*) and 95% CI of reading and related skills.

Study	Decoding	Listening comprehension	Reading comprehension	Verbal memory	Phonemic awareness
Åsberg Johnels et al. (2017)	0.45 [-0.44, 1.33]	-0.10 [-0.98, 0.78]	-1.25 [-2.21, -0.30]	n/a	n/a
Cardoso-Martins and Da Silva (2010) study 1	-0.14 [-1.27, 1.00]	-1.31 [-2.55, -0.06]	-2.35 [-3.82, -0.88]	0.41 [-0.73, 1.55]	-1.11 [-2.33, 0.10]
Cardoso-Martins and Da Silva (2010) study 2	-0.50 [-1.96, 0.96]	-4.70 [-6.69, -2.72]	-3.87 [-5.70, -2.04]	0.06 [-1.39, 1.51]	-10.52 [-13.89, -7.15]
Castles et al. (2010)	-0.54 [-2.03, 0.96]	-2.88 [-5.17, -0.60]	-2.47 [-4.20, -0.73]	n/a	n/a
Cobrinik (1982)	1.78 [0.71, 2.84]	n/a	n/a	n/a	n/a
Cohen et al. (1987)	1.92 [0.42, 3.41]	-2.26 [-3.85, -0.67]	-1.56 [-3.38, 0.27]	-1.24 [-2.63, 0.15]	n/a
Cohen et al. (1997)	0.64 [-0.07, 1.35]	-2.29 [-3.18, -1.40]	-1.25 [-2.21, -0.30]	-0.88 [-1.61, -0.16]	n/a
Enoch-Holman (2004)	-0.84 [-2.02, 0.34]	-1.29 [-2.53, -0.04]	-1.46 [-2.73, -0.19]	-1.38 [-2.64, -0.12]	-1.19 [-2.42, 0.04]
Glosser et al. (1996)	-0.34 [-2.40, 1.72]	-3.29 [-5.76, -0.82]	-2.69 [-5.04, -0.35]	0.00 [-2.06, 2.06]	n/a
Grigorenko et al. (2003)	0.50 [-0.32, 1.31]	-1.25 [-2.51, 0.02]	n/a	n/a	n/a
Jones et al. (2009)	-0.74 [-1.50, 0.03]	n/a	-1.67 [-2.54, -0.81]	n/a	n/a
Lee and Hwang (2015)	0.07 [-0.81, 0.94]	n/a	n/a	n/a	n/a
Naples (2009)	-0.01 [-1.17, 1.15]	-0.80 [-2.00, 0.40]	-0.72 [-1.91, 0.47]	-0.48 [-1.78, 0.82]	-0.19 [-1.35, 0.97]
Newman et al. (2007)	0.19 [-0.45, 0.84]	-0.30 [-0.94, 0.34]	-0.26 [-0.89, 0.38]	0.02 [-0.66, 0.70]	-0.09 [-0.88, 0.69]
Richman and Kitchell (1981)	n/a	n/a	n/a	0.22 [-0.46, 0.90]	n/a
Richman and Wood (2002) Verbal IQ impaired group	n/a	-1.81 [-2.81, -0.82]	n/a	0.51 [-0.20, 1.21]	n/a
Richman and Wood (2002) Nonverbal IQ impaired group	n/a	0.87 [0.20, 1.53]	n/a	0.72 [0.03, 1.40]	n/a
Saldaña et al. (2009)	-0.50 [-1.41, 0.41]	-1.79 [-2.88, -0.70]	-3.12 [-4.48, -1.76]	-0.28 [-1.21, 0.66]	-0.40 [-1.32, 0.51]
Snowling and Frith (1986)	0.61 [-0.50, 1.72]	n/a	-1.34 [-2.36, -0.31]	n/a	n/a
Sparks (2004)	0.11 [-1.49, 1.71]	-1.43 [-3.22, 0.36]	-1.53 [-3.35, 0.29]	-0.26 [-1.87, 1.35]	-2.06 [-4.04, -0.08]
Temple and Carney (1996)	1.01 [0.21, 1.81]	n/a	0.64 [-0.13, 1.42]	n/a	n/a
Tobia et al. (2018)	-0.43 [-1.10, 0.24]	-1.25 [-1.97, -0.54]	n/a	n/a	n/a
Wei et al. (2015)	0.06 [-0.74, 0.86]	n/a	-1.22 [-2.09, -0.35]	n/a	n/a
Welsh et al. (1987)	1.24 [-0.12, 2.59]	-1.02 [-2.34, 0.30]	-0.34 [-1.59, 0.91]	n/a	n/a
Zuccarello et al. (2015) ASD average IQ group	-0.15 [-0.92, 0.62]	n/a	-0.40 [-1.14, 0.34]	n/a	n/a
Zuccarello et al. (2015) ASD lower extreme IQ group	-0.15 [-0.83, 0.52]	n/a	-1.45 [-2.20, -0.69]	n/a	n/a
Overall effect	0.16 [-0.11, 0.44]	-1.38 [-1.97, -0.80]	-1.31 [-1.76, -0.85]	-0.10 [-0.48, 0.26]	-1.51 [-2.72, -0.31]
<i>Q</i> within	41.18	74.38	58.95	21.37	38.95
<i>p</i> <i>Q</i> within	0.01*	< 0.001***	< 0.001***	0.05*	< 0.001***
<i>tau</i> ²	0.20	1.07	0.65	0.18	2.05
Normative sample vs. Study-recruited control groups	<i>p</i> <i>Q</i> between = 0.54	<i>p</i> <i>Q</i> between = 0.30	<i>p</i> <i>Q</i> between = 0.22	<i>p</i> <i>Q</i> between = 0.88	<i>p</i> <i>Q</i> between = 0.62

Note. *Q* between = Between group heterogeneity.

p* < 0.05; *p* < 0.01; ****p* < 0.001.

language delay, samples that have a mixed type of disorder), performance IQ scores and language type (opaque vs. transparent). Additionally, we investigated the influence of decoding and listening comprehension on phonemic awareness. Each moderator was investigated via simple linear regression analyses (i.e., meta-regression).

To examine the effect of various decoding criteria on reading comprehension, we investigated the effect of decoding on reading comprehension, controlling for listening comprehension, in a meta-regression model (analogous to multiple regression). As five studies missed listening comprehension reports, we performed multiple imputation for missing effect sizes by using SAS proc MI function (see Ellington et al., 2015, for a validation of using imputation for meta-regression). The moderator effect is valid when the variable(s) significantly predicted the variance of reading comprehension or phonemic awareness in a random-effect model.

5. Meta-analysis results

5.1. Descriptive statistics

Twenty-six studies were included in Step 2 (meta-analysis). The sample size of hyperlexics was 257 (age: *M* = 9.46, *SD* = 2.93). These participants were all identified from atypically developing populations. The sample size of control groups was 392 (age: *M* = 9.09, *SD* = 2.34). Based on the available data, hyperlexia groups had 73% males and 27% females, and this percentage was 75% and 25% in control groups, respectively. According to Table 2, typically developing readers as control groups had no reports of language delays or developmental disorders, although some control groups did not match with hyperlexics on decoding, gender,

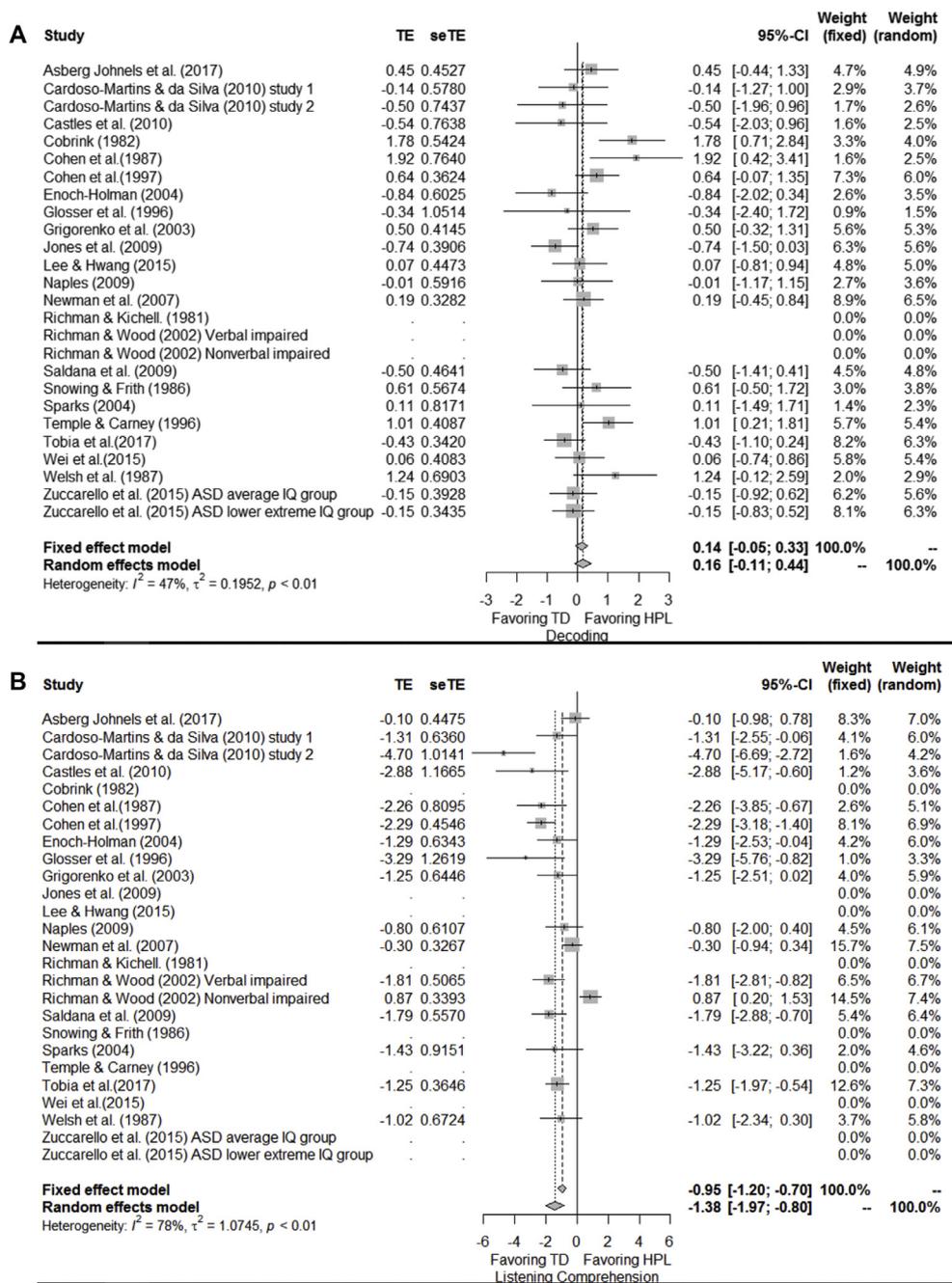


Fig. 1. (a). Forest plot of decoding; “HPL” represents hyperlexics, “TD” represents typical developing students. (b). Forest plot of listening comprehension; “HPL” = Hyperlexics, “TD” = Typical developing population. (c). forest plot of reading comprehension; “HPL” = Hyperlexics, “TD” = Typical developing students. (d). Forest plot of verbal memory; “HPL” = Hyperlexics; “TD” = Typical developing students. (e). Forest plot of phonemic awareness. “HPL” = hyperlexics, “TD” = typical developing students.

sample size or chronological age (see Table 2, for details).

The results of composite reading and reading-related skills are shown in Table 3a, with the positive signs indicating a favor to the hyperlexic group. Forest plots of these skills are presented in Fig. 1a–e. The effect sizes of all skills showed between-study heterogeneity (ps of $Q_{\text{between}} < 0.05$; τ^2 values > 0.18) so that we can perform moderator analyses, but the type of control group (normative sample vs. study-recruited sample) did not alter the results (ps of $Q_{\text{between}} > .20$; see Table 3a).

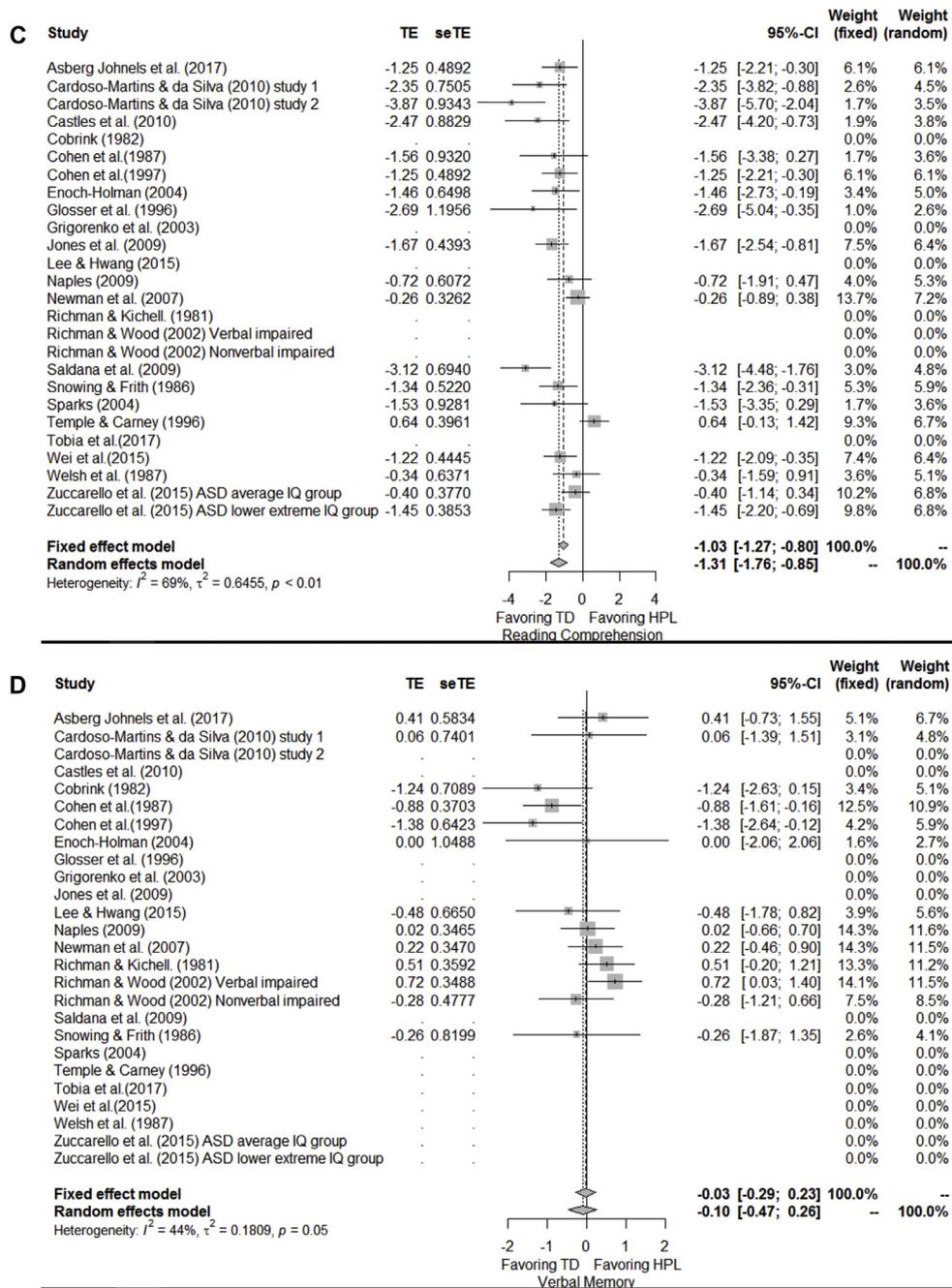


Fig. 1. (continued)

5.2. Profiles of reading

Decoding performance of hyperlexics ($n = 23$) was not significantly different from control groups ($g = 0.16$, $CI = [-0.11, 0.44]$). The listening comprehension ($n = 17$) comparison generated a Hedges' g of -1.38 ($CI = [-1.97, -0.80]$) indicating hyperlexics' impaired listening comprehension ability. Reading comprehension ($n = 19$) comparison yielded a Hedge's g of -1.31 ($CI = [-1.76, -0.85]$), also signaling large impairments. The verbal memory capacity ($n = 13$) comparison yielded no statistical difference ($g = -0.10$; $CI = [-0.48, 0.26]$). Another skill that hyperlexics were far below typically developing readers was phonemic awareness ($n = 7$; $g = -1.51$; $CI = [-2.72, -0.31]$). In summary, hyperlexics' listening comprehension, reading comprehension, and phonemic awareness were poorer than typically developing readers, but the two groups shared a similar ability of verbal memory and decoding.

Table 3b shows variable results of decoding, listening, reading comprehension and verbal memory. Variable comparisons in decoding (real word, nonword, and fluency of decoding), listening comprehension (receptive vocabulary, oral vocabulary definition,

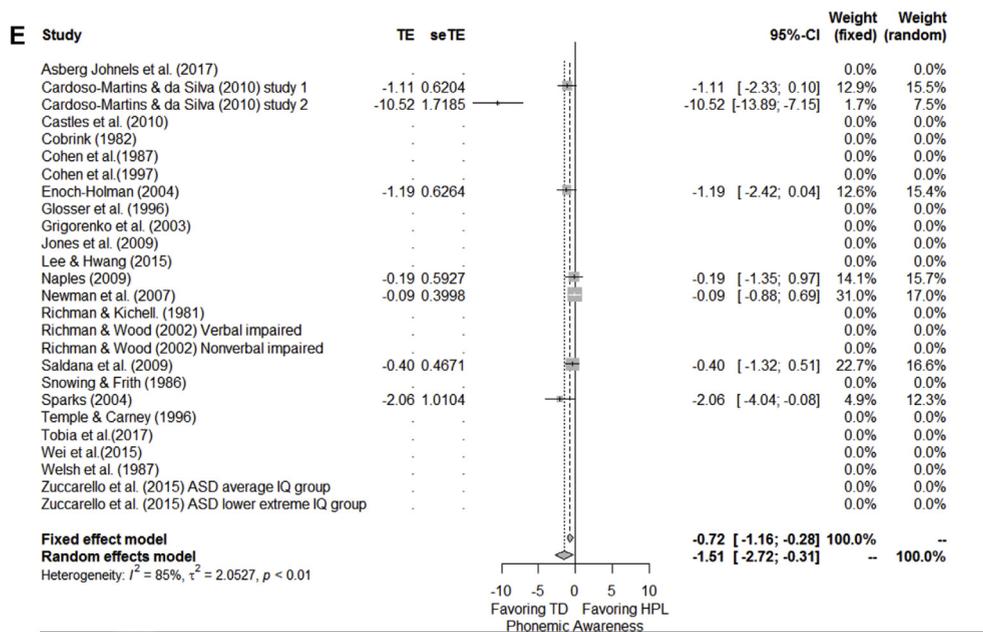


Fig. 1. (continued)

Table 3b

Variable effect sizes of decoding, listening comprehension, reading comprehension and verbal memory.

Decoding	Number of measures	Effect sizes	95% CI	Between variable variation
Word reading	21	0.15	[-0.05; 0.36]	$Q_{\text{between}} = 1.52$; $p_{Q_{\text{between}}} = 0.47$
Nonword reading	10	0.11	[-0.18; 0.41]	
Fluency of word/nonword reading	4	-0.25	[-0.64; 0.14]	
Listening comprehension				
Receptive vocabulary	14	-1.45	[-2.44; -0.85]	$Q_{\text{between}} = 2.37$; $p_{Q_{\text{between}}} = 0.67$
Oral vocabulary	8	-1.49	[-1.79; -0.79]	
Oral cloze	1	-1.29	[-3.30; 0.32]	
Syntactic skills	1	-1.49	[-3.19; 0.38]	
Passage listening comprehension	1	-2.04	[-4.01; -0.06]	
Reading comprehension				
Word reading comprehension	6	-1.41	[-3.07; 0.26]	$Q_{\text{between}} = 0.15$; $p_{Q_{\text{between}}} = 0.70$
Passage reading comprehension	13	-1.06	[-1.55; -0.57]	
Verbal memory				
Verbal short-term memory	7	-0.07	[-1.03; 0.90]	$Q_{\text{between}} = 5.23$; $p_{Q_{\text{between}}} = 0.02^*$
Verbal working memory	5	-1.53	[-2.32; -0.73]	

Note. Q_{between} = Between-group heterogeneity.

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

syntactic awareness, and passage listening comprehension) and reading comprehension (word reading comprehension and passage listening comprehension) did not yield effect size differences (ps of $Q_{\text{between}} > 0.05$). However, verbal short-term and working memory yielded different results ($Q_{\text{between}} = 5.23$, $p_{Q_{\text{between}}} = 0.02 < 0.05$). From Table 4b, verbal short-term memory skills of hyperlexics were matched with those of typically developing peers ($g = -0.07$; $CI = [-1.03; 0.90]$), but verbal working memory was much lower than the control groups ($g = -1.51$, $CI = [-2.32; -0.73]$). Therefore, subsequent analyses will treat verbal working memory and verbal short-term memory as two different skills.

5.3. Publication bias

Publication bias tests were conducted on listening comprehension, reading comprehension, phonemic awareness and verbal working memory (i.e., skills that hyperlexics were evidentially lower than typically developing peers). For listening comprehension, the Rosenthal's Fail-safe N analysis yielded a result of 483 to make the p value of the group discrepancy larger than 0.05, which meant that the significant difference for listening comprehension ability would be eliminated only when having 483 unpublished, statistically non-significant studies. Also, Rosenthal's analysis generated the study number of 643 for reading comprehension. Considering the difficulties of collecting hyperlexic samples, we maintained no possibility that there were more than 643 unpublished statistically non-significant studies. Therefore, the Rosenthal's Fail-safe N analysis showed no threat to the validity of listening comprehension

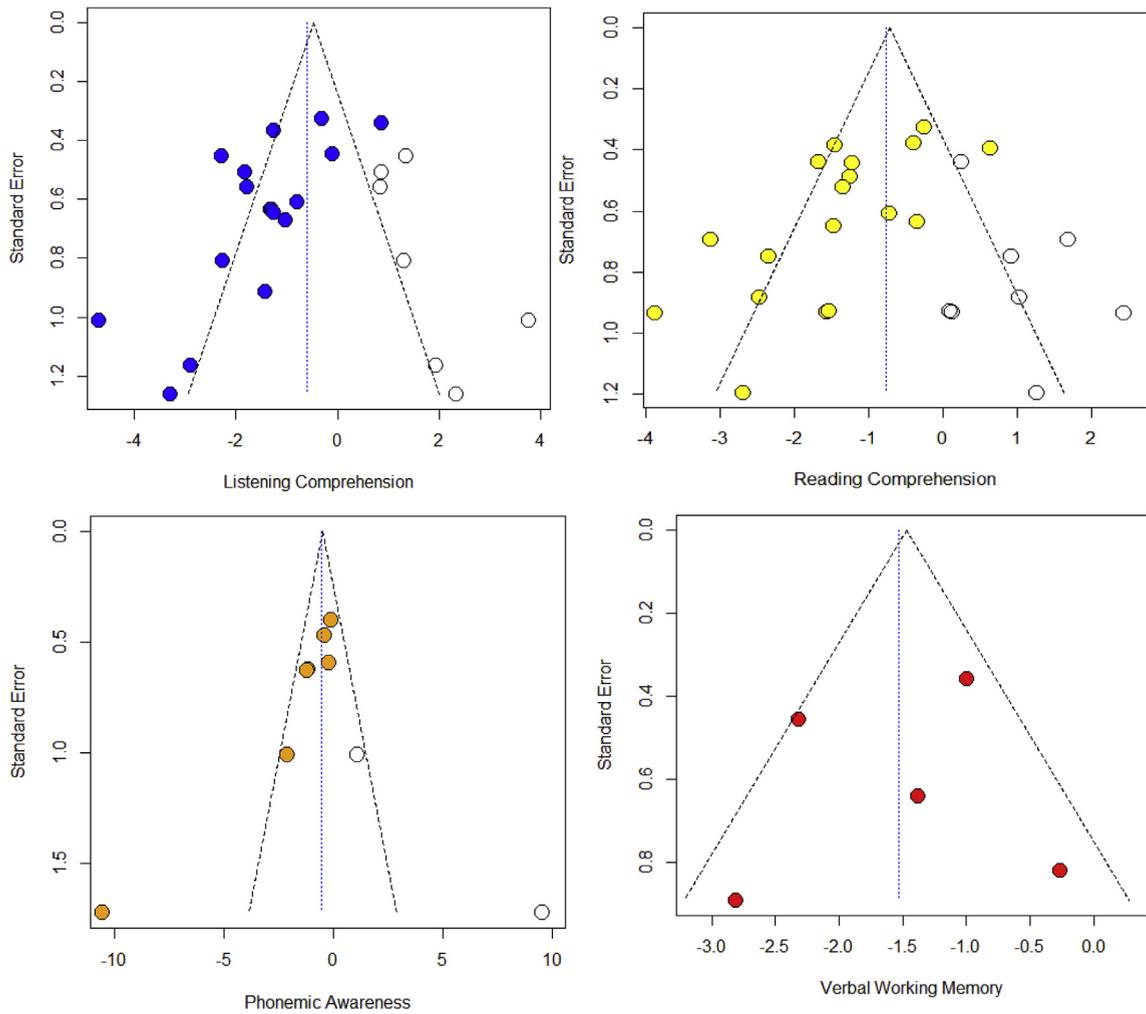


Fig. 2. Funnel Plots (Uncolored dots are “filled” studies).

and reading comprehension. In Orwin's Fail-safe N , effect size larger than -0.10 was used as a non-significant statistical threshold (i.e., typically developing peers were 0.10 effect size better than hyperlexic groups on the two comprehension skills). This analysis yielded a need for 253 non-significant studies for listening comprehension and 264 for reading comprehension. Again, neither number was plausible. Rosenthal's Fail-safe N analyses for phonemic awareness and verbal working memory yielded 59 and 62 non-significant statistical studies, and Orwin's analyses yielded 149 and 73. These numbers signaled for more potential threats if we were doing a meta-analysis on other populations, but it should not be a threat to the field of hyperlexia due to the scarcity of quantitative investigations.

As Fig. 2 shows, the “filling” happened on listening comprehension, reading comprehension, and phonemic awareness. In total, seven studies for listening comprehension were “filled” to the right side (favoring hyperlexics) of the mean Hedge's g , and the Hedge's g changed from -1.38 to -0.60 ; $CI = [-1.20, 0.01]$). Eight studies for reading comprehension were “filled” to the right side of the mean Hedge's g , and the mean Hedge's g changed from -1.31 to -0.76 ; $CI = [-1.22, -0.30]$). Two studies for phonemic awareness were “filled” to the right side of the mean Hedge's g , and the Hedge's g became non-significant (g changed from -1.51 to -0.37 ; $CI = [-0.82, 0.08]$).

The publication bias was not validated in verbal working memory as there were no studies suggested to adjust. Also, the adjusted confidence interval of reading comprehension excluded 0, so the reading comprehension also had evidence against publication bias (Peters, Sutton, Jones, Abrams, & Rushton, 2007; Terrin, Schmid, Lau, & Ingram, 2003). However, there may be studies that we could not include reported higher listening comprehension and phonemic awareness (i.e., favoring hyperlexics) than the mean Hedges' g s of these two skills (Borenstein et al., 2009). The publication bias threat of listening comprehension is no longer present when we removed a study that reported much higher listening comprehension than the comparison group (adjusted $g = -0.95$; $CI = [-1.48, -0.43]$).

Table 4a
Effects of definition debates on reading comprehension.

	<i>df</i>	β	95% CI	<i>Q</i> _{between}	<i>P</i> value of β
PIQ	10	0.03	[0.01, 0.06]	5.99	0.01*
Types of developmental disorder	<i>n</i>	Effect Size	95% CI	<i>Q</i> _{between}	<i>P</i> _{<i>Q</i> between}
ASD	13	-1.43	[-1.96, -0.90]	21.79	< 0.001***
ADHD	1	-0.28	[-2.14, 1.57]		
Turner's syndrome	1	0.64	[-0.13; 1.42]		
SLI	3	-1.48	[-2.38, -0.68]		
Mixed type	1	-1.25	[-2.21, -0.30]		
Report of precocious reading	<i>n</i>	Effect Size	95% CI	<i>Q</i> _{between}	<i>P</i> _{<i>Q</i> between}
No report	9	-1.25	[-1.92, -0.58]	0.08	0.78
Precocious decoding	10	-1.38	[-2.04, -0.73]		
Language type	<i>n</i>	Effect Size	95% CI	<i>Q</i> _{between}	<i>P</i> _{<i>Q</i> between}
English	13	-1.25	[-1.83, -0.66]	0.17	0.68
Transparent languages	6	-1.45	[-2.23, -0.68]		

Note. *Q*_{between} = Between-group heterogeneity.

p* < 0.05; *p* < 0.01; ****p* < 0.001.

5.4. Moderator analysis

Table 4a lists the results of moderator investigations on reading comprehension. Turner's syndrome group had higher reading comprehension skills than ASD groups (Turner's syndrome: $g = 0.64$, CI = [-0.13, 1.42]; ASD: $g = -1.43$, CI = [-1.96, -0.90]). PIQ is marginally predicting reading comprehension ($\beta = 0.03$; CI = [0.01, 0.06]). Precocity or language type did not moderate reading comprehension comparison results.

Table 4b shows the results of moderator analyses on phonemic awareness. It was listening comprehension, but not decoding that explained the phonemic awareness (decoding: $\beta = 1.80$, $p = 0.30$, CI = [-1.74, 5.65]; listening comprehension: $\beta = 2.35$, $p < 0.001$, CI = [1.51, 3.20]).

As Table 4c shows, both decoding and listening comprehension significantly explained the variance of reading comprehension (decoding: $\beta = 0.79$, $p < 0.001$, CI = [0.38, 0.84]; listening comprehension: $\beta = 0.44$, $p < 0.001$, CI = [0.32, 0.56]).

6. Discussion

The current research adopted a systematic and meta-analytic approach to reconcile the debates of hyperlexia research. Then we provided a comprehensive reading profile and investigated how identification inconsistencies may affect these profiles. We further attempted to understand if decoding and listening comprehension are related to phonemic awareness and reading comprehension, and thus examine if hyperlexia-type reading is consistent with current reading models such as SVR. These findings may also suggest a difference between poor comprehenders and hyperlexics.

6.1. Hyperlexics' comprehensive reading profile and the impact of criteria debates

When investigating the RQ1 (What is the comprehensive reading profile of individuals with hyperlexia? How consistent are researchers in defining and identifying hyperlexia? How does each specific criterion affect reading comprehension profiles?), we found that despite good decoding and verbal short-term memory skills, individuals with hyperlexia exhibit poor listening, verbal working memory, and reading comprehension skills. Also, very few studies ($n = 3$; 4.34%) identified individuals with hyperlexia from typically developing children. These results should have reconciled some conflicts, suggesting that hyperlexia research tend to agree with "good decoding and poor listening comprehension" and should identify hyperlexics from atypically developing students. We, therefore, suggest that

Table 4b
Effect of decoding and listening comprehension on phonemic awareness.

	β	CI	<i>SE</i>	<i>P</i> value of β
Decoding	1.96	[-1.74, 5.65]	0.8	0.3
Listening comprehension	2.17	[1.21, 3.13]	0.49	< 0.001***

p* < 0.05; *p* < 0.01; ****p* < 0.001.

Table 4c
Contribution of decoding and listening comprehension to reading comprehension.

	β	CI	SE	P value of β
Decoding	0.61	[0.38, 0.84]	0.12	< 0.001***
Listening comprehension	0.44	[0.32, 0.56]	0.06	< 0.001***

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

this is the basic guideline to follow for future hyperlexia research.

When looking into our included studies, we found that the definition debates indeed affected empirical research, and caused conflicting results. First, although researchers agree that hyperlexics have good decoding skills, the ways to look for “good decoders” varied (See Table 1). Also, we found that one study reported the hyperlexics’ listening comprehension was even higher than typically developing readers (See Table 3a). This may be due to the fact that this study only used the criteria of “exceptional decoding” (similar to Silberberg & Silberberg’s, 1968) but did not control for comprehension abilities. As shown in the publication bias analysis (see Fig. 2), we found several studies (that we were unable to include) may have reported higher listening and reading comprehension than the control groups (e.g., the case in Turkeltaub et al., 2004). Therefore, our guidelines may help future hyperlexia research to follow the trend and avoid identifying participants who have good listening comprehension.

Except for three studies that included typically developing children, all other studies had hyperlexics identified from various atypically developing populations (e.g., ASD, ADHD, Turner’s syndrome, SLI), and VIQ and PIQ were both varied. Some inconsistencies occurred on precocity (66.22% reported vs. 33.78% not reported). However, our meta-regression analyses on reading comprehension suggest that the effect sizes did not alter by the syndrome type (except for one Turner’s syndrome case), precocious decoding, or language type. As the Turner’s syndrome case had good reading comprehension ($g = 0.64$), this again may not be a hyperlexic case. Therefore, maybe precocious decoding, the type of disorder and language differences are not impacting reading comprehension profiles.

The PIQ variations indeed affected the reading comprehension results ($\beta = 0.03$, CI = [0.01, 0.06]), suggesting that nonverbal skills may have an association with reading. In fact, Tiu, Thompson, and Lewis (2003) suggest that PIQ may have influenced *dyslexics’* reading comprehension, and we suggest that PIQ may be a potential area to investigate among children with reading disorders. However, we observed that only 11 (42.31%) studies reported PIQ in our meta-analysis that may have biased our results, and we encourage future reading researchers to provide a comprehensive IQ report.

6.2. Factors affecting phonemic awareness and reading comprehension

When answering the RQ 2 (*How are decoding and listening comprehension related to phonemic awareness and reading comprehension profiles among individuals with hyperlexia?*), we first found hyperlexics’ phonemic awareness skill was lower than that of typically developing populations ($g = -1.51$, CI = [-2.72, -0.31]). Perhaps individuals with hyperlexia showed no impairments on verbal short-term memory ($g = -0.07$, CI = [-1.03, 0.90]) because short-term memory skills are associated with decoding (Brady, 1986; Peter, 2018) and short-term memory tasks are easy to be understood by hyperlexics. The verbal working memory was also reasonably poorer than typically developing readers ($g = -1.53$, CI = [-2.32, -0.73]) as the “processing” procedure (e.g., recall the digits in the reverse order) requires comprehension ability (Daneman & Merikle, 1996; Peng & Fuchs, 2016). Therefore, our synthesis on verbal memory is consistent with findings in typically developing children (Daneman & Merikle, 1996; Peng et al., 2018). However, phonemic awareness is known as the best predictor of decoding abilities (Buil-Legaz, Aguilar-Mediavilla, & Rodríguez-Ferreiro, 2016; Catts, Herrera, Nielsen, & Bridges, 2015; Conners, 2009; Gathercole & Baddeley, 2014; Georgiou, Das, & Hayward, 2009; Silverman, Speece, Haring, & Ritchey, 2013; Uhry, 2011), but it seems that for hyperlexics’ phonemic awareness was isolated from decoding. Although the Trim and Fill analysis suggests a possibility of publication bias, our included studies consistently reported that hyperlexics had lower phonemic awareness skills than the controls (see Table 3).

However, our results may be consistent with researchers (e.g., Nation, 1999; Newman et al., 2007; Sparks, 2004) who suggest that hyperlexics have unimpaired phonemic awareness skills, and the low scores of phonemic tasks are primarily due to the difficulty of understanding task demands. As these researchers have claimed, we found that listening comprehension ($\beta = 2.17$, $p < 0.001$) but not decoding ($\beta = 1.96$, $p = 0.30$) is related to phonemic awareness. However, the reasons why hyperlexics show poor phonemic awareness but maintained good decoding still need to be explored.

Further, hyperlexics whose decoding skills were higher had less impaired reading comprehension ($\beta = 0.61$, $p < 0.001$, CI = [0.38, 0.84]), after controlling for listening comprehension. As reviewed in the Step 1 analysis, two types of quantitative decoding identifiers were “decoding higher than typically developing readers” (Lin, 2014) and “decoding matched with typically developing readers” (Naples, 2009). Therefore, our meta-analysis suggests that at least these two decoding descriptors generated different reading comprehension abilities (e.g., mild and severe reading comprehension difficulties).

In the current analysis, we found that decoding and listening comprehension are both significant predictors of reading comprehension. Therefore, although the hyperlexics were identified in different groups, the results were consistent with research findings which show that decoding skill is predictive of reading comprehension, even without proper development of neurological, linguistic, or cognitive abilities (Cardoso-Martins & Mervis, 2018; Healy, 1982; Kuppen, Huss, & Goswami, 2014; Patti & Lupinetti, 1993). To further explain this, better decoding accuracy can provide precise sound information and release more cognitive load for processing

meanings (Harm & Seidenberg, 2004; Hoover & Gough, 1990).

6.3. Poor comprehenders versus hyperlexics

Our results may suggest the difference between poor comprehenders and hyperlexics. Except for three studies that identified hyperlexics from typically developing populations, the remaining hyperlexics all had developmental disorders or SLI. Therefore, this trend aligns with the claim by Nation's (1999; also see Grigorenko et al., 2003) that hyperlexics should be identified from atypically developing populations while poor comprehenders should be identified from typically developing populations. Further, Table 3 shows that phonemic awareness skills of hyperlexics were consistently poorer than typically developing populations. However, other studies found that poor comprehenders had intact phonemic awareness skills (Hogan et al., 2014; Nation, Cocksey, Taylor, & Bishop, 2010; Nation et al., 2007; Ricketts et al., 2008; Stothard & Hulme, 1995). Although we were unable to compare these two groups in the current study directly, it appears that hyperlexics and poor comprehenders are two separate groups as they are identified from different populations (atypically vs. typically developing) and at least have distinct phonemic awareness profiles. Future studies may use “poor comprehenders” as a search criterion to look for any studies that meet the criteria of “hyperlexics” but used “poor comprehender” to identify their participants.

6.4. Limitations

The current study has some limitations. First, because of the scarcity of hyperlexia research and the restrictions of each study, our meta-analysis could not capture all the aspects of criteria debates that were reviewed in Step 1 (e.g., hyperlexics identified from 22q11.2 deletion syndrome). Moreover, small sample sizes may have created larger standard errors of effect sizes (Lipsey & Wilson, 2001). One example is that we can only analyze seven studies in the phonemic awareness analysis. Further, random effect models may have enlarged confidence intervals compared to fixed-effect models (Borenstein et al., 2009; also see Fig. 1a–e for comparisons of the two models).

7. Conclusions and future directions

Our study proposes trends of future research on reading models, research designs, and neurological investigations. From the theoretical perspective, our analysis is in line with the SVR by suggesting that reading comprehension is the product of decoding and listening comprehension. Future research may explore the applicability of other reading models for hyperlexia. For example, Share's (1995, 2008) *self-teaching theory* states that the repeated practice of grapheme-phoneme correspondence rules helps typically developing readers achieve decoding fluency. However, hyperlexics in our study did not show intact phonemic awareness to support the application of these rules, but they still demonstrated above-average word and nonword decoding skills. The *Triangle model of reading* (Harm & Seidenberg, 2004) suggests that children can learn to decode familiar words or differentiate homophone words through the help of word reading comprehension, but previous reviews suggest that hyperlexics do not have these capabilities (Ostrolenk et al., 2017). In our sample the hyperlexics' word reading comprehension ($g = -1.41$; $CI = [-3.07, 0.36]$; see Table 3b) was not evidentially poorer than the control groups. This may be due to the impact of decoding based on the SVR, but more research studies are needed to further explore the pathways of decoding in hyperlexia.

Also, the differing results of these three constructs might indicate that most decoding and verbal short-term memory tasks demand much less cognitive load than phonemic awareness tasks, as Sparks (2004) suggested. Future studies may also be needed in exploring the influence of task complexity on reading or pre-reading tasks in hyperlexia or poor comprehenders.

Most of the inconsistencies (e.g., precocity of decoding, types of atypical syndromes) did not cause considerable variations in hyperlexics' reading comprehension. However, we suggest that the “higher than typically developing readers” and “matched with typically developing readers” decoding identifiers may generate different reading comprehension profiles. Meanwhile, with less focus on the criteria debates, neurological or brain studies may want to investigate the phenomenon that hyperlexics' phonemic awareness scores, verbal short-term memory, and decoding capacity are not cohesive, as they are for typically developing peers (Gathercole & Baddeley, 2014). Further, researchers should provide complete reports of IQ, and specific sample descriptions (e.g., age, gender and control group information).

Hyperlexics in our meta-analysis show good decoding, poor listening, and poor reading comprehension, and atypically developing syndromes (e.g., ASD and SLI). Therefore, the atypically developing syndrome is a risk factor for poor listening and reading comprehension. Future research may investigate other risk factors that cause atypically developing populations to have poor listening and reading comprehension. As a comparison, Dilnot, Hamilton, Maughan, and Snowling (2017) found both genetic (family history) and environmental (e.g., home literacy level) factors are risk factors of dyslexia. Although the current research could not investigate family history or home literacy levels, these factors may be relevant topics for future hyperlexia research to explore.

Before proceeding to these investigations, we suggest researchers to have the following criteria as considerations: a) “hyperlexic” as a term should describe those who have good decoding but poor listening and (as a product) poor reading comprehension; b) hyperlexics should show atypically developing syndromes; and c) hyperlexics' decoding skills may have impacts on their reading comprehension, and it may not be appropriate to isolate decoding from reading comprehension. When these criteria are considered, we suggest researchers and educators to be aware of the “hyperlexia” type reading disorder, and investigations on the possible correlates and risk factors of hyperlexia should be pursued. Most importantly, understanding profiles and risk factors of hyperlexia may help educators to design appropriate intervention strategies to remediate this type of reading difficulty.

Acknowledgements

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Appendix A. Supplementary data

Supplementary data related to this article can be found at <https://doi.org/10.1016/j.jneuroling.2018.08.001>.

References

- Studies included in the analysis (n = 70) are indicated by an asterisk (*).
- Aaron, P. G. (1989). *Dyslexia and hyperlexia: Diagnosis and management of developmental reading disabilities*. Boston, MA: Kluwer Academic Publishers.
- *Abnett, J. M. (2013). *Effectiveness of instructional strategies in reading comprehension for students with autism spectrum disorder and hyperlexia (Doctoral Dissertation)*. Retrieved from ProQuest Dissertations & Theses (PQDT) database. (UIM No. 3559769).
- *Aram, D. M. (1997). Hyperlexia: Reading without meaning in young children. *Topics in Language Disorders*, 17, 1–13.
- *Aram, D. M., Rose, D. F., & Horwitz, S. J. (1984). Hyperlexia: Developmental reading without meaning. In R. N. Malatesha, & H. A. Whitaker (Eds.). *Dyslexia: A global issue* (pp. 518–533). The Hague, Netherlands: Martinus Nijhoff.
- *Åsberg Johnels, J., Gillberg, C., & Kopp, S. (2017). A hyperlexic-like reading style is associated with increased autistic features in girls with ADHD. *Journal of Attention Disorders*, 47, 424–434.
- *Åsberg Johnels, J.Å., & Miniscalco, C. (2014). Excellent word-reading ability in the context of an autism spectrum disorder: A case study of a Swedish-speaking 7-year-old boy. *Journal of Cognitive Education and Psychology*, 13, 88–102.
- *Atkin, K., & Lorch, M. P. (2006). Hyperlexia in a 4-year-old boy with autistic spectrum disorder. *Journal of Neurolinguistics*, 19, 253–269.
- Berninger, V., Abbott, R., Cook, C. R., & Nagy, W. (2017). Relationships of attention and executive functions to oral language, reading, and writing skills and systems in middle childhood and early adolescence. *Journal of Learning Disabilities*, 50, 434–449.
- Bishop, D. V., & Snowling, M. J. (2004). Developmental dyslexia and specific language impairment: Same or different? *Psychological Bulletin*, 130, 858–886.
- Borenstein, M., Hedges, L. V., Higgins, J. P. T., & Rothstein, H. R. (2009). *Introduction to meta-analysis*. West Sussex, UK: John Wiley.
- Brady, S. (1986). Short-term memory, phonological processing, and reading ability. *Annals of Dyslexia*, 36, 138–153.
- Braze, D., Katz, L., Magnuson, J. S., Mencl, W. E., Tabor, W., Van Dyke, J. A., et al. (2016). Vocabulary does not complicate the simple view of reading. *Reading and Writing: An Interdisciplinary Journal*, 29, 435–451.
- 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, 932–955.
- Buil-Legaz, L., Aguilar-Mediavilla, E., & Rodríguez-Ferreiro, J. (2016). Oral morphosyntactic competence as a predictor of reading comprehension in children with specific language impairment. *International Journal of Language & Communication Disorders*, 51, 473–477.
- *Burd, L., Fisher, W., Knowlton, D., & Kerbeshian, J. (1987). Hyperlexia: A marker for improvement in children with pervasive developmental disorder? *Journal of the American Academy of Child & Adolescent Psychiatry*, 26, 407–412.
- *Burd, L., & Kerbeshian, J. (1985). Hyperlexia and a variant of hypergraphia. *Perceptual & Motor Skills*, 60, 940–942.
- *Burd, L., & Kerbeshian, J. (1988). Familial pervasive development disorder, Tourette disorder and hyperlexia. *Neuroscience & Biobehavioral Reviews*, 12, 233–234.
- *Burd, L., & Kerbeshian, J. (1989). Hyperlexia in prader-willi syndrome. *The Lancet*, 2, 983–984.
- *Burd, L., Kerbeshian, J., & Fisher, W. (1985). Inquiry into the incidence of hyperlexia in a statewide population of children with pervasive developmental disorder. *Psychological Reports*, 57, 236–238.
- *Cardoso-Martins, C., & Da Silva, J. R. (2010). Cognitive and language correlates of hyperlexia: Evidence from children with autism spectrum disorders. *Reading and Writing: An Interdisciplinary Study*, 23, 129–145.
- *Cardoso-Martins, C., Gonçalves, D. T., & de Magalhães, C. G. (2013). What are the mechanisms behind exceptional word reading ability in hyperlexia? Evidence from a 4-year-old hyperlexic boy's invented spellings. *Journal of Autism and Developmental Disorders*, 43, 3001–3003.
- Cardoso-Martins, C., & Mervis, C. B. (July, 2018). Does the simple view of reading (SVR) apply to children with intellectual disabilities? Evidence from children with Williams Syndrome (WS). *Symposium session presented at the society of scientific reading conference, Brighton, UK*.
- Carretti, B., Borella, E., Cornoldi, C., & De Beni, R. (2009). Role of working memory in explaining the performance of individuals with specific reading comprehension difficulties: A meta-analysis. *Learning and Individual Differences*, 19, 246–251.
- Carver, R. P. (1998). Predicting reading level in grades 1 to 6 from listening level and decoding level: Testing theory relevant to the simple view of reading. *Reading and Writing: An Interdisciplinary Journal*, 10, 121–154.
- *Castles, A., Crichton, A., & Prior, M. (2010). Developmental dissociations between lexical reading and comprehension: Evidence from two cases of hyperlexia. *Cortex*, 46, 1238–1247.
- Catts, H. W., Adlof, S. M., & Weismer, S. E. (2006). Language deficits in poor comprehenders: A case for the simple view of reading. *Journal of Speech, Language, and Hearing Research*, 49, 278–293.
- Catts, H. W., Herrera, S., Nielsen, D. C., & Bridges, M. S. (2015). Early prediction of reading comprehension within the simple view framework. *Reading and Writing: An Interdisciplinary Study*, 28, 1407–1425.
- *Catts, H. W., Hogan, T. P., & Fey, M. E. (2003). Subgrouping poor readers on the basis of individual differences in reading-related abilities. *Journal of Learning Disabilities*, 36, 151–164.
- *Chia, N. K. H., & Kee, N. K. N. (2013). Effectiveness of Scaffolding Interrogatives Method: Teaching reading comprehension to young children with hyperlexia in Singapore. *The Journal of International Association of Special Education*, 14, 67–75.
- *Cobrinik, L. (1982). The performance of hyperlexic children on an “incomplete words” task. *Neuropsychologia*, 20, 569–577.
- *Cohen, M., Campbell, R., & Gelardo, M. (1987). Hyperlexia: A variant of aphasia or dyslexia. *Pediatric Neurology*, 3, 22–28.
- *Cohen, M. J., Hall, J., & Riccio, C. A. (1997). Neuropsychological profiles of children diagnosed as specific language impaired with and without hyperlexia. *Archives of Clinical Neuropsychology*, 12, 223–229.
- Connors, F. A. (2009). Attentional control and the simple view of reading. *Reading and Writing: An Interdisciplinary Journal*, 22, 591–613.
- *Cossu, G., & Marshall, J. C. (1986). Theoretical implications of the hyperlexia syndrome: Two new Italian cases. *Cortex*, 22, 579–589.
- *Craig, H. K., & Telfer, A. S. (2005). Hyperlexia and autism spectrum disorder: A case study of scaffolding language growth over time. *Topics in Language Disorders*, 25, 364–374.
- Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior*, 19, 450–466.
- Daneman, M., & Merikle, P. M. (1996). Working memory and language comprehension: A meta-analysis. *Psychonomic Bulletin & Review*, 3, 422–433.
- *DeLong, G. R., Ritch, C. R., & Burch, S. (2002). Fluoxetine response in children with autistic spectrum disorders: Correlation with familial major affective disorder and intellectual achievement. *Developmental Medicine and Child Neurology*, 44, 652–659.
- Dilnot, J., Hamilton, L., Maughan, B., & Snowling, M. J. (2017). Child and environmental risk factors predicting readiness for learning in children at high risk of dyslexia. *Development and Psychopathology*, 29(1), 235–244.
- Duval, S., & Tweedie, R. (2000). Trim and fill: A simple funnel-plot-based method of testing and adjusting for publication bias in meta-analysis. *Biometrics*, 56, 455–463.

- Ehri, L. (1992). Reconceptualizing the development of sight word reading and its relationship to recoding. In P. Gough, L. Ehri, & R. Treiman (Eds.). *Reading acquisition* (pp. 107–143). Hillsdale, NJ: Erlbaum.
- Ehri, L. C., Nunes, S. R., Willows, D. M., Schuster, B. V., Yaghoub-Zadeh, Z., & Shanahan, T. (2001). Phonemic awareness instruction helps children learn to read: Evidence from the National Reading Panel's meta-analysis. *Reading Research Quarterly*, 36, 250–287.
- Ellington, E. H., Bastille-Rousseau, G., Austin, C., Landolt, K. N., Pond, B. A., Rees, E. E., et al. (2015). Using multiple imputation to estimate missing data in meta-regression. *Methods in Ecology and Evolution*, 6, 153–163.
- Elliott, J. G., & Grigorenko, E. L. (2014). *The dyslexia debate*. New York, NY: Cambridge University Press.
- *Enoch-Holman, D. (2004). *Reading profiles of children with autism and hyperlexia: Toward an explanation of reading comprehension deficits* (doctoral dissertation). Retrieved from ProQuest Dissertations & Theses (PQDT) database. (UMI No. 3140480).
- Florit, E., & Cain, K. (2011). The simple view of reading: Is it valid for different types of alphabetic orthographies? *Educational Psychology Review*, 23, 553–576.
- Floyd, R., Meisinger, E., Gregg, N., & Keith, T. (2012). An explanation of reading comprehension across development using models from Cattell–Horn–Carroll theory: Support for integrative models of reading. *Psychology in the Schools*, 49, 725–743.
- *Fontenelle, S., & Alarcon, M. (1982). Hyperlexia: Precocious word recognition in developmentally delayed children. *Perceptual & Motor Skills*, 55, 247–252.
- Gathercole, S. E., & Baddeley, A. D. (2014). *Working memory and language*. New York, NY: Psychology Press.
- 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, 76–84.
- *Glosser, G., Friedman, R. B., & Roeltgen, D. P. (1996). Clues to the cognitive organization of reading and writing from developmental hyperlexia. *Neuropsychology*, 10, 168–175.
- *Goldberg, T., & Rothermel, R. (1984). Hyperlexic children reading. *Brain*, 107, 759–785.
- Goswami, U. (2015). Sensory theories of developmental dyslexia: Three challenges for research. *Nature Reviews Neuroscience*, 16, 43–54.
- Gough, P. B., Hoover, W. A., & Peterson, C. L. (1996). Some observations on a simple view of reading. In C. Cornoldi, & J. Oakhill (Eds.). *Reading comprehension difficulties: Processes and intervention* (pp. 1–13). Mahwah, NJ: Erlbaum.
- Gough, P. B., & Tunmer, W. E. (1986). Decoding, reading, and reading disability. *Remedial and Special Education*, 7, 6–10.
- *Grigorenko, E. L., Klin, A., Pauls, D. L., Senft, R., Hooper, C., & Volkmar, F. (2003). A descriptive study of hyperlexia in a clinically referred sample of children with developmental delays. *Journal of Autism and Developmental Disorders*, 32, 3–12.
- Harm, M. W., & Seidenberg, M. S. (2004). Computing the meanings of words in reading: Cooperative division of labor between visual and phonological processes. *Psychological Review*, 111, 662–720.
- Healy, J. M. (1982). The enigma of hyperlexia. *Reading Research Quarterly*, 17, 319–338.
- *Healy, J. M., Aram, D. M., Horwitz, S. J., & Kessler, J. W. (1982). A study of hyperlexia. *Brain and Language*, 17, 1–23.
- Hedges, L. V. (1984). Estimation of effect size under nonrandom sampling: The effects of censoring studies yielding statistically insignificant mean differences. *Journal of Educational Statistics*, 9, 61–85.
- Helenius, P., Laasonen, M., Hokkanen, L., Paetau, R., & Niemivirta, M. (2011). Impaired engagement of the ventral attentional pathway in ADHD. *Neuropsychologia*, 49, 1889–1896.
- Hogan, T. P., Adlof, S. M., & Alonzo, C. N. (2014). On the importance of listening comprehension. *International Journal of Speech Language Pathology*, 16, 199–207.
- Hoover, W. A., & Gough, P. B. (1990). The simple view of reading. *Reading and Writing: An Interdisciplinary Journal*, 2, 127–160.
- Hulme, C., Hatcher, P. J., Nation, K., Brown, A., Adams, J., & Stuart, G. (2002). Phoneme awareness is a better predictor of early reading skill than onset-rime awareness. *Journal of Experimental Child Psychology*, 82, 2–28.
- *Ichiba, N. (1990). West syndrome associated with hyperlexia. *Pediatric Neurology*, 6, 344–348.
- *Jensen, A. (2005). *When babies read: A practical guide to help young children with hyperlexia, asperger syndrome and high-functioning autism*. London, United Kingdom: Jessica Kingsley Publishers.
- *Jones, C. R., Happé, F., Golden, H., Marsden, A. J., Tregay, J., Simonoff, E., et al. (2009). Reading and arithmetic in adolescents with autism spectrum disorders: Peaks and dips in attainment. *Neuropsychology*, 23, 718–728.
- Joshi, R. M., & Aaron, P. G. (2000). The component model of reading: Simple view of reading made a little more complex. *Reading Psychology*, 21, 85–97.
- Joshi, M., & Aaron, P. G. (2006). *Handbook of orthography and literacy*. Mahwah, NJ: Lawrence Erlbaum Associates.
- *Joshi, R., Padakannaya, P., & Nishanimath, S. (2010). Dyslexia and hyperlexia in bilinguals. *Dyslexia*, 16, 99–118.
- *Kennedy, B. (2003). Hyperlexia profiles. *Brain and Language*, 84, 204–221.
- Kuppen, S., Huss, M., & Goswami, U. (2014). A longitudinal study of basic auditory processing and phonological skills in children with low IQ. *Applied Psycholinguistics*, 35, 1109–1141.
- *Kupperman, P., Bligh, S., & Barouski, K. (1992). *The syndrome of hyperlexia vs. high functioning autism and Asperger's syndrome*. Elmhurst, IL: Center for Speech and Language Disorders.
- Lachmann, T., Khera, G., Srinivasan, N., & Van Leeuwen, C. (2012). Learning to read aligns visual analytical skills with grapheme-phoneme mapping: Evidence from illiterates. *Frontiers in Evolutionary Neuroscience*, 4, 1–8.
- *Lamônica, D. A. C., Gejão, M. G., do Prado, L. M., & Ferreira, A. T. (2013). Reading skills in children diagnosed with hyperlexia: Case reports. *CoDAS*, 25, 391–395.
- *Lebrun, Y., Van Endert, C., & Szliwowski, H. (1988). Trilingual hyperlexia. In L. K. Opler, & D. Fein (Eds.). *The exceptional brain* (pp. 253–264). New York, NY: Guilford Press.
- *Lee, S. H., & Hwang, M. (2015). Word and nonword processing without meaning support in Korean-speaking children with and without hyperlexia. *Reading and Writing: An Interdisciplinary Journal*, 28, 217–238.
- *Lin, C. S. (2014). Early language learning profiles of young children with autism: Hyperlexia and its subtypes. *Research in Autism Spectrum Disorders*, 8, 168–177.
- Lipsey, M. W., & Wilson, D. B. (2001). *Practical meta-analysis*. Thousand Oaks, CA: Sage Publications.
- Maisog, J. M., Einbinder, E. R., Flowers, D. L., Turkeltaub, P. E., & Eden, G. F. (2008). A meta-analysis of functional neuroimaging studies of dyslexia. *Annals of the New York Academy of Sciences*, 1145, 237–259.
- Marzola, E. S. (2011). Strategies to improve reading comprehension in the multisensory classroom. In J. R. Birsh (Ed.). *Multisensory teaching of basic language skills* (pp. 365–403). (3rd ed.). Baltimore, MD: Brookes.
- Mervis, C. B., & Cardoso-Martins, C. (July, 2018). The simple view of reading (SVR): Application to children with 7q11.23 duplication syndrome (Dup7). *Symposium session presented at the society of scientific reading conference, Brighton, UK*.
- *Naples, A. J. (2009). *Variability in reading ability* (doctoral dissertation). Retrieved from ProQuest Dissertations & Theses (PQDT) database. (UMI No. 3395801).
- Nation, K. (1999). Reading skills in hyperlexia: A developmental perspective. *Psychological Bulletin*, 125, 338–355.
- National Reading Panel (2000). *Report of the National Reading Panel: Teaching children to read: An evidence-based assessment of the scientific research literature on reading and its implications for reading instruction: Reports of the subgroups*. Rockville, MD: NICHD Clearinghouse.
- Nation, K., Cocksey, J., Taylor, J. S., & Bishop, D. V. (2010). A longitudinal investigation of early reading and language skills in children with poor reading comprehension. *Journal of Child Psychology and Psychiatry*, 51, 1031–1039.
- Nation, K., Snowling, M. J., & Clarke, P. (2007). Dissecting the relationship between language skills and learning to read: Semantic and phonological contributions to new vocabulary learning in children with poor reading comprehension. *Advances in Speech Language Pathology*, 9, 131–139.
- *Needleman, R. M. (1982). A linguistic analysis of hyperlexia. In C. Johnson (Ed.). *Proceedings of the second international study of child language* (pp. 473–482). Washington, DC: University Press of America.
- *Newman, T. M., Macomber, D., Naples, A. J., Babitz, T., Volkmar, F., & Grigorenko, E. L. (2007). Hyperlexia in children with autism spectrum disorders. *Journal of Autism and Developmental Disorders*, 37, 760–774.
- *Ng, P. M. H., & Chia, N. (2014). Reading comprehension for children with hyperlexia: A scaffolding method. *International Journal of Case Studies*, 3, 71–77.
- *O'Connor, N., & Hermelin, B. (1994). Two autistic savant readers. *Journal of Autism and Developmental Disorders*, 24, 501–515.

- *Oberschneider, M. S. (2003). A case of a four-year-old boy with hyperlexia: Some considerations for diagnosis and treatment from a psychodynamic perspective. *Clinical Child Psychology and Psychiatry*, 8, 205–214.
- Orwin, R. G. (1983). A fail-safe N for effect size in meta-analysis. *Journal of Educational Statistics*, 8, 157–159.
- Ostrolenk, A., d'Arc, B. F., Jelenic, P., Samson, F., & Mottron, L. (2017). Hyperlexia: Systematic review, neurocognitive modelling, and outcome. *Neuroscience & Biobehavioral Reviews*, 79, 134–149.
- Palikara, O., Dockrell, J. E., & Lindsay, G. (2011). Patterns of change in the reading decoding and comprehension performance of adolescents with specific language impairment (SLI). *Learning Disabilities: A Contemporary Journal*, 9(2), 89–105.
- *Patti, P. J., & Lupinetti, L. (1993). Brief report: Implications of hyperlexia in an autistic savant. *Journal of Autism and Developmental Disorders*, 23, 397–405.
- *Pazzaglia, R., Ravarelli, A., Balestra, A., Orio, S., & Zanetti, M. A. (2012). Using eye-tracking to study reading patterns and processes in autism with hyperlexia profile. In Z. S. Hippe, J. L. Kulikowski, & T. M. Wtorek (Eds.), *Human-computer systems interaction: Backgrounds and applications 2* (pp. 159–174). Berlin, Germany: Springer Berlin Heidelberg.
- Peng, P., Barnes, M., Wang, C., Wang, W., Li, S., Swanson, H. L., et al. (2018). A meta-analysis on the relation between reading and working memory. *Psychological Bulletin*, 144, 48–76.
- Peng, P., & Fuchs, D. (2016). A meta-analysis of working memory deficits in children with learning difficulties: Is there a difference between verbal domain and numerical domain? *Journal of Learning Disabilities*, 49, 3–20.
- *Pennington, B. F., Johnson, C., & Welsh, M. C. (1987). Unexpected reading precocity in a normal preschooler: Implications for hyperlexia. *Brain and Language*, 30, 165–180.
- Peter, B. (2018). The role of short-term memory impairment in nonword repetition, real word repetition, and nonword decoding: A case study. *Clinical Linguistics and Phonetics*, 32, 1–6.
- Peters, J. L., Sutton, A. J., Jones, D. R., Abrams, K. R., & Rushton, L. (2007). Performance of the trim and fill method in the presence of publication bias and between study heterogeneity. *Statistics in Medicine*, 26, 4544–4562.
- *Prasad, S., & Srivastava, A. N. (1992). Psychogenic disorders in hyperlexic and mentally retarded children. *Psycho-Lingua*, 22, 105–114.
- Protopapas, A., Mousaki, A., Sideridis, G. D., Kotsolakou, A., & Simos, P. G. (2013). The role of vocabulary in the context of the simple view of reading. *Reading & Writing Quarterly: Overcoming Learning Difficulties*, 29, 168–202.
- Reid, R., Gonzalez, J. E., Nordness, P. D., Trout, A., & Epstein, M. H. (2004). A meta-analysis of the academic status of students with emotional/behavioral disturbance. *The Journal of Special Education*, 38, 130–143.
- *Richman, L. C., & Kitchell, M. M. (1981). Hyperlexia as a variant of developmental language disorder. *Brain and Language*, 12, 203–212.
- *Richman, L. C., & Wood, K. M. (2002). Learning disability subtypes: Classification of high functioning hyperlexia. *Brain and Language*, 82, 10–21.
- Ricketts, J., Bishop, D. V., & Nation, K. (2008). Investigating orthographic and semantic aspects of word learning in poor comprehenders. *Journal of Research in Reading*, 31, 117–135.
- Ricketts, J., Jones, C. R., 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, 807–816.
- Roch, M., & Levorato, M. C. (2009). Simple view of reading in Down's syndrome: The role of listening comprehension and reading skills. *International Journal of Language & Communication Disorders*, 44, 206–223.
- Rosenthal, R. (1979). The file drawer problem and tolerance for null results. *Psychological Bulletin*, 86, 638–641.
- *Saldaña, D., Carreiras, M., & Frith, U. (2009). Orthographic and phonological pathways in hyperlexic readers with autism spectrum disorders. *Developmental Neuropsychology*, 34, 240–253.
- Samson, F., Mottron, L., Soulières, I., & Zeffiro, T. A. (2012). Enhanced visual functioning in autism: An ALE meta-analysis. *Human Brain Mapping*, 33, 1553–1581.
- *Santorio, A., Healey, J., & McGinley, J. (2016). A-70a case of hyperlexia or comprehension disorder. *Archives of Clinical Neuropsychology*, 31, 584–673.
- Seidenberg, M. S., & McClelland, J. L. (1989). A distributed, developmental model of word recognition and naming. *Psychological Review*, 96, 523–568.
- Seymour, P. H., Aro, M., & Erskine, J. M. (2003). Foundation literacy acquisition in European orthographies. *British Journal of Psychology*, 94, 143–174.
- Share, D. L. (1995). Phonological recoding and self-teaching: Sine qua non of reading acquisition. *Cognition*, 55, 151–218.
- Share, D. L. (2008). Orthographic learning, phonology and the self-teaching hypothesis. In R. Kail (Ed.), *Advances in child development and behavior* (pp. 31–82). Amsterdam, Netherland: Elsevier.
- *Siegel, L. S. (1984). A longitudinal study of a hyperlexic child: Hyperlexia as a language disorder. *Neuropsychologia*, 22, 577–585.
- Siegel, L. S. (2006). Perspectives on dyslexia. *Paediatrics & Child Health*, 11(9), 581–587.
- Silberberg, N. E., & Silberberg, M. C. (1967). Hyperlexia—Specific word recognition skills in young Children. *Exceptional Children*, 34, 41–42.
- Silberberg, N. E., & Silberberg, M. C. (1968). Case histories in hyperlexia. *Journal of School Psychology*, 7(1), 3–7.
- Silverman, R. D., Speece, D. L., Harring, J. R., & Ritchey, K. D. (2013). Fluency has a role in the simple view of reading. *Scientific Studies of Reading*, 17, 108–133.
- Singh, B. D., Moore, D. W., Furlonger, B. E., Anderson, A., Busacca, M. L., & English, D. L. (2017). Teaching reading comprehension skills to a child with autism using behavior skills training. *Journal of Autism and Developmental Disorders*, 47, 3049–3058.
- *Smith, I. M., & Bryson, S. E. (1988). Monozygotic twins concordant for autism and hyperlexia. *Developmental Medicine and Child Neurology*, 30, 527–531.
- *Snowling, M., & Frith, U. (1986). Comprehension in “hyperlexic” readers. *Journal of Experimental Child Psychology*, 42, 392–415.
- *Sparks, R. L. (2004). Orthographic awareness, phonemic awareness, syntactic processing, and working memory skill in hyperlexic children. *Reading and Writing: An Interdisciplinary Journal*, 17, 359–386.
- Spencer, M., & Wagner, R. K. (2018). The comprehension problems of children with poor reading comprehension despite adequate decoding: A meta-analysis. *Review of Educational Research*, 88, 1–35.
- Stothard, S. E., & Hulme, C. (1995). A comparison of phonological skills in children with reading comprehension difficulties and children with decoding difficulties. *Journal of Child Psychology and Psychiatry*, 36, 399–408.
- *Su, I. F., To, C. K. S., & Weekes, B. (2011). Hyperlexia in a Chinese speaking child. *Procedia-social and Behavioral Sciences*, 23, 71–72.
- *Talero-Gutierrez, C. (2006). Hyperlexia in Spanish-speaking children: Report of 2 cases from Colombia, South America. *Journal of the Neurological Sciences*, 249, 39–45.
- Tanaka, H., Black, J. M., Hulme, C., Stanley, L. M., Kesler, S. R., Whitfield-Gabrieli, S., et al. (2011). The brain basis of the phonological deficit in dyslexia is independent of IQ. *Psychological Science*, 22, 1442–1451.
- *Temple, C. M. (1990). Auditory and reading comprehension in hyperlexia: Semantic and syntactic skills. *Reading and Writing: An Interdisciplinary Journal*, 2, 297–306.
- *Temple, C. M., & Carney, R. (1996). Reading skills in children with Turner's syndrome: An analysis of hyperlexia. *Cortex*, 32, 335–345.
- Temple, E., Deutsch, G. K., Poldrack, R. A., Miller, S. L., Tallal, P., Merzenich, M. M., et al. (2003). Neural deficits in children with dyslexia ameliorated by behavioral remediation: Evidence from functional MRI. *Proceedings of the National Academy of Sciences*, 100, 2860–2865.
- Terrin, N., Schmid, C. H., Lau, J., & Olkin, I. (2003). Adjusting for publication bias in the presence of heterogeneity. *Statistics in Medicine*, 22, 2113–2126.
- *Tirosh, E., & Canby, J. (1993). Autism with hyperlexia: A distinct syndrome? *American Journal on Mental Retardation*, 98, 84–92.
- Tiu, R. D., Jr., Thompson, L. A., & Lewis, B. A. (2003). The role of IQ in a component model of reading. *Journal of Learning Disabilities*, 36(5), 424–436.
- *Tobia, V., Brigstocke, S., Hulme, C., & Snowling, M. J. (2018). Developmental changes in the cognitive and educational profiles of children and adolescents with 22q11.2 deletion syndrome. *Journal of Applied Research in Intellectual Disabilities*, 31, e177–e181.
- Tunmer, W. E., & Chapman, J. W. (2012). The simple view of reading redux: Vocabulary knowledge and the independent components hypothesis. *Journal of Learning Disabilities*, 45(5), 453–466.
- Tunmer, W., & Greaney, K. (2010). Defining dyslexia. *Journal of Learning Disabilities*, 43, 229–243.
- *Turkeltaub, P. E., Flowers, D. L., Verbalis, A., Miranda, M., Gareau, L., & Eden, G. F. (2004). The neural basis of hyperlexic reading: An fMRI case study. *Neuron*, 41, 11–25.
- Uhry, J. K. (2011). Teaching phonemic awareness. In J. R. Birsh (Ed.), *Multisensory teaching of basic language skills* (pp. 113–143). (3rd ed.). Baltimore, MD: Brookes.

- Vidyasagar, T. R., & Pammer, K. (2010). Dyslexia: A deficit in visuo-spatial attention, not in phonological processing. *Trends in Cognitive Sciences*, 14, 57–63.
- Viechtbauer, W. (2010). Conducting meta-analyses in R with the metafor package. *Journal of Statistical Software*, 36, 1–48.
- Wechsler, D. L. (2003). *Wechsler intelligence scale for children - fourth edition (WISC-IV)*. San Antonio: The Psychological Corporation.
- *Wei, X., Christiano, E. R., Jennifer, W. Y., Wagner, M., & Spiker, D. (2015). Reading and math achievement profiles and longitudinal growth trajectories of children with an autism spectrum disorder. *Autism*, 19, 1–11.
- *Welsh, M. C., Pennington, B. F., & Rogers, S. (1987). Word recognition and comprehension skills in hyperlexic children. *Brain and Language*, 32, 76–96.
- *Whitehouse, D., & Harris, J. C. (1984). Hyperlexia in infantile autism. *Journal of Autism and Developmental Disorders*, 14, 281–289.
- Winner, E. (1997). Exceptionally high intelligence and schooling. *American Psychologist*, 52, 1070–1081.
- *Wong, W., Weekes, B., Iao, L., To, K., & Su, I. (2013). Is reading aloud semantically mediated in Chinese hyperlexia? *Procedia-social and Behavioral Sciences*, 94, 153–154.
- *Worthy, J., & Invernizzi, M. A. (1995). Linking reading with meaning: A case study of a hyperlexic reader. *Journal of Literacy Research*, 27, 585–603.
- *Yokochi, K. (2000). Reading of Kana (phonetic symbols for syllables) in Japanese children with spastic diplegia and periventricular leukomalacia. *Brain & Development*, 22, 13–15.
- Ziegler, J. C., & Goswami, U. (2005). Reading acquisition, developmental dyslexia, and skilled reading across languages: A psycholinguistic grain size theory. *Psychological Bulletin*, 131, 3–29.
- *Zuccarello, R., Di Blasi, F. D., Zingale, M., Panerai, S., Finocchiaro, M., Trubia, G., et al. (2015). Reading decoding and comprehension in children with autism spectrum disorders: Evidence from a language with regular orthography. *Research in Autism Spectrum Disorders*, 17, 126–134.