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# Predicting literacy in children with a high-functioning autism spectrum disorder

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ABSTRACT

The most commonly reported reading profile for children with a high-functioning autism spectrum disorder (HFASD) is one of intact decoding combined with reduced reading comprehension. Whether or not the variables that predict decoding and reading comprehension for children with a HFASD are exactly the same as those identified for a non-ASD population is unknown. Therefore, the ability of cognition, phonological processing, oral language, and vision to predict decoding and reading comprehension was investigated. Regression analysis revealed that cognition, phonological processing, and syntax predicted decoding and reading comprehension for the HFASD and non-ASD groups. One notable difference was that semantics predicted literacy for the non-ASD children but not their HFASD peers.



## 1. Introduction

Reading is a complex cognitive skill that children require to successfully access the school curriculum. Children achieving early reading success typically exhibit better long-term educational and occupational attainment than children with a history of reading deficit (Boetsch, Green, & Pennington, 1996). However, not all children develop adequate reading, with children diagnosed with a high-functioning autism spectrum disorder (HFASD) being one group identified at risk for reading difficulty.

Autism spectrum disorder (ASD) is an umbrella term comprising those individuals diagnosed with autistic disorder (AD), Asperger's disorder (AsD), or pervasive developmental disorder not otherwise specified (PDDNOS). Children with an ASD diagnosis who do not have a co-morbid intellectual disability (ID), that is they have an IQ greater than 70, are diagnosed with a HFASD; those with AD and an IQ above 70 are referred to as having high-functioning autism (HFA). The most typical reading profile reported for individuals diagnosed with an ASD is one of adequate decoding from pre-school to adulthood combined with impaired reading comprehension, particularly from the later primary school years (Frith & Snowling, 1983; Griswold, Barnhill, Myles, Hagiwara, & Simpson, 2002; O'Connor & Klein, 2004). Nation, Clarke, Wright, and Williams (2006) found that as a group 41 children aged 6–15 years with an ASD had decoding skills that were in advance of reading comprehension. Similarly, Huemer and Mann (2010) in a study of 384 children diagnosed with an ASD with a mean age of 10–11 years reported disjunct between decoding and reading comprehension across the entire group.

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The profile of decoding in advance of reading comprehension also applies to individuals diagnosed with a HFASD. Minshew, Goldstein, Taylor, and Siegal (1994) for example identified no group differences on word and non-word reading but significant group differences on passage comprehension between 54 individuals with HFA (mean age 16 years) and IQ- and age-matched controls. O'Connor and Hermelin (1994) reported on a two year study of two males aged 5 and 8 years respectively at intake and identified decoding in advance of reading comprehension at all four testing points. In a retrospective analysis of school reports of 40 children with AsD aged 3–15 years Church, Alisanski, and Amanullah (2000) found that even though decoding was easily achieved reading comprehension for non-factually based materials was reduced. Finally, Williams, Goldstein, and Minshew (2006) reported that passage comprehension but not decoding discriminated group membership for 56 children with HFA aged 8–15 years and 56 age- and IQ-matched controls.

Proficient readers generally demonstrate competency with cognitive, phonological processing, oral language, and visual tasks, all of which have been identified as predictive of concurrent and future reading for typically achieving readers (Scarborough, 1998). Whether or not all of the predictors identified as important for normal reading development are also equally predictive of concurrent reading development for young children diagnosed with a HFASD has not yet been specifically investigated.

Nevertheless, there is evidence that at least some of the predictors of reading for the non-HFASD population apply equally to those diagnosed with a HFASD. Mayes and Calhoun (2008) examined the relationship between intellectual ability (Wechsler Intelligence Scale for Children – Fourth edition [WISC-IV]) (Wechsler, 2003) and reading achievement (Wechsler Individual Achievement Test – Second edition [WIAT-II]) (Wechsler, 2001) for 54 children diagnosed with HFA, aged 6–14 years. Full-scale IQ (FSIQ) was identified as the best predictor of reading (as opposed to the WISC-IV general ability index [derived from 6 of the 10 subtests used to calculate FSIQ], or the WISC-IV index scores). FSIQ and the WIAT-II word reading ($r = .64$) and passage comprehension ($r = .68$) composites were strongly associated. This suggests that cognition (as measured using FSIQ) is a strong predictor of literacy for young children with a HFASD as it is for non-HFASD populations. However, the authors did not examine the role of other known predictors of reading such as phonological processing in their HFASD group.

Phonological processing encompasses mental procedures dependent upon the phonological structure of language. Phonological processing in the current study refers phonological awareness (PA), phonological memory (PM) and rapid naming (RN). It is however acknowledged that researchers differ with regard to the inclusion of RN as a phonological processing skill. Regardless, the relationship of PA, PM, and RN to early literacy development has not fully and concurrently been investigated for young children with HFASD. Possibly this reflects Frith and Snowling (1983) who stated that there is no indication that phonological abilities are impaired for individuals with AD who read. However, more recent research has reported phonological processing deficits within the HFASD population.

After controlling for FSIQ, Hooper, Poon, Marcus, and Fine (2006) reported that 23 children with HFA aged 5–12 years performed more poorly than a TD age-matched comparison group on PA tasks as measured by the phonological processing subtest of the Developmental NEuroPSYchological Assessment (Korkman, Kirk, & Kemp, 1998): reading ability or the relationship of PA to reading was not examined. Newman et al. (2007) found that 20 children with HFASD and no history of hyperlexia performed equally on PA (the sound awareness subtest of the Woodcock–Johnson Tests of Achievement-III [Woodcock, McGrew, & Mather, 2004]) to 20 age-matched children with an autism spectrum disorder (ASD) plus a history of hyperlexia, but poorer than 18 typically developing (TD) children (the latter groups did not differ). The groups may however have varied on FSIQ as this was not measured for the TD group. Additionally, only two groups, HFASD plus hyperlexia and TD, were matched on word reading. FSIQ and PA are associated with word reading and thus the poorer PA results of the HFASD without hyperlexia compared with the TD group may be expected given that word reading was lower in the former group. Differences may also have been due to differences in FSIQ between the groups. Hence, future research should ensure matching on FSIQ and word reading ability when examining predictor variables such as PA across HFASD and TD groups.

Most recently, Asberg and Sandberg (2012) found that 15 children aged 10–15 years with ASD (2 with low IQ) or an autism-like condition (2 children) were poorer on PA (a composite of a sound deletion and two spoonerisms tasks) than 14 TD, age-matched peers. Five ASD children identified as poor readers (decoders) (based on word reading below the 10th %ile) were compared on PA with five, word reading-level matched TD controls with no significant difference found. This suggests that for ASD children with impaired decoding, PA is also impaired, just as occurs within the non-ASD population. Whether or not the ASD children with adequate decoding in this study had PA skills similar to those of their TD peers is unknown as this comparison was not conducted. Furthermore, none of the above studies (Asberg & Sandberg, 2012; Hooper et al., 2006; Newman et al., 2007) examined whether or not PA correlated with, or predicted, decoding with none measuring reading comprehension and/or its relationship with PA. Nevertheless, the findings of Asberg and Sandberg (2012), suggest that PA is associated with decoding, and thus should predict decoding for young children diagnosed with a HFASD as it does for TD children.

Gabig (2010) though found no significant correlation between decoding (word and non-word decoding) and PA (elision and sound blending) for 14 children aged 5–7 years with AD. Based on the participants' description (functional verbal skills, non-verbal IQ $\geq$ 70) however it is unclear if all participants would meet criteria for HFA. Further, for the TD group only one correlation (between elision and non-word decoding) was significant, which is an unexpected finding for a TD population. Thus Gabig's results may reflect the small sample sizes and requires verification with larger participant groups.

Conversely, White et al. (2006) examined a cohort aged 8–12 years and reported a strong correlation between 'phonology' (a combination of PA and RN tasks) and literacy (a composite of word, non-word decoding, and spelling) for 9 ASD children identified as good readers, 13 ASD children identified as poor readers (with poor reading defined as being below an unspecified outlier threshold), 23 individuals with dyslexia, and 22 TD peers. Regression analysis examined which factors (phonology, auditory discrimination, visual motion and form coherence, and manual dexterity and balance) predicted literacy after accounting for age and general ability (non-verbal IQ). Phonology was the only factor that accounted for a significant amount of variance in literacy accounting for 52% of the variability for the entire participant sample. Similar results were found when regression analyses were conducted for each group (ASD poor reading, ASD good reading, dyslexic, TD) although individual group data were not provided (White et al., 2006).

While, White et al. (2006) concluded that in general phonology predicts literacy level for ASD, dyslexic, and TD individuals, the mix of PA and RN tasks within the phonology composite means that the individual relationship of PA and RN to literacy is unclear. Further, the literacy factor was also a composite and thus the relationship and predictive ability of PA and RN to each of non-word decoding, word decoding, and spelling is unknown. Finally, it is unclear whether or not all the ASD participants in their study were high-functioning, and FSIQ was not accounted for in their analyses.

Thus regression analysis, controlling for FSIQ should be conducted with a larger sample of children clearly identified as having a HFASD so as to remove any potentially confounding effect of comorbid intellectual disability. Additionally, the predictive ability of PA should be contrasted with factors currently known to be more closely associated with literacy such as PM, RN, and oral language. Furthermore dyslexia does not typically result from deficits with visual-motor integration, perception, analysis, or organization (Vellutino, 1979) but rather phonological and oral language deficits, which casts doubts on the usefulness of the examination of motor skills, and visual perception in White et al.'s study. Last, when examining the predictors of 'literacy' the relationship should be examined for all components required for functional literacy namely non-word decoding, word decoding, as well as reading comprehension. No study to date has examined the relationship or predictive ability of PA to reading comprehension.

Only two studies have investigated PM and reading in individuals with ASD. Kjelgaard and Tager-Flusberg (2001) examined the relationship of PM (non-word repetition) to language ability in 44 children aged 4–14 years diagnosed with AD and FSIQ ranging from well below to well above average, concluding that when children with AD have impaired language, PM is equally impaired. However, they had no TD, or indeed language-impaired, comparison group. Bishop et al. (2004) did compare ASD and TD children on PM finding that PM was poorer for the 69 children with ASD (not all were HFASD) than for 59 TD age-matched peers. Neither study however examined the association of PM with reading. Therefore, whether or not PM predicts reading for young children with HFASD remains unknown.

Several studies have examined RN in individuals with a HFASD, with inconsistent findings. Newman et al. (2007) identified no significant group differences on RN between HFASD participants without hyperlexia, ASD individuals with hyperlexia, and TD peers. Similarly, Asberg and Sandberg (2012) reported no significant difference between their ASD and TD participants for RN. White et al. (2006) however obtained mixed results with ASD participants performing worse than TD peers on rapid digit naming, but similarly on rapid picture naming, whilst Hooper et al. (2006) found that HFA children had significantly poorer RN than TD children. None of these studies however examined the relationship of RN to reading. Therefore, whether or not RN predicts reading for HFASD children is unknown.

Oral language has also been associated with reading, particularly reading comprehension for individuals with an ASD. Frith and Snowling (1983) identified that children with AD can successfully utilize syntax to aide reading comprehension but experience difficulty utilizing semantic information. Accordingly, Myles et al. (2002) and Saldana, Carreiras, and Frith (2009) noted that students with ASD exhibited deficits comprehending inference, whilst in a study of 384 ASD and 100 dyslexic children Huemer and Mann (2010) identified that receptive vocabulary loaded onto a comprehension rather than decoding factor. Newman et al. (2007) initially reported that HFASD children without hyperlexia were worse on reading comprehension than both ASD children with hyperlexia and TD peers, but after excluding outliers and running statistics in multiple formats concluded that the ASD groups did not differ on reading comprehension with both being worse than TD peers. Reading comprehension also reportedly maximally discriminated TD participants from the two ASD groups. No studies though have examined whether or not oral language predicts reading comprehension in HFASD readers.

Additionally, pragmatic awareness is important for reading comprehension (Tunmer & Hoover, 1992). Pragmatic deficits are requisite for an ASD diagnosis and thus may particularly impact on literacy for HFASD individuals. Minshew et al. (1994) reported that 62 adolescents and adults with HFA obtained significantly lower scores on pragmatic tasks and passage comprehension than 50 TD peers; whilst not investigated, a link between pragmatics and comprehension may have existed. Thus, whether or not pragmatic ability predicts decoding and reading comprehension for HFASD and TD children remains to be investigated.

The relationship of oral language to decoding in individuals with an ASD is less clear due to minimal investigation in this area per se and to the relationship between oral language and decoding only being examined at word level. Asberg and Sandberg (2012) found no significant difference on receptive vocabulary or word decoding between same-aged ASD and TD individuals but did not investigate the relationship between the two. Gabig (2010) reported no significant correlation between receptive vocabulary and word- and non-word reading for AD or TD children. Neither study examined if receptive vocabulary predicted decoding. Functional reading however requires the individual to decode at passage rather than word level. Decoding at passage level requires semantic, syntactic, and narrative language skills allowing for analogy and prediction to identify upcoming words in text (Ehri, 1995; Snyder & Downey, 1991). A reader must comprehend a variety of syntactic structures and word meanings (semantics) to understand a passage of written information. Semantic knowledge beyond word level is needed to comprehend passages of connected text to enable the individual to understand the meaning of the text as explicitly and literally written (Kintsch & Rawson, 2005). Thus, investigation of the relationship of oral language to decoding requires that a language battery examining language skills at word level and beyond be utilized with decoding measured at both word and sentence level.

Finally, good decoding skill reported for ASD individuals has sometimes been hypothesized as reflecting intact visual abilities, particularly adequate immediate and delayed visual recognition and memory (Ozonoff & Strayer, 2001; Rumsey & Hamburger, 1988). Thus, it may be that visual skills are more predictive of literacy, especially decoding, for HFASD than TD peers. More recently, however Hooper et al. (2006) identified that orientation judgement was poorer in children with HFA than TD peers whilst Newman et al. (2007) found that HFASD children without hyperlexia were significantly worse on simple visual memory than TD peers; children with ASD plus hyperlexia did not differ from either group. No significant group differences existed for complex visual memory. Neither study examined the relationship between visual skill and reading. White et al. (2006) however found that visual skill (motion and form coherence) did not explain a significant amount of variance in the literacy skills of individuals with AD. Investigation of the predictive ability of immediate and delayed visual recognition and memory to literacy for individuals with an ASD is still needed.

In summary, despite evidence to date suggesting that at least some of the predictors of decoding and reading comprehension identified for the TD population, namely cognition (FSIQ), phonological processing, receptive and expressive language, and visual skill also predict literacy for individuals with a HFASD, no research has formally investigated this hypothesis within a single study. The role of PA, RN, PM, oral language, and visual skill in reading development for children with HFASD remains unclear or even unknown, and any role of pragmatics is unknown. Thus, the aim of the present study was to establish whether the predictors of decoding and reading comprehension for young children with a HFASD parallel those that have been identified for young, non-ASD readers.

## 2. Method

### 2.1. Participants

To address the aims of this study we examined predictors of reading in children with HAFSD and TD children. Children with high or low IQ (FSIQ > 130; FSIQ < 85) were excluded so as remove any potential confound of significantly above or below average intelligence. This provides some control for the impact of cognition on potential group differences across the predictor variables and literacy skills (Fletcher & Buckley, 2002; Sun & Kemp, 2006).

The children included here were members of a group of 168 children in the age range 6–8 years with a diagnosis of HFA or AsD, dyslexia, specific language impairment, or who were otherwise TD, who participated in a cross-sectional study of early reading development. Children were recruited from schools, private speech pathology practitioners, or via advertisement and lived within the state of Victoria, Australia. There were 42 children (38 male, 4 female; $M_{age}$ = 7 years, 8 months, *SD* = 7.41 months, Range = 6 years, 7 months – 8 years, 10 months) diagnosed with HFASD. Forty-two children (13 male, 29 female; $M_{age}$ = 7 years, 9 months, *SD* = 8.78 months, Range = 6 years, 5 months – 8 years, 11 months) were TD, with no identified concerns prior to, or at the point of entry into the study.

In the HFASD group 16 males with a VIQ and FSIQ more than one *SD* below the mean (<85) were excluded. The 26 remaining participants all had a VIQ and FSIQ within the average or above average range. Nine participants had a diagnosis of AsD and 17 a diagnosis of HFASD; all had a Childhood Autism Rating Scale (CARS) score >30 according to diagnostic reports. The CARS is a 15 item rating scale to assist with the identification and severity of autism in children aged 2 years and older. All students spoke English only at home. According to diagnostic reports, diagnosis was made using DSM-IV (APA, 1994) or DSM-IV-TR (APA, 2000) criteria; 24 children were assessed by a specialist autism assessment team, and 2 via a private psychiatrist or psychologist specializing in ASDs. Fourteen students were in Year 1 (second year of school) and 12 in Year 2 (third year of school) with all attending a mainstream primary school. No child with a HFASD met criteria for hyperlexia; the ability to recognize written words in advance of age and cognitive functioning (Richman & Kitchell, 1981; Silberberg & Silberberg, 1967).

In the TD group, two children were excluded as they had a very superior VIQ and FSIQ (>130). The remaining 40 participants had obtained an average or above average score for each of VIQ, PIQ, and FSIQ. The two groups did not differ on FSIQ, VIQ or PIQ (see Table 1 for IQ scores). Thirty-six of the TD participants spoke English only, whilst four spoke English and another language at home; 19 students were in Year 1 and 21 were in Year 2 at a mainstream primary school.

No significant group difference existed for age, $t = -.414$, $df = 64$, $p = .68$, years of schooling completed, $t = 2.11$, $df = 64$, $p = .09$, or numbers of children exposed to a language other than English, $t = 2.36$, $df = 39.00$, $p = .08$. There was however a significant sex difference across the groups, $t = -5.68$, $df = 63.76$, $p < .001$, with more males in the HFASD group and more females in the TD group. The former is not unexpected and reflects the higher number of males diagnosed with an ASD. For the control group the higher number of females is an artefact of the response by parents to an invitation to participate in the study; more parents of females provided consent for participation.

### 2.2. Materials and procedure

Participants completed tests of cognition, phonological processing, oral language, vision, and reading. Cognition was examined using the Wechsler Abbreviated Scale of Intelligence (WASI) (Wechsler, 1999), four subtest version. All HFASD and 10 control participants had however completed either the Wechsler Intelligence Scale for Children – Third edition

**Table 1**
Mean, SD, and range of predictor variable scores for the TD and HFASD groups.

| Variable | Group | | | | | | |
|---|---|---|---|---|---|---|---|
| | TD ($n$ = 40) | | | HFASD ($n$ = 26) | | | |
| | *M* | *SD* | Range | *M* | *SD* | Range | |
| FSIQ | 102.50 | 9.52 | 87.00–117.00 | 101.23 | 11.08 | 87.00–129.00 | $F(1, 64) = .25$, $p = .62$, $\eta^2 = .62$ |
| VIQ | 100.03 | 9.79 | 86.00–124.00 | 100.04 | 10.27 | 85.00–131.00 | $F(1, 64) = <.001$, $p = .97$, $\eta^2 = <.001$ |
| PIQ | 105.00 | 12.74 | 87.00–123.00 | 104.04 | 18.27 | 85.00–151.00 | $F(1, 64) = .06$, $p = .80$, $\eta^2 = .001$ |
| PA | 116.65 | 14.04 | 91.00–139.00 | 117.35 | 16.91 | 73.00–145.00[b] | $F(1, 64) = .03$, $p = .86$, $\eta^2 = .001$ |
| RN | 107.25 | 9.57 | 88.00–130.00 | 103.00 | 13.23 | 67.00–136.00[b] | $F(1, 64) = 2.29$, $p = .14$, $\eta^2 = .04$ |
| PM | 99.63 | 11.15 | 76.00–133.00 | 96.76 | 14.89 | 67.00–148.00[b] | $F(1, 64) = 1.09$, $p = .30$, $\eta^2 = .02$ |
| Semantics | 98.22 | 8.80 | 86.63–117.00 | 92.59 | 12.94 | 62.75–116.50 | $F(1, 64) = 5.59$, $p = .02$, $\eta^2 = .09$ |
| Syntax | 100.46 | 9.69 | 85.33–119.25 | 102.40 | 10.14 | 86.25–120.00 | $F(1, 64) = .25$, $p = .62$, $\eta^2 = .004$ |
| Pragmatics[a] | 92.37 | 9.82 | 68.97–100.00 | 46.41 | 19.02 | 10.34–82.76 | $F(1, 64) = 141.52$, $p < .001$, $\eta^2 = .72$ |
| Visual perception | 110.67 | 8.29 | 83.80–125.40 | 102.04 | 17.82 | 71.60–133.20 | $F(1, 64) = 7.06$, $p = .01$, $\eta^2 = .10$ |
| Visual memory | 111.30 | 8.11 | 94.33–126.67 | 101.17 | 15.61 | 74.33–130.67 | $F(1, 64) = 11.96$, $p = .001$, $\eta^2 = .16$ |
| Decoding | 107.74 | 11.76 | 87.50–130.50 | 107.97 | 19.20 | 75.00–151.67[b] | $F(1, 64) = .004$, $p = .95$, $\eta^2 = <.001$ |
| Reading comprehension | 101.88 | 9.38 | 87.50–130.50 | 99.83 | 16.27 | 77.50–149.50[b] | $F(1, 64) = .25$, $p = .62$, $\eta^2 = .007$ |

[a] Percentage scores reported.
[b] One HFASD participant outlier with below average scores on PA, PM, RM, decoding, and reading comprehension; i.e. dyslexia profile.

(Wechsler, 1991) or Wechsler Pre-School and Primary Scale of Intelligence – Revised (Wechsler, 1989) within 12 months of participating in the study. The WASI was not completed with these students; previous assessment data were used.

The Comprehensive Test of Phonological Processing (CTOPP) (Wagner, Torgesen, & Rashotte, 1999) was used to examine PA, PM, and RN.

Three areas of language were assessed; semantics, syntax, and pragmatics. Semantics was assessed via the Peabody Picture Vocabulary Test-III (PPVT-III) (Dunn & Dunn, 1997), the Expressive Vocabulary Test (EVT) (Williams, 1997), the Clinical Evaluation of Language Fundamentals – Third edition (Semel, Wiig, & Secord, 1995) (CELF-3), and the Renfrew Bus Story (Renfrew, 1991). The CELF-3 (Semel et al., 1995) does not provide standard scores for semantics and syntax. As such the two subtests that specifically examined semantics, the Concepts and Directions subtest and the Word Classes subtest, were averaged to develop a semantics score.

A semantics composite was developed using the scores from CELF-3 semantics, PPVT, EVT, and the Bus Story information recall. CELF-3 semantics standard scores (*M* (10), *SD* (3)) were converted as outlined in Sattler (2001) to be equivalent to those of the other semantics variables (*M* (100), *SD* (15)). The four scores were then summed and averaged to form a semantics composite.

A syntax composite was developed by averaging the Sentence Structure, Word Structure, Recalling Sentences, and Formulated Sentences subtests from the CELF-3 and converting them as outlined in Sattler (2001).

The Pragmatics Profile of Everyday Communication Skills in School-Aged Children examined pragmatics (Dewart & Summers, 1995). The profile provides qualitative and not normative data. To obtain comparison scores the number of items on which parents identified adequate skill was summed for each participant. A maximum raw score of 29 was possible and a minimum score of 0. Raw scores were converted into percentages that were compared across groups giving a maximum score of 100% and a minimum score of 0%. Higher percentage scores indicated better pragmatic ability.

The Test of Visual-Perceptual Skills (non-motor) – Revised (Gardner, 1996) (TVPS-R) examined visual perception; the capacity to interpret or give meaning to what is seen. A visual perceptual composite was developed using the visual discrimination, visual-spatial relationships, visual form-constancy, visual figure-ground, and visual closure subtests of the TVPS-R. A visual-memory composite was made using the visual memory and visual sequential-memory subtests from the TVPS-R and the visual immediate recognition and delayed recognition subtests from the Attention and Memory Battery of the Leiter-R (Roid & Miller, 1997).

The Woodcock Reading Mastery Tests – Revised, Form G, (Woodcock, 1987) (WRMT-R) and the Neale Analysis of Reading – Third edition (Neale, 1999) (Neale-III) measured reading at word and paragraph level. A decoding composite was developed via averaging results from the Word Identification and Word Attack subtests from the WRMT-R and the accuracy scale of the Neale–III. A comprehension composite was formulated using the Word Comprehension subtest of the WRMT-R and the comprehension scale of the Neale-III. Neale-III standard scores were calculated using M and SD data provided within the test manual.

After obtaining ethical clearance from the relevant human research ethics committees, recruitment and assessment began. Children were assessed at the university psychology clinic, the child's school, or home. Testing occurred over two or three sessions, in a one-to-one situation or with a parent also present. Sessions ranged from 60 to 90 min in length, excluding breaks.

### *2.3. Statistical analysis*

To investigate group differences on a single dependent variable a single-factor between-subjects analysis of variance (ANOVA) was utilized. Group comparisons for conceptually related tasks were completed using a single-factor, between subjects multivariate analysis of variance (MANOVA). Partial eta-squared, a measure of the magnitude of experimental effect, is reported for all analyses thus providing a measure of the 'practical importance' of group differences (Howell, 2007). The data were screened for univariate and multivariate outliers at $\alpha = .001$ as well as for violations of the assumptions of normality, linearity, homogeneity of variance–covariance matrices, and homogeneity of regression. The results of these examinations were satisfactory. Correlations were run to investigate the relationship between FSIQ, non-verbal, and language predictors. Simple regression analysis was conducted to identify the significant predictor variables for decoding and reading comprehension for the TD and HFASD participant groups. The significant predictor variables were then used to develop a final model for decoding and reading comprehension for each participant group.

## 3. Results

### *3.1. Results of group comparisons*

No significant group differences were obtained for cognition (FSIQ, VIQ, and PIQ), phonological processing (PA, PM, and RN), syntax, decoding, or reading comprehension (see Table 1). Significant group differences were however evident for visual perception, visual memory, semantics, and pragmatics with the TD children performing better than HFASD peers.

### *3.2. Results of correlations between predictor variables*

The correlations between cognition, phonological, oral language, and visual measures for each participant group are in Table 2. Multicollinearity (correlations of >.9, see Tabachnick & Fiddell, 2001) was not evident between any predictor variables across the groups. A strong correlation ($r \geq .7$) was found between PM and decoding and reading comprehension and between reading comprehension and syntax for the HFASD group. Additionally, a strong correlation was obtained between decoding and reading comprehension for both groups.

Many moderate correlations ($r = .3–.7$) were also obtained. Correlations greater than or equal to $r \geq .6$ were found between PA and RN, PM, decoding, and reading comprehension, between syntax and FSIQ and decoding, and between RN and decoding for the HFASD group and between FSIQ and reading comprehension and between PA and decoding for the TD group.

### *3.3. Regression analyses*

Simple linear regression assessed the contribution of FSIQ, PA, PM, RN, semantics, syntax, pragmatics, visual perception, and visual memory to decoding and reading comprehension for each participant group. The same set of predictor variables was entered into the regression for both decoding and reading comprehension in order to examine the contribution of each predictor variable to the two facets of reading even though post hoc testing revealed that not all predictors resulted in a significant $R^2$ change. Table 3 shows that for both groups FSIQ and measures of phonological processing (PA and PM for both HFASD and TD; RN for HFASD) and oral language (syntax for both HFASD and TD; semantics for TD) predicted decoding. Visual perception failed to predict decoding for either group while visual memory was a significant predictor for the

**Table 2**
Correlations between FSIQ, non-verbal, and language predictors.

| Variable | Group | FSIQ | PA | PM | RN | Semantics | Syntax | Pragmatics | Visual memory | Visual perception | Decoding |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PA | TD | .46** | | | | | | | | | |
| | HFASD | .42** | | | | | | | | | |
| PM | TD | .40** | .52** | | | | | | | | |
| | HFASD | .42** | .63** | | | | | | | | |
| RN | TD | .13 | .06 | .29 | | | | | | | |
| | HFASD | .25 | .65** | .43* | | | | | | | |
| Semantics | TD | .23 | .35* | −.23 | .24 | | | | | | |
| | HFASD | .03 | .04 | −.02 | .006 | | | | | | |
| Syntax | TD | .23 | .49** | .23 | .24 | .35* | | | | | |
| | HFASD | .65** | .52** | .64** | .33 | .15 | | | | | |
| Pragmatics | TD | .28 | .34* | .23 | .13 | −.39* | .54** | | | | |
| | HFASD | .24 | .16 | .05 | .06 | .24 | −.17 | | | | |
| Visual memory | TD | .12 | .10 | .17 | .09 | .02 | .21 | .14 | | | |
| | HFASD | .35 | .18 | −.11 | .21 | .06 | .13 | .16 | | | |
| Visual perception | TD | .50** | .18 | .15 | .24 | .27 | .19 | .44* | .55** | | |
| | HFASD | −.04 | −.18 | −.38 | .001 | .23 | −.11 | −.04 | .17 | | |
| Decoding | TD | .33* | .64** | .34* | .29 | .38* | .38* | .19 | .31 | | |
| | HFASD | .58** | .64** | .74** | .61** | .02 | .64** | .20 | .13 | | |
| Reading comprehension | TD | .60** | .55** | .35* | .16 | .46** | .46** | .35 | .45* | .40** | .74** |
| | HFASD | .57** | .65** | .75** | .46* | .15 | .78** | .03 | .12 | −.15 | .88** |

* $p < .05$.
** $p < .01$.

**Table 3**
Predictor variables of decoding for the TD and HFASD groups.

| Predictor | TD | | HFASD | |
|---|---|---|---|---|
| | $\Delta R^2$ | $B$ | $\Delta R^2$ | $B$ |
| FSIQ | .08* | .33 | .31** | .58 |
| PA | .40** | .64 | .39** | .64 |
| PM | .10* | .34 | .52** | .74 |
| RN | .06 | .29 | .35** | .61 |
| Semantics | .12* | .38 | −.04 | .02 |
| Syntax | .11* | .37 | .39** | .64 |
| Pragmatics | .006 | .19 | −.003 | .20 |
| Visual memory | .08* | .31 | −.02 | .13 |
| Visual perception | .06 | .29 | .01 | −.22 |

* $p < .05$.
** $p < .01$.

TD group. The strongest predictor of decoding for the TD group was PA and for the HFASD group PM; accounting for 40% and 52% of the variance in decoding respectively.

FSIQ, PA, PM, and syntax predicted reading comprehension for both groups (see Table 4). Visual memory, visual perception, semantics, and pragmatics also predicted reading comprehension for the TD group whilst RN predicted reading comprehension for the HFASD group. Syntax was the strongest predictor of reading comprehension for both groups accounting for approximately 43% and 61% of the variance for the TD and HFASD groups respectively. Re-running analyses (using multiple linear regression) with decoding entered at Step 1 revealed that decoding accounted for 54% and nearly 78% of the variance in reading comprehension for the TD and HFASD groups respectively. Syntax also predicted reading comprehension for both groups of children. FSIQ and visual memory were additional significant predictors of comprehension for the TD group only.

### *3.4. Models of decoding and reading comprehension*

The significant predictor variables of decoding and reading comprehension were next utilized to develop literacy models for the HFASD and TD groups. This was to establish whether the same or similar predictor variables would be included in final literacy models for both HFASD and TD readers. Modelling involved predictor variables identified as significant at the $p \leq .05$ level for decoding and reading comprehension for each group being entered using the forward selection method. See Table 5.

Decoding models for the HFASD and TD groups comprised a measure of phonological processing (PA for the TD group; PM and RN for the HFASD group). Visual memory was also included in the model for the TD group, and cognition (FSIQ) was

**Table 4**
Predictor variables of reading comprehension for the TD and HFASD groups.

| Predictor | TD | | HFASD | |
|---|---|---|---|---|
| | $\Delta R^2$ | $\beta$ | $\Delta R^2$ | $B$ |
| FSIQ | .35** | .60 | .33** | .57 |
| PA | .28** | .55 | .39** | .65 |
| PM | .12* | .35 | .57** | .75 |
| RN | .03 | .16 | .21* | .46 |
| Semantics | .21** | .46 | .02 | .15 |
| Syntax | .43** | .66 | .61** | .78 |
| Pragmatics | .12* | .35 | .001 | .03 |
| Visual memory | .20** | .45 | .01 | .12 |
| Visual perception | .16* | .40 | .02 | −.15 |
| Step 1 | | | | |
| Decoding | .54** | .74 | .78** | .88 |
| Step 2 | | | | |
| FSIQ | .14** | .40 | .005 | .08 |
| PA | .01 | .13 | .01 | .14 |
| PM | .01 | .11 | .02 | .23 |
| RN | .003 | −.05 | .01 | −.14 |
| Semantics | .04 | .21 | .02 | .13 |
| Syntax | .17** | .45 | .08** | .37 |
| Pragmatics | .04 | .21 | .02 | −.15 |
| Visual memory | .05* | .24 | .01 | .14 |
| Visual perception | .04 | .20 | .003 | .05 |

* $p < .05$.
** $p < .01$.

**Table 5**
Final regression models for decoding and reading comprehension according to participant group.

| Groups | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| TD | | | | | | HFASD | | | | | |
| Variable | Beta | Sig. | $R^2$ change | Total$\Delta R^2$ | *p* value for model | Variable | Beta | Sig. | $R^2$ change | Total$\Delta R^2$ | *p* value for model |
| Decoding | | | | | | | | | | | |
| PA | .641 | <.001 | .412 | | | PM | .459 | .002 | .540 | | |
| Visual memory | .251 | .043 | .062 | .445 | <.001 | RN | .339 | .01 | .108 | | |
| | | | | | | FSIQ | .305 | .02 | .076 | .686 | <.001 |
| Reading comprehension | | | | | | | | | | | |
| Syntax | .459 | .001 | .432 | | | Syntax | .511 | .002 | .613 | | |
| Visual memory | .360 | .003 | .144 | | | PM | .425 | .007 | .107 | .695 | <.001 |
| PA | .297 | .03 | .065 | .603 | <.001 | | | | | | |
| Reading comprehension | | | | | | | | | | | |
| Step 1 | | | | | | | | | | | |
| Decoding | .570 | <.001 | .540 | | | Decoding | .646 | <.001 | .779 | | |
| Step 2 | | | | | | | | | | | |
| Syntax | .447 | <.001 | .172 | .697 | <.001 | Syntax | .369 | .001 | .080 | .847 | <.001 |

included in the model for the HFASD group. The final models explained around 68% of the variance in decoding for the HFASD group and 44% of the variance in decoding for the TD group.

Reading comprehension models for both groups included syntax and a phonological processing measure (PA for the TD group; PM for the HFASD group), with visual memory also included in the model for the TD group. These models explained approximately 60% and 70% of the variance in reading comprehension for the TD and HFASD groups respectively. When reading comprehension models were developed with decoding entered at Step 1, syntax was the only other variable that was included in the model for both groups. These second models explained nearly 70% and 85% of the variance in reading comprehension for the TD and HFASD groups respectively.

## 4. Discussion

### *4.1. Group comparisons*

The present study showed that HFASD and TD children matched for cognition (FSIQ) did not differ significantly on variables typically associated with decoding success (cognition, PA, PM, RN). Thus, like their non-ASD peers, HFASD children with average cognitive ability typically demonstrate adequate performance on skills requisite for the early stages of learning to decode. An exception to this pattern is dyslexia whereby cognition is adequate but phonology and decoding are poor. One HFASD participant in the current study was an outlier with low results on all phonological processing and literacy tasks, i.e. a dyslexia profile. This matches previous research identifying poor decoding in a subset of HFASD children (Huemer & Mann, 2010). Additionally, the TD group performed better than HFASD peers on visual perception and visual memory reinforcing that visual skills are not necessarily advanced in the ASD population and showing that visual skills do not account for intact decoding in young children with a HFASD.

No significant group differences emerged on reading comprehension despite the HFASD group demonstrating poorer skills than TD peers on semantics and pragmatics. In ASD and non-ASD groups semantic deficits are associated with poor reading comprehension (Bishop & Snowling, 2004; Snowling & Frith, 1986) with semantics above vocabulary level frequently differentiating HFASD and TD individuals matched on average FSIQ (Minshew, Goldstein, Muenz, and Payton, 1992; Rumsey & Hamburger, 1988). Pragmatics also aligns with reading comprehension, with pragmatic difficulties being a hallmark of ASD and being present even in individuals with average or above cognition and/or oral language (APA, 2000). Hence, the lack of significant group differences on reading comprehension was unexpected. Syntax however did not differentiate the groups. Syntax is generally viewed as a relative area of strength in verbal ASD children with a subgroup of HFASD individuals presenting with average syntactic ability (Tager-Flusberg & Joseph, 2003). Text provided to students within the first few years of school comprises more fact- than inference-based information with corresponding questions typically requiring factual answers rather than problem-solving and inference. As such, differences in reading comprehension may not become apparent until the mid to late primary school years when texts require both problem-solving and inference skills, and thus higher-level semantic and pragmatic interpretation is needed. Longitudinal research could confirm whether or not this is the case.

### *4.2. Literacy predictors*

The predictors of decoding were remarkably similar for the HFASD and TD groups. FSIQ, measures of phonological processing, and syntax predicted decoding for both the HFASD and TD groups, with semantics, pragmatics, and visual memory and perception being additional predictors for the TD group. Predictors of reading comprehension were also similar across the groups. Decoding and syntax predicted reading comprehension for both groups with FSIQ and visual memory also predictors for the TD group. Decoding was the strongest predictor of reading comprehension for the HFASD and TD groups reinforcing the importance of decoding ability to the understanding of written material.

Cognition (FSIQ) is associated with current academic level and academic progression for TD children (Shaywitz, Fletcher, Holahan, & Shaywitz, 1992). The present study suggests that this is also the case for HFASD children without hyperlexia. While two aspects of phonological processing, PA and PM, were important predictors in both groups, RN was an additional predictor of both decoding and reading comprehension in the HFASD group. RN is important in beginning readers as identifying those at risk for reading failure (dyslexia), and it seems it may be similarly important for HFASD beginning readers (Scarborough, 1998). Bishop, McDonald, Bird, and Hayiou-Thomas (2009) likewise hypothesized that RN may predict early literacy risk in children with language impairment whilst Groen, Laws, Nation, and Bishop (2006) reported a single case study of an 8-year-old girl with Down syndrome in whom intact RN paralleled good decoding. Hence, RN may be predictive of early literacy regardless of the type of developmental disorder.

That phonological processing significantly predicted decoding for the HFASD group aligns with findings for non-ASD individuals and with White et al.'s (2006) report that PA predicted literacy (decoding and spelling composite) for ASD children. Phonological processing also predicted reading comprehension but only when decoding was not already accounted for, thus reinforcing the relationship between phonological processing and decoding. The current study therefore confirms that phonological processing is important for the reading development of young children with a HFASD just as it is to their TD peers.

Oral language related to literacy skill somewhat differently for the TD and HFASD groups. Whilst syntax predicted decoding and reading comprehension for both groups, semantics and pragmatics were additional predictors of decoding for young TD readers.

Syntactic and semantic knowledge assist with the prediction of upcoming text and its comprehension for TD children. Frith and Snowling (1983) identified that AD children with hyperlexia use syntactic but not semantic knowledge when decoding. The current study supports that the same applies to HFASD children without hyperlexia. Likewise, that semantics failed to predict reading comprehension for the HFASD group matches previous research identifying that ASD individuals have difficulty utilizing semantics to assist reading comprehension (Frith & Snowling, 1983; Saldana et al., 2009; Wahlberg & Magliano, 2004). That said the groups failed to differ on reading comprehension suggesting that, at least in the early stages of literacy development, HFASD children utilize syntactic knowledge to buffer semantic deficits and aide their understanding of written material. Such buffering would however apply only to those HFASD children with intact syntactic skills and not HFASD children presenting with a co-morbid SLI profile. HFASD children with an SLI profile exhibit difficulties with morpho-syntax, semantics, and non-word repetition (phonological memory) (Tager-Flusberg, 2006).

Pragmatics and world knowledge are typically identified as important for text comprehension for both TD and HFASD populations (Wahlberg & Magliano, 2004). Pragmatics did not however predict decoding or reading comprehension in the HFASD group. That pragmatics failed to predict decoding is not unexpected as pragmatics has not previously been identified as important for decoding skills for TD individuals. That pragmatics did not predict reading comprehension for HFASD children in the present study may be an artefact of sample size, as for the TD group pragmatics only just reached significance and this sample was larger than the HFASD sample. Therefore, the relationship between pragmatics and reading comprehension should be investigated within a larger HFASD sample. Alternatively, pragmatics may be a better predictor of reading comprehension in older-aged samples, regardless of presence or absence of HFASD. Hence, an investigation into the relationship of pragmatics and reading comprehension in older individuals should be conducted.

Visual perception and visual memory failed to predict decoding and reading comprehension for the HFASD group. Whilst these results confirm previous reports that decoding is not attributable to superior visual memory for HFASD individuals they do not align with results obtained in the current study for the TD group where visual skills did predict both decoding and comprehension. There is no obvious explanation as to why visual perception and visual memory predicted decoding and/or reading comprehension for the TD, but not the HFASD group aside from the fact that the TD performed better than their HFASD peers on these tasks. Both groups however performed within the average range on these tasks.

### *4.3. Literacy models*

When the final literacy models were formed, we again found that phonological processing was important for decoding and comprehension in both groups of children. Phonological awareness was important for the TD children, while in the HFASD group, PM and RN were significant predictors of decoding, and PM was a significant predictor of comprehension. The results may suggest that children with a HFASD rely more on phonological memory to support both aspects of reading and on the rapid retrieval of phonological information to support decoding, than on the knowledge of sound patterns within words (PA). Alternatively phonological processing per se may be key to literacy development for all individuals. Phonological awareness and PM moderately correlated for the HFASD and TD groups. For the HFASD group PM predicted decoding and reading comprehension better than PA with the opposite occurring for the TD group. This corresponds with PM being included in literacy models for the HFASD group and PA being included in models for the TD group.

Relatively few studies simultaneously examine the predictive value of PA, PM, and RN to literacy for any participant groups and for studies that do incorporate two or more of the variables different combinations have been identified as important at different ages (e.g. Badian, 1998). Additionally, study differences may be due to varied sample sizes or other differences in the composition across the samples tested, for example age or IQ. Hence, while for the current participant groups different phonological aspects were identified as most important for literacy, future studies may show that the same aspects of phonological processing are important.

Visual memory was important in the final decoding and comprehension models for the TD but not the HFASD children. This indicates that, as expected within the early stages of literacy development, the TD children are using memory of the visual form of a word (visual contextual clues and overall word pattern recognition) to support early reading. The children with HFASD however, appear to be relying on memory for sounds to support their reading. This is unexpected as it is often claimed that children with ASD are visual rather than auditory learners. Alternatively, the TD group may already be using a combined top-down and bottom-up approach to reading in that oral language is predicting upcoming text (hence syntax in the final reading models) with letters and words identified only to confirm these hypotheses (visual memory in the reading models). Conversely, the HFASD group may be predominantly relying on a bottom up approach to reading with the emphasis on phonological processing to decode and thus comprehend the written information.

Finally, cognition (FSIQ) was incorporated into the final reading models for HFASD children, but not TD children. FSIQ has previously been identified as predictive of decoding and reading comprehension for the HFASD population (Mayes & Calhoun, 2008) with a higher FSIQ associated with higher decoding ability in individuals with an ASD (Howlin, Goode, Hutton, & Rutter, 2004; Mayes & Calhoun, 2003). That said, for individuals with a low FSIQ, decoding is often higher than expected based on FSIQ (Mayes & Calhoun, 2003); a pattern that is found in individuals with hyperlexia. Hence, the current model applies to HFASD individuals without hyperlexia and not ASD children with hyperlexia. It may be that this latter group relies more on intact phonological awareness skills and relatively superior rote auditory and/or visual memory to support their decoding. Overall though the importance of FSIQ to academic skill appears equally relevant to HFASD children as to their TD peers.

When decoding was accounted for at Step 1 in the final literacy models, only syntax was an additional predictor of reading comprehension for both groups of early readers. Thus, semantics was not important in these early school years for either TD or HFASD children. As discussed earlier, this may relate to the type of reading tasks that early readers confront. Early reading texts tend to be factual and to require little inference, thus semantic skills are more likely to be important later in schooling as reading demands increase. Accordingly, different language skills predict reading ability at different ages (Scarborough, 2005).

### 4.4. Limitations

The major strength of this study was that it is the first to simultaneously explore all predictors of decoding and reading comprehension previously identified for TD children, in a group of early readers with HFASD that were well matched with a group of TD children. Nevertheless there were some limitations. First, whilst every effort was made to recruit participants the sample size particularly for the HFASD was not ideal. Therefore, further study with a larger sample is recommended. Second ASD diagnosis was verified using diagnostic reports, though according to these reports all children had a CARS score >30. While confirmation of diagnosis using an instrument such as the ADOS (Lord et al., 2000) would be desirable, training was not readily available in Australia at the time this study commenced and access was beyond the scope of the current study. Finally, the participant samples comprised children whose parents had volunteered them to participate. Therefore systematic differences may exist between families who did and did not wish to participate. Specifically, families concerned about the language and academic functioning of their children with HFASD may have been more likely to participate.

## 5. Conclusions

White et al. (2006) concluded that literacy in ASD and non-ASD populations can usually be explained by phonology after accounting for age and general ability. The current study more specifically indicates that for young HFASD children with average cognitive and language abilities cognition, phonological processing, and oral language underpin literacy development. In particular, decoding is associated with cognition (FSIQ) and phonology, and reading comprehension is associated with cognition and syntax.

One notable difference from TD children was the failure of semantics to predict decoding and reading comprehension for the HFASD group. This suggests that TD children may be more successfully utilizing a combined bottom-up and top-down approach to reading than HFASD children. It further suggests that TD children are simultaneously decoding and comprehending what they read whilst HFASD children are more focussed on decoding. That TD children appeared to use semantics more successfully than HFASD children to assist decoding and reading comprehension parallels the finding that semantics was superior in the TD group compared with the HFASD group. Even so, decoding and reading comprehension did not differ between the two groups. Therefore, additional investigation is required to establish whether or not cognitive or other language skills such as syntax initially compensate for semantic deficits for HFASD children, or if the impact of semantic deficits becomes apparent at a later, not yet directly specified, age or stage of literacy development.

Finally, heterogeneity is well reported within the HFASD population. This therefore necessitates that phonological processing, oral language, and literacy should be routinely screened to ensure that any weaknesses are identified and early intervention is provided.

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