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Title: Predictors of early reading skills in 5-year-old children with hearing loss who use spoken language

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Abstract: This research investigated the concurrent association between a range of language, literacy, cognitive, and demographic variables and early reading skills in 101 5-year-old children with prelingual hearing losses ranging from mild to profound. All participants were fitted with hearing aids (n = 71) or cochlear implants (n = 30). They completed standardised assessments of phonological awareness (PA), receptive vocabulary, letter knowledge, word and non-word reading, passage comprehension, maths r ...

Abstract

This research investigated the concurrent association between a range of language, literacy, cognitive, and demographic variables and early reading skills in 101 5-year-old children with prelingual hearing losses ranging from mild to profound. All participants were fitted with hearing aids (n = 71) or cochlear implants (n = 30). They completed standardised assessments of phonological awareness (PA), receptive vocabulary, letter knowledge, word and non-word reading, passage comprehension, maths reasoning, and nonverbal cognitive ability. Multiple regressions revealed that PA (assessed using judgements of similarity based on words' initial or final sounds) made a significant, independent contribution to children's early reading ability (for both letters and words/non-words) after controlling for variation in receptive vocabulary, nonverbal cognitive ability, and a range of demographic variables (including gender, degree of hearing loss, type of sensory device, age at fitting of sensory devices, and level of maternal education). Importantly, the relationship between PA and reading was specific to early reading and did not generalise to another academic ability, maths reasoning. Finally, the results showed that letter knowledge (names or sounds) was superior in children whose mothers had undertaken post-secondary education, and that more severe hearing losses were associated with inferior levels of receptive vocabulary. By contrast, earlier fitting of sensory devices was not significantly associated with better PA, vocabulary, reading, or maths outcomes in this cohort of children, most of whom were fitted with sensory devices before 3 years of age.

Language and literacy skills predicting early reading

in 5-year-old children with hearing loss

Learning to read is arguably a child's most important academic achievement, yet children with hearing loss typically underachieve in reading (e.g., Dyer, MacSweeney, Szczerbinski, Green, & Campbell, 2003; Johnson & Goswami, 2010; Kyle & Harris, 2010; Traxler, 2000). One factor that might contribute to this underachievement is a difficulty in becoming "phonologically aware." Phonological awareness (PA) can be defined as the ability to reflect on and/or manipulate the sound structure of language. It is commonly assessed in tasks requiring segmentation, blending, and judgements of phonological similarity or difference. Segmentation is the process by which larger phonological units, usually words or non-words, are broken down into smaller constituents, such as syllables or phonemes (e.g., "cat" = /k/ + /æ/ + /t/). Blending is essentially the reverse of segmentation, whereby small phonological units, such as syllables or phonemes, are combined in sequence to form longer units, usually words or non-words (e.g., /f/ + /æ/ + /n/ = "fan"). Finally, judgements of phonological similarity or difference ("odd-one-out" tasks) are commonly used to assess PA when the focus is on awareness of alliteration or rhyme, both of which rely on the ability to identify the sub-syllabic units of onset (the initial consonant or consonant cluster) and rime (the vowel and any following consonants) (e.g., /m/ + /æn/, /sp/ + /æn/).

Since publication of a seminal study by Bradley and Bryant (1983), numerous investigations have provided empirical evidence for the existence of a positive association between PA and early reading skill in children with typical development (e.g., Oakhill & Cain, 2012; Tunmer, Herriman, & Nesdale, 1988; Wagner, Torgeson, & Rashotte, 1994; Wimmer, Landerl, Linortner, & Hummer, 1991). In a recent meta-analysis of 235 studies, Melby-Lervåg, Lyster, and Hulme (2012) examined the association between concurrent measures of word and non-word reading on the one hand, and two types of PA on the other: awareness of phonemes and awareness of rimes (i.e., rhyming ability). A consistent pattern of findings emerged across comparative studies of children with typical versus disordered reading, and correlational studies of unselected groups of children. Inferior reading was associated with significantly poorer awareness of both rimes and phonemes. The effects were, however, typically smaller for rime awareness than for phonemic awareness; and only phonemic awareness accounted for significant, unique variance in reading performance once other phonological processing variables (rime awareness and phonological short-term memory) were controlled. On the basis of these findings, Melby-Lervåg et al. concluded that "there is a specific and substantial association between concurrent measures of phonemic awareness and children's word reading skills" (p. 340).

Most researchers would agree that PA is associated with early word and non-word reading skills in children with typical development. In an alphabetic language, such as English, this well-documented association is presumably underpinned by the beginning reader's need to understand the logic underlying the mapping of graphemes onto phonemes. More specifically, if a sequence of phonemes cannot be identified in the speech stream, the basis for representing spoken words as a sequence of corresponding graphemes will remain inaccessible (Authors, year). There remain, however, several points of controversy regarding the exact nature of the association between PA and reading.

One issue that has been the subject of considerable debate is the direction of the causal relationship between the variables. Although this issue remains unresolved at the present time, evidence from carefully designed training studies (e.g., Lundberg, Frost, & Peterson, 1988; Schneider, Küspert, Roth, Visé, & Marx, 1997) and comprehensive metaanalyses (e.g., National Institute of Child Health and Human Development [NICHD], 2000) suggests a facilitative role for PA training in the development of early reading skills.

A second issue concerns the level of phonological structure to which beginning readers must gain access; in particular, phonemes or onsets and rimes. Melby-Lervåg et al. (2012) argued that awareness of phonemes is crucial for reading development on the grounds that reading is more strongly associated with phonemic awareness than with rime awareness. On the other hand, Ziegler and Goswami (2005) argued that rime awareness is also critical to the development of English reading skills, because the mapping from English orthography to phonology is more consistent at the level of rimes (e.g., "all," "ight") than individual graphemes and phonemes. A similar argument was proposed by Bryant (2002), who distinguished this direct role for rime awareness from a more indirect one, in which rime awareness was also considered to be an important precursor to phonemic awareness.

A third issue relates to theoretical interpretation of the observed association between PA and reading. Two aspects are relevant. First is the question of whether early reading development is associated with awareness of phonological structure *per se* (i.e., the realisation that phonological units such as onsets, rimes, and phonemes exist), or more generally with the strength and accuracy of children's underlying lexical-phonological representations, which in turn is reflected in their performance on PA tasks (e.g., Snowling & Hulme, 1994; Melby-Lervåg et al., 2012; Swan & Goswami, 1997). On the latter view, PA is underpinned by the establishment of segmentally-based lexical representations (or ordered sequences of phonemic segments), which develop in response to children's vocabulary growth and the associated need to discriminate between an ever-increasing number of similar sounding words (e.g., Metsala, 1999; Walley, 1993).

Second is the question of whether PA is associated specifically with early reading skills, or with cognitive ability and/or academic performance more generally. If as suggested earlier, the association between PA and reading is underpinned by children's need to learn the mappings between graphemes and phonemes, then the association should be specific to reading (Bryant, MacLean, Bradley, & Crossland, 1990). In practice, however, there may be some limited generalisation, depending on the extent to which particular academic skills involve processes that are shared with tasks designed to measure PA. Thus, in investigating the link between PA and mathematical ability, Krajewski and Schneider (2009) found that PA was associated directly with children's ability to learn basic counting skills but not their understanding of the links between number-words and quantities.

Despite these contentious issues surrounding interpretation of the association between PA and early reading skills in typically developing children, the association itself has been well-documented and is widely accepted (Melby-Lervåg et al., 2012). The same cannot be said for this association in children with prelingual hearing loss, whose access to spoken language may be limited by their hearing loss, resulting in reduced opportunities to develop both PA and reading skills. As a result, two distinct theoretical perspectives can be identified in the literature regarding the role of PA in reading for individuals with hearing loss.

On the one hand are researchers who have placed primary importance on the nature of reading as building on spoken language processes (e.g., Perfetti & Sandak, 2000; Wang, Trezek, Luckner, & Paul, 2008). According to this view, "… reading English is basically the same for everyone, including individuals who have learning or other disabilities …" (Wang et al., 2008, p. 397); hence, it has been linked to the belief that phonological decoding processes (or the use of grapheme-phoneme rules to "sound words out") are important for the development of reading skill in children with hearing loss, as they are for children with normal hearing. Results from recent intervention studies provide some support for this proposal, in demonstrating the effectiveness for children with hearing loss of phonics-based reading instruction (including PA training) that has been adapted through the use of visual phonics, a system of hand cues designed to represent individual phonemes (e.g., Trezek & Malmgren, 2005; Trezek & Wang, 2006). In the present context, this theoretical perspective, which has been labelled the "qualitative similarity" hypothesis, predicts a positive association between PA and reading in children with hearing loss.

By contrast with this view of reading as essentially sound-based, other researchers have documented the use of effective, alternative reading strategies in individuals with hearing loss, which reduce their reliance on phonological decoding skills and PA; for example, through increased attention to visual, orthographic, morphological, and syntactic information (e.g., Allen, Clark, del Giudice, Koo, Lieberman, Mayberry, et al., 2009; Clark, Gilbert, & Anderson, 2011; Mayberry, del Giudice, & Lieberman, 2011; McQuarrie & Parrila, 2009; Miller, 2010; Miller & Clark, 2011). Proponents of this theoretical perspective have claimed that "the role of phonology in reading is currently being overstated" (Miller & Clark, 2011) and that "language ability may have an even greater influence … on reading development" (Mayberry et al., 2011, p. 181). In the present context, this alternative theoretical perspective predicts no necessary positive association between PA and reading in children with hearing loss.

The literature contains empirical support for both of these theoretical perspectives. Consistent with the qualitative similarity hypothesis, are studies that have reported a positive association between PA and reading development in children with hearing loss (e.g., Colin, Magnan, Ecalle, & Leybaert, 2007; Dillon, de Jong, & Pisoni, 2012; Dyer et al., 2003; Easterbrooks, Lederberg, Miller, Bergeron, & McDonald Connor, 2008; Harris & Beech, 1998; Spencer & Tomblin, 2009).

Colin et al. (2007) reported a longitudinal study of 21 French-speaking children with severe to profound prelingual hearing loss. The children, who were fitted with hearing aids (HAs) (*n* = 13) or cochlear implants (CIs) (*n* = 8), were exposed to oral French and varying amounts of Cued Speech (CS). They were assessed twice: once in kindergarten (at mean age 6;2), and then approximately one year later in first grade (at mean age 7;2). The results showed that PA in kindergarten, assessed using rhyme decision and rhyme generation, predicted children's performance in written word-recognition tasks in first grade. Since Colin et al. did not include a measure of vocabulary in their assessment battery however, the relationship they observed between PA and reading might have been mediated by vocabulary knowledge. In a related vein, since reading was the sole measure of academic achievement included in their first grade assessment, it is impossible to know whether the observed association with PA would have generalised to other academic skills. Finally, although there was no significant association between degree of hearing loss and children's reading or PA performance, the restricted range of hearing losses (severe to profound) may well have contributed to this null effect.

Further evidence for an association between PA and reading came from a study by Spencer and Tomblin (2009) of 29 children with prelingual profound hearing loss who were aged between 7;2 and 17;8 at the time of testing. Whereas Colin et al.'s (2007) participant sample included children with HAs or CIs, children in this study all had CIs, which they received at ages ranging from 1;6 to 10;8 (years;months). In addition, all participants were exposed to Total Communication at school. PA was assessed using two subtests from the Comprehensive Test of Phonological Processing (CTOPP; Wagner, Torgeson, & Rashotte, 1999), elision and blending words, and a rhyme judgement task adapted from James, Rajput, Brown, Sirimanna, Brinton, & Goswami (2005). Elision and blending scores were both significantly correlated with reading ability in the form of non-word decoding and written word comprehension. The authors did not, however, investigate whether variation in some other measured variables might have mediated the observed effects.

This potential weakness was addressed to some extent in a study by Dillon et al. (2012), which also focused on profoundly deaf children with CIs. In Dillon et al.'s study, however, the children were reported to use spoken English to communicate. They were aged between 6.2 and 14.0 years (M = 9.1) at the time of testing, having received their CIs at ages ranging from 1 to 6 years old. Simple bivariate correlations revealed a strong positive association between PA (for phonemes and syllables) and several measures of reading, including oral reading of non-words and sentence-picture matching. Age at testing was also strongly correlated with the reading outcome measures and with receptive vocabulary; whereas age at cochlear implantation was only weakly correlated ($p < .05$) with two of the four reading measures; namely, oral reading of non-words and sentence-picture matching.

Dillon et al. (2012) also computed partial correlations to investigate whether age at testing or vocabulary knowledge might mediate the observed associations between PA and reading. They concluded that age at testing was not a mediating factor, because the magnitude of the correlations between PA and reading altered minimally when age at testing was controlled. On the other hand, the association between reading ability and PA was partially, but not completely, mediated by vocabulary knowledge, as evidenced by partial correlations that reduced in magnitude but remained significant.

Whereas Dillon et al. (2012) and Spencer and Tomblin (2009) were both concerned with the association between PA and reading in children with CIs, Dyer et al. (2003)

investigated the association in a sample of 49 13-year-old teenagers with severe or profound hearing losses, who did not have CIs, and who used sign-supported English and British Sign Language (BSL) to communicate. It might have been expected that this group of participants would be less likely to show an association between PA and reading, due to a potentially greater reliance on visual than sound-based reading processes. Nevertheless, a significant association was observed between accuracy in a rhyme judgement task and sentence reading ability. The generalizability of this finding might be questioned, however, on the grounds that Dyer et al. selected their participants to have a minimum (6-year-old) level of reading ability.

The studies reviewed above all reported evidence of a positive association between PA and reading in children with hearing loss. Furthermore, Colin et al. (2007) reported longitudinal data indicating that early PA predicted later reading in their participant sample, a finding consistent with (though not necessarily indicative of) a causal relationship between the variables. By contrast, Kyle and Harris (2010) suggested that PA was more a consequence of early reading than a predictor (see also Kyle & Harris, 2011; Musselman, 2000). In support of this view, they reported longitudinal associations between reading, hearing loss, productive vocabulary, PA, and speech reading in 29 English-speaking children with severe to profound prelingual hearing losses (22 with HAs and 7 with CIs). Their participants differed from those in Colin et al.'s study in that most (22 out of 29) preferred to communicate using BSL or Total Communication. PA was assessed using judgements of rhyme and alliteration, and reading was assessed at the level of words, sentences, and texts. Five multiple regressions were conducted: In two of these analyses, measures of reading, hearing loss, vocabulary, speech reading and PA collected at 7;10 were used to predict word reading and sentence comprehension at 8;10; while in the other three analyses, the same set of predictor measures collected at 8;10 was used to predict word reading, sentence comprehension, and text comprehension at 10;11. The results showed that earlier PA did not account for significant unique variance in any later-measured reading scores after removing the variance associated with children's earlier reading ability, hearing loss, vocabulary, and speech reading. On the other hand, when PA at 10;11 was predicted from measures collected at 8;10, both earlier word reading and sentence comprehension accounted for significant unique variance in later-measured PA after removing the variance associated with hearing loss and earlier PA.

There is a clear lack of consistency in the findings reported by Kyle and Harris (2010) and Colin et al. (2007) regarding the longitudinal nature of the association between PA and reading. Since longitudinal data were not reported by Spencer and Tomblin (2009), Dillon et al. (2012), or Dyer et al. (2003), their findings cannot shed additional light on this discrepancy. It may be that the inconsistency reflects methodological differences (e.g., in the majority of participants' preferred communication mode, and/or the number and type of demographic and other variables accounted for in statistical analyses), but before drawing any firm conclusions, we need a clearer understanding of the relationships that exist between various cognitive-linguistic and demographic variables on the one hand, and reading and PA outcomes on the other.

In spite of some inconsistency in the results, when taken together, the studies described above support the qualitative similarity hypothesis in providing evidence for a positive association between PA and reading in diverse, though relatively small (*N*s < 30), samples of children with hearing loss. As noted earlier however, the literature also contains empirical studies more consistent with the alternative theoretical position that PA is not a necessary correlate of reading in this population. These studies have reported either no significant association between PA and reading (e.g., Gibbs, 2004; Izzo, 2002; McQuarrie & Parrila, 2009), or an association that is mediated by a third variable, such as hearing loss (e.g., Kyle & Harris, 2006) or vocabulary knowledge (e.g., Johnson & Goswami, 2010).

Gibbs (2004) found no significant association between awareness of initial phonemes or rhymes and two measures of single word reading in a sample of 15 children with moderate hearing losses who were aged between 6;2 and 7;10. As Gibbs acknowledged, however, strong claims could not be made on the basis of such a small sample. In a second study, Izzo (2002) made use of a story retelling task to assess reading ability. Clearly, however, story retelling relies on narrative ability as much as the ability to read and understand a text. In fact, the scoring procedure used by Izzo reflected this fact, with children's retellings scored for "the inclusion of story structure elements and for sequence" (Izzo, 2002, p. 23). It is perhaps not surprising, therefore, that a significant association with PA was not observed.

Similarly, McQuarrie and Parrila (2009) failed to find evidence of an association between PA and reading in a sample of 52 students with severe or profound hearing loss, all of whom used American Sign Language (ASL) as their preferred communication mode. The students, who were aged between 6;6 and 18;10 (M = 13;1), were classified into two groups according to reading ability. The performance of each group was examined on a task requiring them to judge words' phonological similarity at the level of syllable, rhyme and phoneme. The results showed that neither group achieved better than chance performance on the judgement task, leading the authors to conclude that "increased reading ability did not result in functional phonological representations for these deaf students" (McQuarrie & Parrila, 2009, p. 147).

Finally, some studies have demonstrated that the role of PA in reading is mediated entirely by other variables for children with hearing loss. In an antecedent to their 2010 study, Kyle and Harris (2006) examined the concurrent association between PA (judgements of alliteration and rhyme) and reading (word reading and sentence comprehension) in the same sample of children aged 7;10 (range 6;8 to 8;7). Although the zero-order correlation between PA and reading was significant, the partial correlation controlling for degree of hearing loss was not. It is difficult to know how much weight to assign to this null effect however, given that the zero-order correlation between PA and reading was also non-significant in a reading-age matched sample of children without hearing loss (Kyle & Harris, 2006).

In a related vein, Johnson and Goswami (2010) analysed data from 39 children, aged between 5 and 15 years, all of whom had CIs, 20 implanted early (before 3;3) and 19 implanted late (after 3;7). The results of multiple regression analyses using reading accuracy and comprehension as dependent variables showed that PA (assessed on a rhyme judgement task) was a significant predictor of children's reading when entered into the regression equation after nonverbal IQ but before receptive vocabulary. On the other hand, after removing the variance associated with vocabulary, PA was no longer significant (see also James, Rajput, Brinton, & Goswami, 2009). These results, along with those of Kyle and Harris (2006), once again highlight the need to understand and control for the influence of relevant demographic and cognitive-linguistic variables in order to obtain an accurate understanding of the nature of the association between PA and early reading skill in children with hearing loss.

To summarise, previous empirical research examining the association between PA and reading ability in children with hearing loss is inconclusive due to a lack of consistency in the findings reported across studies (see Mayberry, del Giudice, & Lieberman, 2011, for a recent meta-analysis). Whereas some research has revealed a positive association between PA and reading in line with the qualitative similarity hypothesis, other research is more compatible with the alternative view that the role of PA has been overstated, and that other variables, including language ability, may be more important for the development of skilled reading in this population. It seems likely that some of the observed inconsistency between studies may reflect the inclusion of relatively small participant samples combined with the heterogeneous nature of the population of children with hearing loss. Thus, a range of audiological, and child- and family-related variables that differ across studies have been shown to influence children's PA and/or reading outcomes; in particular, degree of hearing loss (e.g., Kyle & Harris, 2006), age at fitting of sensory devices (e.g., Connor & Zwolan, 2004; Dillon et al., 2012; James, Rajput, Brinton, & Goswami, 2008), socio-economic status (e.g., Geers, 2003), cognitive ability (e.g., Geers, 2003; Harris & Beech, 1998), and gender (Geers, 2003). In the current context, preferred communication mode (oral or signed) may also be of particular importance given that written English encodes spoken language.

In light of this background, it is clear that further investigation is needed in order to arrive at an accurate picture of the relationship between PA and reading in children with hearing loss, preferably using samples large enough to simultaneously control for or manipulate the potentially influential variables described above. With this aim in mind, the current investigation included a large sample of 101 children with hearing loss. Participants were drawn from a population-based cohort who took part in the 5-year-old assessment phase of a large longitudinal study investigating outcomes of children with hearing loss (the "Longitudinal Outcomes of Children with Hearing Impairment" or "LOCHI" study) (see Authors, year).

The current study

The primary aims of the research were: (1) to shed further light on the concurrent association between PA and early reading skill in children with hearing loss; and (2) to identify the demographic and cognitive-linguistic variables associated with children's PA and reading-related outcomes. We focused our attention on the earliest stages of reading development to reduce the likelihood that any observed associations would result from systematic instruction in alphabetic reading (see Kyle & Harris, 2010). Hence, we conducted our assessments as close to 5 years of age as possible. All participants were required to have spoken English as a primary form of communication, either alone or in combination with sign (simultaneous communication) or another spoken language (bilingualism). This requirement was necessary to ensure that standardised tests could be administered in spoken English according to instructions provided in the respective test manuals. In light of findings demonstrating that an association between PA and reading could be mediated (or partially mediated) by vocabulary knowledge (e.g., Dillon et al., 2012; James, Rajput, Brinton, & Goswami, 2009; Johnson & Goswami, 2010), this variable was included in our assessment battery with a view to controlling its effects during statistical analysis. Receptive vocabulary was used for this purpose, in light of Johnson and Goswami's finding that it showed a stronger association with reading than productive vocabulary. In regard to demography, data were collected on gender, degree of hearing loss, type of sensory device (hearing aid or cochlear implant), socio-economic status (including level of maternal education), age at fitting of sensory devices, and cognitive ability.

Given the conflicting findings reported in the published literature, hypotheses were tentative. Nevertheless, we predicted that PA would be associated with early reading skill after controlling for variation in receptive vocabulary, nonverbal cognitive ability, and a range of demographic variables (including gender, degree of hearing loss, age at fitting of sensory devices, and level of maternal education). Furthermore, we predicted that the association with PA would be specific to early reading, and would not generalise to another academic skill, in particular, mathematical ability. Finally, and in line with previous research, we hypothesised that gender, degree of hearing loss, age at fitting of sensory devices, and level of maternal education would be associated with PA, reading, and related outcomes in our sample of 5-year-old children with hearing loss.

Method

Design

A cross-sectional, correlational design was used to investigate the research hypotheses.

Participants

Participants were drawn from a population-based cohort taking part in the LOCHI study referred to earlier. An invitation to participate in a prospective study on outcomes was issued to all families of children who were born between 2002 and 2007, and who presented for hearing services below 3 years of age at pediatric centers administered by Australian Hearing (the government-funded hearing service provider for all children in Australia) in New South Wales, Victoria, and Southern Queensland. When participants in the LOCHI study reached a chronological age of approximately 5 years, they were administered a test battery that included assessments of PA and reading.

Data included in this paper were obtained from a large sample of 101 LOCHI participants whose PA was assessed using relevant subtests from the CTOPP (Wagner et al., 1999); namely: elision, blending words, and sound matching. Data from a further 9 children were excluded from the present sample: 3 were from non-English-speaking backgrounds, 4 had normal hearing in their better ear, and 2 were fitted with HAs after they were 4 years old, approximately 16 to 23 months later than all other participants. An additional 95 potentially eligible LOCHI participants were not included in the study sample for a variety of reasons. In 29 cases children were unavailable for all or part of the assessment interval. In a further 16 cases, the CTOPP was not attempted because participants had additional disabilities, were from a non-English-speaking background, or were not wearing their HAs or CIs at the time of assessment. In the remaining 50 cases, administration of the CTOPP was attempted, but valid scores could not be achieved on all three subtests, most often because participants were unable to cope with the difficulty of the test.

The strategy of excluding children who were unable to complete the CTOPP from the final participant sample might be criticized on the grounds that these children may have acquired the ability to read in the absence of PA. If so, their omission could artificially enhance the correlation between PA and reading in the final (included) study sample; however, inspection of the reading assessment data for these children does not support this view. The majority of the 50 excluded participants were also unable to attempt/complete the primary reading assessment, the Woodcock-Johnson III Diagnostic Reading Battery (WJ III® DRB) (Woodcock, Mather, & Schrank, 2004). In fact, for 34 of the 50 participants, the WJ III® DRB could either not be administered at all (*n* = 24), or was only partially administered (with one or both of the oral reading subtests remaining incomplete) (*n* = 10). Of the 16 participants who did achieve a score on all three included subtests of the WJ III® DRB, 12 were unable to read any real words or non-words correctly, although in some cases they were able to provide the names or sounds associated with individual letters. The final four excluded participants demonstrated limited reading ability of real words. Three children read a single word, one of whom also demonstrated some PA on the word-blending subtest of the CTOPP (achieving a raw score of 2 correct). The fourth child read six real words, and although he failed to complete any subtests of the CTOPP, that failure reflected a lack of compliance with testing, which may or may not have been associated with a lack of PA *per se*.Table 1 presents relevant background data on the included sample of 101 children, more than half of whom were boys (*n* = 60, 59.4%). Demographic information describing the children, their families, and their environment was elicited from caregivers using custom-designed questionnaires. Audiological information was collected from the databases of Australian Hearing and relevant intervention agencies.

Insert Table 1 about here

Hearing loss is represented as a four-frequency-average in the better ear (4FA HL, the average of hearing threshold levels at 0.5, 1, 2, and 4 KHz, represented non-linearly). Across the cohort, hearing loss at 5 years of age ranged from mild (20-40 dB, *n* = 15), through to moderate (41-60 dB, *n* = 44), severe (61-80 dB, *n* = 6), and profound (>80 dB, *n* = 36). On average, children were diagnosed with a hearing loss at 11.0 months of age, and first fitted with HAs approximately 3 to 4 months later at 14.7 months of age (Range: 1 to 36 months). At 5 years of age, the majority of children were HA users (70.3%), with just under one third (29.7%) using unilateral or bilateral CIs. Device use was associated with degree of hearing loss: All children with mild, moderate, or severe losses (*n* = 65) used HAs, whereas most children with a profound loss (30 out of 36 or 83.3%) had CIs. For children using CIs, devices were first switched-on between 7 and 46 months of age (*M* = 22.3; *SD* = 12.1). Given that age at CI switch-on and duration of CI use provide essentially redundant information in the current study, duration of use is not included in Table 1. It is important to note, nevertheless, that 27 of the 30 children with CIs (90%) had more than 24 months experience with their device, and the remaining 3 (10%) had between 17 and 24 months experience.

Similarly, of the 71 children with HAs, all had at least 24 months experience with their device.

Children's socio-economic status was measured using the Index of Relative Socio-economic Advantage and Disadvantage (IRSAD) from the Socio-Economic Index for Areas (Australian Bureau of Statistics, 2008). Lower IRSAD scores indicate geographic areas with relatively fewer resources, whereas higher scores indicate geographic areas with relatively more resources. Scores are expressed as deciles. In the current cohort there were children living in the most advantaged and the most disadvantaged areas of Australia. The majority of children, however, lived in more advantaged areas, with 70.3% of the cohort scoring 7 or above on the IRSAD (Mean = 7.3, Median = 8.0, Mode = 10.0). Parental education was measured using a three-point scale. Female caregivers were fairly evenly divided between those who had a university qualification (Rank 1, 42.4%), those with a diploma or certificate (Rank 2, 28.3%), and those with 12 years or less of school attendance (Rank 3, 29.3%). Male caregiver levels of education were similarly distributed (see Table 1).

Caregivers were asked to describe their children's method of communication at home as being oral only, simultaneous communication (i.e., sign and speech), or sign only. The majority of children in this cohort (95.0%) used oral communication only, with just a handful of children (3.0%) using simultaneous communication. A similar pattern of results was obtained for mode of communication used in early intervention (see Table 1). More specifically in regard to spoken language, all of the children used spoken English at home, with 19 (18.8%) reporting use of another spoken language as well. The most frequently reported language other than English was Arabic.

Assessment tools

The data reported here were collected using a range of formal assessments aimed at evaluating children's receptive vocabulary, PA, reading skill, mathematical ability, and nonverbal cognitive ability.

Receptive vocabulary.

The Peabody Picture Vocabulary Test 4th Edition (PPVT-4) (Dunn & Dunn, 2007) was used to evaluate children's receptive language, in particular, their vocabulary knowledge. This widely used test is based on a four-alternative, forced-choice picture-selection format. It was administered according to instructions in the test manual. Spoken words were presented one at a time to the child who was asked to indicate which one of four pictures best showed the word's meaning. The PPVT-4 has been used successfully to assess individuals from a range of special populations, results of which are presented in the test manual. Split-half reliabilities are excellent, in the vicinity of .93 to .97 for children in the target age range (from 5;0 to 6;5). In this study, children's performance was measured in terms of their total number of correct responses (raw score) and their percentile rank.

Phonological awareness.

Three subtests from the CTOPP (Wagner et al., 1999) were administered to assess children's PA: elision, blending words, and sound matching. In elision (20 items), children were asked to repeat a spoken word and then to say the word again after omitting specified sounds. The sounds to be omitted could constitute a morpheme, syllable, or phoneme. In blending words (20 items), the examiner uttered a sequence of syllables or phonemes and the child was asked to "put these parts together to make a whole word." Finally, in sound matching, a target word and three optional words were presented in spoken and pictorial form on each trial, and the child was asked to indicate which optional word either began (10 items) or ended (10 items) with the same sound as the target. Notably, children did not progress to final sound matching if they reached the specified ceiling (4 out of 7 errors) on initial sound matching. Implementation of this ceiling rule resulted in just 14 children from the current sample (or 13.9%) proceeding to final sound matching. Cronbach's alpha, as reported in the test manual, indicates good reliability for each of the three subtests, with values ranging from .88 to .93 for children aged 5 to 6 years. Performance was measured in terms of the total number of correct responses (raw score) on each subtest and the corresponding percentile rank.

Reading.

Reading ability was assessed using a variety of stimuli, from letters to short passages. Letter knowledge was evaluated using a subtest from the Phonological Abilities Test (PAT) (Muter, Hulme, & Snowling, 1997), in which children were asked to provide either the name or the sound associated with each letter of the alphabet. Good test-retest reliability for this subtest (r = .86) was reported in the test manual for a group of 35 children with a mean age of 5;4 (range 4;5 to 5;8). Good split-half reliability was reported by Muter, Hulme, Snowling, & Stevenson (2004) for a group of 90 children tested initially at age 4;9 (r = .96) and then 1 year later (r = .89).

Other aspects of reading were evaluated using three subtests from the Woodcock Johnson III® Diagnostic Reading Battery (WJ III® DRB) (Woodcock, Mather, & Schrank, 2004). Letter-word identification assessed children's ability to recognise and name individual letters and words. Letter recognition and naming were assessed in items 1 to 9 and 11-14; whereas word recognition was assessed in items 10 and 15 (selecting one of four written words to match a word spoken by the examiner), and oral reading was assessed from item 16 onwards. Word attack measured children's ability to recognise and produce sounds associated with single letters (3 items) and to read non-words aloud (item 4 onwards).

Finally, the passage comprehension subtest assessed children's understanding of words, phrases, and/or short passages using word-picture matching and cloze procedures. Good Split-half reliabilities are reported in the test manual for each of the three subtests in the age range 5 to 6 years, with values of .98-.99 for letter-word identification, .94 for word attack, and .96 for passage comprehension. Children's performance on each of these four reading subtests was measured in terms of their total number of correct responses (raw score) and their percentile rank. Data collected in the WJ III® DRB letter-word identification task were also used to create an additional variable, "real word reading," which was the number of *words* read correctly (i.e., disregarding test items 1-9 and 11-14, which involved recognising or naming single letters). The creation of this additional reading variable was important in enabling us to disentangle associations between PA and letter knowledge from the association between PA and word reading. An analogous strategy could not be used for word attack data, because the majority of children who completed that subtest (92/96) were able to decode only single letters.

Mathematical ability.

The Wechsler Individual Achievement Test – Second Edition, Australian Standardised Edition (WIAT-II Australian) (Wechsler, 2007) was administered to assess children's academic achievement in mathematics. Two subtests, numerical operations and maths reasoning, were initially included for this purpose; however, numerical operations proved too challenging for many participants, so its use was discontinued after collecting data from just 48 children. In the maths reasoning subtest, early items rely on children's ability to create and solve simple problems using whole numbers, and to use grids and graphs to make comparisons and answer questions. Later items become progressively more difficult, requiring use of quantities less than a whole and use of theoretical and experimental probability to make predictions and answer questions. Good split-half reliabilities for the maths reasoning subtest are reported in the test manual for children aged 5 years (.89) to 6 years (.94). Children's performance on this subtest was measured in terms of their number of correct responses (raw score) and percentile rank.

Nonverbal cognitive ability.

Nonverbal cognitive ability was assessed using the Wechsler Nonverbal Scale of Ability (WNV) (Wechsler & Naglieri, 2006), which was designed specifically for linguistically diverse populations, including people with hearing loss. The assessment contains four subtests, the results of which combine to provide a full-scale IQ score. For children aged from 4;0 to 7;11, the relevant subtests are: matrices, coding, object assembly, and recognition. In matrices, children select one of five optional geometric designs to complete a pattern on each trial. For coding, they use a key provided in the test booklet to copy symbols paired with geometric shapes under time pressure (duration 120 seconds). In object assembly children are presented with an array of puzzle pieces (from 2 to 8) on each trial, which they must assemble to create a recognisable object. The final subtest is a recognition memory task. The child is shown a geometric design for 3 seconds, which is then removed from view. A set of similar designs is then presented to the child, whose task is to select the one seen previously. Children's scores on these four subtests were combined according to instructions in the test manual to compute full-scale nonverbal IQ scores, which are used for description and analysis purposes. As reported in the test manual, WNV full scale scores have excellent test-retest reliability, from .90 to .92 (U.S. normative sample) in the target age range of 4 to 7 years.

Procedure

The data reported in this paper were collected when children reached a chronological age of approximately 5 years. Although there was some variation in age at testing across individual children and tasks (range: 57 to 68 months for PPVT-4; and 60 to 73 months for CTOPP, PAT, WJ III® DRB, and WIAT-II Australian), the vast majority of assessments measuring language, PA, reading and mathematical ability (95.0%) were conducted between 60 to 64 months of age. The only assessment task that differed from this general pattern was the WNV, which was administered at ages ranging from 59 to 98 months (M = 70.7; SD = 10.4). Even for this assessment, however, the majority of children (75.5%) were tested within an 18-month timespan (from 60 to 77 months of age inclusive). Furthermore, standardized (full scale IQ) scores were used to minimize interpretive difficulties resulting from variation in age at testing.

A team of research speech pathologists directly assessed children in their homes or educational settings. As mentioned earlier, all standardized assessments were administered using spoken English according to the guidelines provided in the respective test manuals. During evaluations, children wore HAs and/or CIs at their personal settings. As far as possible, research speech pathologists were blinded to children's severity of hearing loss and hearing device settings. All response forms for the primary measures of PA (CTOPP) and reading (WJ III® DRB) were double-scored by the first author.

Statistical considerations and preliminary data analysis

In line with our primary aim of investigating the concurrent associations between PA, early reading skill, and a range of potentially important cognitive-linguistic and demographic variables, an initial statistical analysis was conducted using the Pearson's product-moment correlational procedure (Pearson's r). Not all of the variables described in Table 1 were included in the correlation analysis, primarily because they measured related characteristics. Thus, maternal education level was included in preference to both socio-economic status and level of paternal education, because level of maternal education was more evenly distributed across the participant sample than was socio-economic status, and it was significantly correlated with level of paternal education (r [N = 92] = .44, p < .001) but with fewer missing data points. Degree of hearing loss (4FA HL) was included in preference to device use (HA or CI), because the two variables were highly correlated (r [N = 100] = .89, p < .001), and the former variable was continuous in nature rather than categorical. Age at fitting of HAs was included in preference to age at diagnosis of hearing loss, because the two variables were highly correlated (r [N = 100] = .85, p < .001), and the former variable was considered to be more directly relevant to the research questions. Because all children in the sample, even those who eventually received a CI, were fitted with HAs initially, correlational analyses involving age at fitting were based on data for the entire sample. Importantly, however, when these correlations were recomputed using data from the smaller set of participants who were still using HAs at 5 years of age, there was just one difference in the pattern of significant findings. The correlation between age at HA fitting and 4FA HL was no longer significant (r [N = 71] = .01), reflecting the decrease in variability in hearing loss within the smaller participant sample due to the omission of most children with a profound loss.

Subsequent to the overall correlational analysis, multiple regression techniques were employed to determine whether PA, as measured on the CTOPP sound matching subtest, was associated with children's early reading skill after controlling for variation in receptive language (PPVT-4 scores), nonverbal cognitive ability (WNV scores), and a range of demographic variables including: gender, 4FA HL, sensory device (HA vs. CI), level of maternal education, age at HA fitting, and age at CI switch-on. CTOPP sound matching was used as the measure of PA, rather than elision or blending words, because it produced the greatest amount of useful data. Thus, 83.7% of children achieved a non-zero score on sound matching, with a majority managing 3 or more correct responses. By contrast, just 54.4% achieved a non-zero score on blending words and 37.9% on elision.

Three measures of early reading were used as dependent variables in the regression analyses: PAT letter knowledge, real word reading (assessed using children's responses to item 10 and items 15 onwards from the WJ III® DRB letter-word identification subtest), and WJ III® DRB word attack (letter and non-word reading). The passage comprehension subtest of the WJ III® DRB was not included as a dependent variable because approximately 38% of participants were unable to respond correctly to any items beyond the first four on this subtest. These initial items assess the ability to match a rebus (or pictographic representation of a word) to a picture of an object rather than the ability to comprehend written language, thus complicating interpretation of children's outcomes on the assessment. In the event that evidence of a positive association between PA and reading would be found, a further aim of the research was to investigate the specificity of that relationship. To this end, an analogous multiple regression was computed to examine the association between PA and maths reasoning ability. Finally, findings from the multiple regressions described above and two additional regression analyses were used to identify the demographic variables associated with children's outcomes in receptive vocabulary, PA, reading, and mathematical ability. For this purpose, PPVT-4 scores were used as the dependent measure of receptive vocabulary, and CTOPP sound matching as the dependent measure of PA.

All correlations and regression analyses were performed using SPSS and R (R Development Core Team, 2011). In line with standard practice, a Type I error rate of $\alpha = .05$

(two-tailed) was adopted for regression analyses. A more conservative rate of α = .01 (two-tailed) was deemed appropriate in evaluating the statistical significance of correlations, however, due to the large number of individual correlations computed and the associated increase in likelihood of making a Type I error (i.e., rejecting the null hypothesis when it is true).

Results

Mean scores achieved on formal assessments by the group of 101 included participants are shown in Table 2 along with participant numbers on which the means are based. On some occasions, individual tests other than the CTOPP were not administered to participants, thereby resulting in a small number of missing data points (*M* = 4.1%), which ranged from a low of 1.0% (*n* = 1) on the letter knowledge subtest of the PAT, to a high of 6.9% (*n* = 7) on the WIAT-II and the WNV.

Insert Table 2 about here

PPVT-4 scores show that children knew about 69 words on average, although there was marked variability between participants, with individual scores ranging from 4 to 112. In general, children's vocabulary knowledge was below age expectations, with half of the sample achieving PPVT scores that placed them in the bottom 27% of the normative distribution (see Table 2). Developmental delay was also apparent with respect to maths reasoning ability, with half of the sample achieving scores that placed them in the bottom 19% of the normative distribution. By contrast, nonverbal cognitive ability, measured using the WNV, was in the typical range (from 70 to 130) for all but a single child who scored 132, just over 2*SD*s above the mean. Moreover, the distribution of WNV standard scores was approximately normal, and close to expectations for a typically developing group (with *M* = 104.3, *SD* = 12.1, median percentile rank = 61.0).

In regard to reading, the majority of children were in the early stages of development as intended. They knew the names or sounds associated with just under half the letters of the alphabet on average (*M* = 11.98, *SD* = 8.88 for PAT letter knowledge), were generally able to read aloud 3 or 4 simple words at most (*M* = 0.65, *SD* = 2.85 for real word reading), and in over 95% of cases were unable to decode any simple CVC non-words, although they could provide some of the sounds associated with single letters (*M* = 1.57, *SD* = 1.70 for word attack). Their overall pattern of performance was approximately in line with norms reported for the WJ III® DRB subtests, with median percentile ranks of 47.0 for letter-word identification, 51.0 for word attack, and 66.0 for passage comprehension. A markedly different pattern emerged on the CTOPP, however, where 50% of children's scores fell below the 25th percentile (for blending words and sound matching) and below the 16th percentile for elision. Moreover, these PA scores, like the reading scores reported above, undoubtedly overestimate the abilities of children with hearing loss in the wider population, given that 50 children who were unable to cope with the CTOPP test demands were excluded from our final participant sample.

Although children's reading performance was in general at the level we expected, there was one child in our sample whose scores in word identification and passage comprehension placed him at the top of the normal distribution for children of the same age (above the 99.9th percentile for word identification and at the 99.8th percentile for passage comprehension). This child achieved a raw score of 40 on word identification and 16 on passage comprehension, approximately twice that of the next highest scoring participant (scores of 21 and 8 respectively). To avoid distorting the pattern of statistical results in our primary correlation and regression analyses reported below, this child's data were omitted. It is interesting to note, however, that in line with our experimental predictions his exceptional word reading scores were accompanied by well above average PA (elision at the 91st percentile, blending words at the 75th percentile, and sound matching at the 63rd percentile).

Associations between variables

Insert Table 3 about here

As an initial step in examining the relationships between variables, a bivariate correlational analysis was conducted. The results are presented in Table 3. As shown, two demographic variables were significantly correlated with children's assessment outcomes.

1. Children whose mothers had higher levels of education achieved significantly better outcomes in sound matching (r [N = 98] = -.26, p < .01) and reading (r [N = 97] = -.36, p < .001 for PAT letter-knowledge; and r [N = 94] = -.35, p < .001 for letter-word identification).
2. Children with more severe levels of hearing loss achieved significantly poorer outcomes in receptive vocabulary (r [N = 99] = -.44, p < .001) and maths reasoning (r [N = 93] = -.35, p < .001).

None of the remaining demographic variables (gender, age at HA fitting, or age at CI switch-on) were significantly associated with outcomes. The presence of a more severe hearing loss was, however, significantly associated with earlier fitting of HAs (r [N = 100] = -.32, p = .001); and there was a tendency for earlier fitting of HAs to be associated with earlier CI switch-on, although the correlation was not quite significant using our conservative criterion (r [N = 29] = .46, p = .011).

The only other significant correlations reflected positive associations between the various formal assessment measures. Of particular interest in the present context were associations between measures of PA and reading. Multiple regressions were conducted to shed further light on the nature of the relationships between these variables.

Multiple regressions: PA and reading

In the first instance, three measures of reading were used as dependent variables: letter knowledge, real word reading, and word attack. Real word reading scores were used in preference to letter-word identification scores because the latter measure confounded two potentially important variables; namely, letter-name knowledge and word reading ability. A summary of the results is presented in Table 4. The top half of the table provides information about the change in R^2 as each new predictor (or set of predictors) was added to the regression model. Thus, the first row of data indicates the proportion of variance accounted for in a model including only the four demographic variables: gender, 4FA HL, Maternal Education, and Device (HA vs. CI); the second row indicates the additional proportion of variance accounted for when age at HA fitting and age at CI switch-on were added to the model; the third row indicates the additional proportion of variance accounted for when nonverbal cognitive ability was added; and so forth. The bottom half of the table relates specifically to the final regression model, which included all predictors. It presents the regression coefficients associated with each individual predictor and their statistical significance.

Insert Table 4 about here

The three regression analyses confirm our primary research hypothesis, that PA would be associated with early reading skill after controlling for variation in receptive language, nonverbal cognitive ability, and a range of relevant demographic variables. Thus, PA accounted for significant unique variance of 4% in letter knowledge, 18% in real word reading, and 7% in word attack when added to the final regression model (i.e., after all other predictors had been added). These percentages increased to 27.3% for real word reading and 16.1% for word attack when PA was added to the model *before* letter knowledge. The regression coefficients show further that for each additional correct response in the CTOPP sound-matching task, letter knowledge raw score would be expected to increase by 0.606, real word reading by 0.240, and word attack by 0.150.

Having demonstrated a positive relationship between PA and word reading, it remained to determine whether the association was specific to reading, or would generalise to another academic skill. To this end, an analogous multiple regression was conducted with maths reasoning as the dependent variable. Predictor variables were entered according to the same regression models as those used for the reading measures, but the pattern of results was markedly different. PA accounted for no unique variance when entered in the final regression model, and was associated with a non-significant regression coefficient of 0.094 (see Table 5). The predictor variables that accounted for the most variance in maths reasoning were nonverbal cognitive ability and receptive vocabulary, both of which were significant in the final model with *regression coefficients* of 0.079 ($p < .01$) for nonverbal cognitive ability, and 0.078 ($p < .01$) for receptive vocabulary.

Insert Table 5 about here

Multiple regressions: Demographic variables and outcomes

A further aim of the research was to identify the demographic variables associated with children's outcomes in PA, reading, and related variables. Gender, degree of hearing loss, and level of maternal education were always entered as a block in the first regression model. They accounted for significant variance in receptive vocabulary ($R^2 = .24$, $p < .001$), maths reasoning ($R^2 = .17$, $p < .01$), sound matching ($R^2 = .10$, $p < .05$), and letter knowledge ($R^2 = .13$, $p < .01$). The individual predictor variables responsible for these effects were degree of hearing loss and level of maternal education (for receptive vocabulary and maths reasoning), and level of maternal education (for letter knowledge and PA). As additional predictors were added to the regression models, however, the unique contribution made by these and other demographic variables changed until, in the final regression models (which included all predictor variables), two significant effects were evident.

1. Children whose mothers had completed post-secondary education knew more letters on average than children whose mothers had 12 years or less formal schooling (regression coefficient = -4.899, $p < .05$) (see Table 4).
2. Children with more severe hearing losses (4FA HL) achieved inferior receptive vocabulary scores (regression coefficient = -0.265, $p < .001$) (see Table 5).

Inspection of Tables 4 and 5 shows that the two remaining demographic variables, age at HA fitting and age at CI switch-on, accounted for minimal additional variance across the range of outcome measures when added to the second regression model. Furthermore, although age at CI switch-on was a significant predictor in the final regression models for both letter knowledge and receptive vocabulary, the findings were inconsistent. In the case of receptive vocabulary, earlier age at switch-on was associated with better outcomes as expected (*regression coefficient* = -0.740, $p < .05$) (see Table 5). By contrast, for letter knowledge, better outcomes were unexpectedly associated with an *increase* in age at switch-on (*regression coefficient* = 0.329, $p < .05$) (see Table 4).

Discussion

The primary aims of this research were to investigate the concurrent association between PA and early reading skill in children with hearing loss, and to identify the demographic variables associated with children's PA and reading-related outcomes. Data from a total of 101 children were analysed to address three specific questions. (1) Would PA be associated with early reading skill in 5-year-old children with hearing loss after controlling for variation in receptive vocabulary, nonverbal cognitive ability, and a range of relevant demographic variables? (2) Would any observed association with PA be specific to early reading or generalise to another academic skill, in particular, maths reasoning ability? (3) Which if any, demographic variables would be associated with children's outcomes in PA, reading, and related abilities?

With regard to the first of these questions, the results of multiple regression analyses show that PA, as measured using the sound matching subtest of the CTOPP, accounted for significant, unique variance in several measures of early reading skill after controlling for variation in receptive vocabulary, nonverbal cognitive ability, and a range of demographic variables including gender, degree of hearing loss, level of maternal education, type of sensory device (HA vs. CI), and age at fitting of sensory devices. This relationship was evident when reading was measured in terms of (1) knowledge of letter names or sounds, (2) the ability to recognise or read single words aloud, and (3) the ability to recognise and produce sounds associated with single letters and to read non-words aloud.

A further multiple regression was conducted to address our second research question concerning whether the observed association with PA would generalise to another academic skill, namely, maths reasoning. This analysis showed convincingly that PA did not account for significant unique variance in maths reasoning ability; thus supporting the view that PA was related specifically to aspects of early reading.

Our third and final research question concerned the role of demographic variables, both audiological and child- and family-related, in predicting children's outcomes across the range of PA, reading, and related assessments. There was considerable variation in this aspect of the results. None of the included demographic variables directly predicted concurrent performance in real word reading or word attack after all variables had been entered. Similarly, for maths reasoning and PA, the only demographic variable to account for significant unique variance was cognitive ability. The remaining two outcome measures showed a different pattern. Better outcomes in receptive vocabulary were associated with milder levels of hearing loss and earlier age at CI switch-on, as expected. On the other hand, although better outcomes in letter knowledge were associated with higher levels of maternal education as predicted, age at CI switch-on was also a significant predictor, but the association was in the opposite direction from that predicted (i.e., better letter knowledge was associated with later switch-on).

Our finding of a positive association between PA and reading in children with hearing loss is consistent with a number of previous investigations in the area (e.g., Colin et al., 2007; Dillon et al., 2012; Dyer et al., 2003; Easterbrooks et al., 2008; Harris & Beech, 1998; Spencer & Tomblin, 2009). In particular, the results we obtained for real-word reading and word attack are generally in line with Mayberry et al.'s (2011) meta-analysis of 25 studies, in which they found that approximately 11% of the variance in reading, on average, could be explained by performance on tasks assessing phonological coding and analysis skills. In our study, PA accounted for 17% of unique variance in real word reading and 7% in word attack.

Despite this general similarity, findings obtained in the current investigation also differed from those reported by Mayberry et al. (2011), in that they found a stronger association between language ability and reading than between phonological skills and reading in a subset of seven studies that investigated the role of both variables. More specifically, Mayberry et al. reported that language ability accounted for an average of 35% of the variance in reading ability in this small subset of studies. By contrast, in the current investigation, after controlling for the influence of all other variables, language ability, in the form of receptive vocabulary, accounted for unique variance in only one of the three reading measures, knowledge of letter names and sounds (see Table 4). This difference between our study and the meta-analysis reported by Mayberry et al. probably reflects in part differences between participants and the measures of reading ability used. Whereas our focus was on young children's early single-word reading skills in the form of recognition and oral reading, the majority of studies summarised by Mayberry et al. employed measures of reading comprehension and focused on older children, adolescents, or adults.

The current findings extend previous research in two important ways. First, they demonstrate an association between PA and specific aspects of early reading skill in children who were assessed as close as possible to 5 years of age, on average. By contrast, many previous studies spanned a wide range of ages, from 5 to 7 years old through to 14 to 18 years (e.g., Dillon et al., 2012; Johnson & Goswami, 2010; Spencer & Tomblin, 2009). Because our participants were young and homogeneous with respect to age, we maximised the likelihood that the majority were in the earliest stages of reading development; that is, they could provide the names or sounds associated with just half the letters of the alphabet on average, and were typically able to read only one or two highly frequent real words, if any. Hence, it would seem unlikely that the associations we observed between PA and early reading ability could be attributed to the influence of reading instruction, which has been argued to have a greater impact as children get older (e.g., Kyle & Harris, 2010; Musselman, 2000).

A second way in which the findings extend previous research lies in the different pattern of results obtained for outcomes in maths reasoning ability as compared to early reading. Theoretical interpretation of the association between PA and reading is generally based on the assumption that the association is specific, and should not generalise to other academic skills; however, most previous studies of children with hearing loss have not tested this assumption directly. Importantly, the findings obtained in this investigation provide clear evidence of this specificity. Multiple regression analyses show that PA was a significant predictor of concurrent letter knowledge, real word reading, and word attack, but did not account for significant, unique variance in maths reasoning skill. On the other hand, nonverbal cognitive ability was a significant predictor of concurrent maths reasoning skill, but did not account for significant, unique variance in the three reading measures. There was, however, a common predictor of reading and maths outcomes; namely, receptive vocabulary, which accounted for significant unique variance in maths reasoning and letter knowledge. Purpura, Hume, Sims, and Lonigan (2011), also found that vocabulary predicted children's mathematical ability both concurrently and 1 year later. As in their study, associations observed in the current investigation presumably reflect the verbal nature of the problems used to assess maths outcomes and the need to identify and understand the meanings of printed numbers, mathematical terms, and symbols (Purpura et al., 2011).

As discussed above, our finding that PA predicted significant unique variance in specific early reading skills of children with hearing loss is consistent with results from a range of previous investigations. It stands in opposition to other research however, that has shown either no association between PA and reading (e.g., Clark et al., 2011; Gibbs, 2004; Izzo, 2002; McQuarrie & Parrila, 2009), or an association mediated entirely by variation in a third variable, such as degree of hearing loss or vocabulary knowledge (e.g., Kyle & Harris, 2006; Johnson & Goswami, 2010). To help understand this variability between studies, the current research explored the simultaneous influence of various cognitive-linguistic and demographic variables on children's PA, reading, and related outcomes.

Our findings showed that children's outcomes were not related to gender or age at HA fitting, and were inconsistently related to age at CI switch-on. These results conflict with some reported previously in the literature, showing better reading outcomes in females than males (e.g., Geers, 2003), and better reading, PA, and vocabulary outcomes in children who received their CIs earlier rather than later (e.g., Connor & Zwolan, 2004; James et al., 2008; Johnson & Goswami, 2010). Age at cochlear implantation was, however, later and more variable in these three previous studies than in the current investigation. Implant ages ranged from 2 to 7 years old in the study by James et al. (2008) from <3 to 14 years in Connor and Zwolan's (2004) study, and from 1.5 to 9 years in Johnson and Goswami's (2010) investigation. By contrast, in the current study, all children with CIs had their devices switched on before 4 years of age. It seems likely that the increased variation in age at implantation, which was afforded through inclusion of a larger proportion of children with later implants, provided a greater opportunity to observe consistently negative effects in previous studies (Ambrose, Fey, & Eisenberg, 2012). In regard to what this might mean for the association between PA and reading, one possibility is that including a larger proportion of children with *earlier* CIs (as in the current study) could strengthen the observed association as a result of children's improved access to speech at an earlier age.

Consistent with findings reported by Kyle and Harris (2006), degree of hearing loss was significantly associated with children's outcomes in the current study. In particular, more severe hearing losses were associated with lower receptive vocabulary scores. On the other hand, degree of hearing loss was not linked to either reading or PA outcomes in spite of the increased variability in hearing loss (from mild to profound) in this study compared to earlier ones (e.g., Colin et al., 2007; Dyer et al., 2003).

Consistent with previous research by Geers (2003) suggesting that children with more highly educated parents achieved better reading outcomes, level of maternal education was also associated with children’s outcomes in the current study. In particular, children whose mothers had completed post-secondary education knew more letters’ names or sounds than children whose mothers had 12 years or less formal schooling. No similar association was observed for real word reading or word attack, a pattern that undoubtedly reflects the young age of participants in this study and their early stage of reading development; that is, participants were still in the process of learning the names and sounds associated with individual letters, having acquired fewer than half on average. The nature of this association could well change over the next few years as the focus of children’s learning shifts from letters to words and passages. Regardless of a possible developmental change, however, the current findings suggest that variability in the outcomes of studies investigating reading in children with hearing loss might result from a failure to control for level of maternal education.

Although we cannot attribute causality on the basis of our current data, it is possible that the association we have observed between PA and letter knowledge might reflect a role for PA in enabling children to understand the logic underlying the mapping of orthography onto phonology, which in turn could facilitate the acquisition of grapheme-phoneme (or letter-sound) associations. Notably, findings consistent with this interpretation were obtained in a recent training study of Portuguese-speaking children with normal hearing (Cardoso-Martins, Mesquita, & Ehri, 2011).

PA also accounted for significant, unique variance in children’s recognition and oral reading of single words and non-words after controlling for variation in knowledge of letters’ names or sounds. This association might reflect use of a (more effective) phonic reading strategy in children with superior PA, or it could reflect the high quality, segmentalised nature of their lexical–phonological representations more generally (e.g., Metsala, 1999; Walley, 1993). One might argue that the latter interpretation is less likely however, on the grounds that high quality, segmentalised lexical-phonological representations would typically be associated with an expanded vocabulary, yet PA accounted for significant unique variance in oral reading after controlling for vocabulary knowledge, a finding also reported by Dillon et al. (2012).

This investigation of the association between PA and reading in children with hearing loss has a number of advantages over previous investigations. Whereas the previous published literature has been dominated by relatively small-sample studies of children who often varied widely in age at testing, our major analyses were conducted on a large sample of participants, all of whom were in the earliest stages of reading development. Use of a large sample meant that we could simultaneously evaluate the influence of a range of demographic and cognitive-linguistic variables that have not always been examined in previous studies. Furthermore, nearly 95% of participants were assessed between 60 and 64 months of age, thereby avoiding difficulties inherent in trying to assess and compare reading skills in children of markedly different chronological and reading ages. Finally, the association between PA and reading was replicated using three different measures of early letter, word, and non-word reading, thus confirming the reliability of the findings.

Limitations

Despite the current study's strengths, a number of limitations and suggestions for extension and improvement are also apparent. First, the results cannot be generalised beyond the population of children who are fitted with HAs or CIs and use primarily spoken language to communicate. Further research would be necessary to enable generalisation to children who prefer to communicate using sign language. Second, the findings cannot be generalised to measures of reading skill that reflect comprehension processes at the level of single words, sentences, or texts, since our focus was on aspects of early reading related to the recognition and oral reading of single words, non-words, and letters. Third, since this research was correlational in nature, it does not provide evidence regarding the direction of the causal link between PA and reading; that is, whether higher levels of PA lead to better reading skills, or vice versa. The only way to provide such evidence is through the use of tightly controlled and targeted intervention studies.

In regard to use of the CTOPP as a measure of PA, questions might be raised regarding the influence on children's performance of hearing loss and speech ability (e.g., Mayberry et al., 2011). Thus, in all three subtests used here, accurate performance depended on children's ability to hear spoken stimuli; and in two of the subtests (elision and blending words), children were required to respond orally. If children's performance in the PA tasks were influenced by a difficulty in hearing the stimuli, we might have expected to find an association between PA and degree of hearing loss, but no such association was evident for any of the PA subtests. With respect to speech ability, our use of sound matching (which employed a picture-pointing response) as the measure of PA in multiple regression analyses effectively eliminated the potential confound. There remains, however, a question regarding the use of orthographic strategies in matching tasks that supposedly target phonology (e.g., McQuarrie & Parrila, 2009; Sterne & Goswami, 2000). In the current study, there is a possibility that children heard the words as spoken by the examiner, imagined what they would look like in print, then made their similarity judgements based on shared letters rather than shared sounds (Harris & Beech, 1998). Although we acknowledge the potential for use of such a strategy, we believe it would be unlikely in this investigation given the incomplete nature of children's letter knowledge and their early stage of reading development.

Although the results of this investigation show that PA is uniquely predictive of certain aspects of early reading in 5-year-old children with hearing loss, they do not provide strong evidence for a specific concurrent association between receptive vocabulary and reading ability, except perhaps for learning the names or sounds associated with individual letters, which is in itself a specific type of vocabulary acquisition. It remains possible, however, that children's vocabulary at age 5 might be associated with their reading ability measured at some later stage in development. In this regard, our data show that children were performing relatively better in assessments of early reading (with median percentile ranks from 47 to 66) than either early PA (median percentile ranks from 16 to 25) or early vocabulary (median percentile rank of 27). This relative strength in reading presumably reflects the combined influence of two related factors: first, that even children in the normative sample perform poorly in reading tasks at 5 years of age; and second, that children with hearing loss get progressively further behind in reading as they get older (e.g., Easterbrooks et al., 2008; Kyle & Harris, 2010). This overall pattern of results raises the possibility that any reduction in children's rate of reading development in the future might be linked to their inferior PA or their inferior vocabulary as documented here. This question can only be examined through future longitudinal research.

The collection of longitudinal data would also enable the investigation of aspects that could not be studied here due to participants' young age and early stage of reading development. One example is the extent to which the relationship we have observed between PA and reading would generalise to different types of PA (e.g., elision, blending, sound matching) and different aspects of reading (e.g., oral reading accuracy and fluency, silent reading comprehension). A second example is the extent to which children with an early observed weakness in PA might compensate for that weakness with a subsequent emphasis on visual-orthographic processes in word recognition.

Conclusion

In conclusion, the results of the current investigation provide clear evidence for a concurrent association between PA and specific aspects of early reading skill in a large sample of 5–year-old children with hearing loss. Children's outcomes in real word reading and word attack were predicted by a combination of concurrent letter knowledge and PA; while letter knowledge was predicted by a combination of concurrent PA, vocabulary, and level of maternal education). These findings extend those previously reported in the published literature in demonstrating that the association between PA and reading held after simultaneously controlling for variation in children's vocabulary, nonverbal cognitive ability, gender, degree of hearing loss, maternal education, type of sensory device, and age at fitting of sensory devices. Moreover, the association was specific to measures of early reading (letter knowledge, real word reading, and word attack), and did not generalise to another academic ability, maths reasoning. We infer that the association reflects an important role for PA in the development of alphabetic reading skills.

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Table 1.

Participants' background information (*N* = 101)

Variable		**Frequency or Mean Score**[a]
Gender		
	Male	60 (59.4%)
	Female	41 (40.6%)
Age at Diagnosis (mths) (*n* = 100)		Mean = 11.0; SD = 10.9; Range = 0 – 36
4FA Hearing Loss		Mean = 72.1; SD = 35.2; Range = 24 - 120
Degree Hearing Loss (No. of participants)		
	Mild (20-40 dB)	15 (14.9%)
	Moderate (41-60 dB)	44 (43.6%)
	Severe (61-80 dB)	6 (5.9%)
	Profound (>80 dB)	36 (35.7%)
Device Use (No. of participants)		
	Hearing Aid	71 (70.3%)
	Cochlear Implant	30 (29.7%)
Age at Hearing Aid Fitting (mths)		
	All participants	Mean = 14.7; SD = 11.1; Range = 1 - 36
	Hearing Aid users only (*n* = 71)	Mean = 17.3; SD = 11.3; Range = 1 – 36
Age at CI Switch On (mths) (*n* = 30)		Mean = 22.3; SD = 12.1; Range = 7 - 46
Socio-Economic Status: IRSAD		Mean = 7.3; SD = 2.5; Range = 1 - 10
		Scores ≥ 7 = 70.3%

Maternal Education (n = 99)	
1. University Qualification	42 (42.4%)
2. Diploma or Certificate	28 (28.3%)
3. 12 years or less of schooling	29 (29.3%)
Paternal Education (n = 92)	
1. University Qualification	37 (40.2%)
2. Diploma or Certificate	32 (34.8%)
3. 12 years or less of schooling	23 (25.0%)
Communication Mode - Home (n = 100)	
Oral only	95 (95.0%)
Simultaneous communication	3 (3.0%)
Bilingual	2 (2.0%)
Communication Mode - Early Int[n] (n = 97)	
Oral only	88 (90.7%)
Simultaneous communication	9 (9.3%)

Note: 4FA Hearing Loss = the average of hearing threshold levels at 0.5, 1, 2, and 4 KHz, represented non-linearly.

[a]Due to missing data for some variables, scores are based on different numbers of participants as follows: Age at Diagnosis, n = 100; Maternal Education, n = 99; Paternal Education, n = 92; Communication Mode at Home, n = 100; Communication mode in Early Intervention, n = 97.

Table 2.

Mean scores, standard deviations, ranges and median percentile ranks for all assessment tools (maximum *N* = 101)

Variable and Test	Measure			
	N (age[a])	Mean (SD)[b]	Range	Percentile[c]
Receptive Vocabulary: PPVT	99 (61.3)	68.83 (22.51)	4 - 112	27.0
PA: CTOPP				
Elision	101 (61.8)	0.98 (1.54)	0 - 8	16.0
Blending Words	101 (61.8)	1.44 (2.13)	0 - 13	25.0
Sound Matching	101 (61.8)	3.31 (3.29)	0 - 18	25.0
Reading: PAT Letter Knowledge	100 (61.6)	11.98 (8.88)	0 - 26	25.0
Reading: WJ III® DRB				
Letter-Word Identification	97 (61.8)	8.20 (6.05)	0 - 40	47.0
[Real Word Reading	97 (61.8)	0.65 (2.85)	0 - 27	N/A]
Word Attack	96 (61.7)	1.57 (1.70)	0 - 9	51.0
Passage Comprehension	98 (61.7)	5.16 (1.69)	1 - 16	66.0
Maths Reasoning: WIAT-II Australian	94 (61.7)	8.56 (4.13)	0 - 21	19.0
Cognitive Ability: WNV Full Scale IQ	94 (70.7)	104.34 (12.10)	74 - 132	61.0

Note. Real word reading represents an alternative, non-standardised, scoring method for data collected in the letter-word identification subtest of the WJ III® DRB. It is the number of correct recognition and oral reading responses to real-word test items (items 10 and 15 onwards).

[a]Mean age at testing in months;

[b]Means were computed using raw scores for all assessments except the WNV, where standardised (Full Scale IQ) scores were used;

[c]Percentile ranks are medians.

Table 3.

Bivariate correlations (Pearson's *r*) between demographic variables and formal assessment measures (No. paired observations in parentheses)

	MatEd	**4FAHL**	**AgeHA**	**AgeSO**	**PPVT-4**	**Elision**	**Blend**	**SMatch**	**PATLK**	**WordID**	**RWRead**	**WordAtt**	**Comp^n**	**Maths**	**NVIQ**
Gender	.00	.22	-.20	-.14	-.08	-.08	-.17	-.12	.04	.02	-.11	-.13	-.08	-.04	.09
	(98)	(100)	(100)	(29)	(99)	(100)	(100)	(100)	(99)	(96)	(96)	(95)	(97)	(93)	(93)
MatEd	1.00	-.02	.12	-.02	-.19	-.19	-.20	**-.26****	**-.36*****	**-.35*****	-.18	-.25	-.23	-.21	-.25
	(98)	(98)	(98)	(27)	(97)	(98)	(98)	**(98)**	**(97)**	**(94)**	(94)	(93)	(95)	(92)	(91)
4FAHL		1.00	**-.32*****	--- [a]	**-.44*****	-.23	-.19	-.14	.03	-.02	-.03	-.08	-.01	**-.35*****	-.11
		(100)	**(100)**		**(99)**	(100)	(100)	(100)	(99)	(96)	(96)	(95)	(97)	**(93)**	(93)
AgeHA			1.00	.46	.07	.03	.04	.13	-.07	.01	.13	-.02	-.13	-.05	.03
			(100)	(29)	(99)	(100)	(100)	(100)	(99)	(96)	(96)	(95)	(97)	(93)	(93)
AgeSO				1.00	-.38	-.31	-.13	-.28	.24	.16	.02	.02	-.01	-.24	-.01
				(29)	(29)	(29)	(29)	(29)	(28)	(28)	(28)	(28)	(28)	(27)	(28)
PPVT-4					1.00	**.63*****	**.42*****	**.34*****	**.33*****	**.37*****	**.26****	**.36*****	.21	**.65*****	**.34*****
					(99)	**(99)**	**(99)**	**(99)**	**(98)**	**(95)**	**(95)**	**(94)**	(96)	**(92)**	**(92)**

	MatEd	4FAHL	AgeHA	AgeSO	PPVT-4	Elision	Blend	SMatch	PATLK	WordID	RWRead	WordAtt	Comp^n	Maths	NVIQ
Elision						1.00	**.41*** **	**.53*** **	**.36*** **	**.34*** **	**.47*** **	**.50*** **	.15	**.48*** **	.26
						(100)	**(100)**	**(100)**	**(99)**	**(96)**	**(96)**	**(95)**	(97)	**(93)**	(93)
Blend							1.00	**.53*** **	**.28** **	**.40*** **	**.52*** **	**.47*** **	.08	**.44*** **	**.32** **
							(100)	**(100)**	**(99)**	**(96)**	**(96)**	**(95)**	(97)	**(93)**	**(93)**
SMatch								1.00	**.31** **	**.42*** **	**.62*** **	**.52*** **	.15	**.34*** **	**.32** **
								(100)	**(99)**	**(96)**	**(96)**	**(95)**	(97)	**(93)**	**(93)**
PATLK									1.00	**.88*** **	**.52*** **	**.63*** **	.14	**.38*** **	.16
									(99)	**(95)**	**(95)**	**(94)**	(96)	**(92)**	(92)
WordID										1.00	**.70*** **	**.61*** **	.12	**.31** **	.19
										(96)	**(96)**	**(95)**	(96)	**(92)**	(89)
RWRead											1.00	**.66*** **	.01	**.29** **	.20
											(96)	**(95)**	(96)	**(92)**	(89)
WordAtt												1.00	.13	**.44*** **	.19
												(95)	(95)	**(91)**	(88)

	MatEd	**4FAHL**	**AgeHA**	**AgeSO**	**PPVT-4**	**Elision**	**Blend**	**SMatch**	**PATLK**	**WordID**	**RWRead**	**WordAtt**	**Comp^n**	**Maths**	**NVIQ**
Comp^n													1.00	.25	.16
													(97)	(93)	(90)
Maths														1.00	**.47*****
														(93)	**(86)**

Note. Gender (1 = male; 2 = female); MatEd = Maternal Education (1 = university; 2 = diploma/certificate; 3 = 12 years or less schooling); 4FAHL = 4 Frequency Average Hearing Loss in the better ear; AgeHA = Age at HA fitting; AgeSO = Age at CI switch-on; PPVT-4 = PPVT-4 Receptive vocabulary raw score; Elision = CTOPP Elision raw score; Blend = CTOPP Blending Words raw score; SMatch = CTOPP Sound Matching raw score; PATLK = PAT Letter Knowledge raw score; WordID = WJ III® DRB Letter-Word Identification raw score; RWRead = number of real words read correctly for test items 10 and 15 onwards on the WJ III® DRB letter-word identification subtest; WordAtt = WJ III® DRB Word Attack raw score; Comp^n = WJ III® DRB Passage Comprehension raw score; Maths = WIAT-II Australian Maths Reasoning raw score; NVIQ = WNV Full scale IQ.

[a]4FAHL = 120 for all children with CIs.

** = $p \leq .01$; *** = $p \leq .001$

Table 4

Multiple regression summary table for outcomes in early word and non-word reading

Predictors	Dependent Variable: Letter Knowledge	Real Word Reading[a]	Word Attack
		R^2 change	
Gender, 4FAHL, MatEd	**.13****	.05	.08
AgeHA, AgeSO[b]	.02	.02	.00
Cognitive Ability (WNV)	.01	.03	.02
Receptive Vocab (PPVT-4)	**.12*****	**.05***	**.09****
Letter Knowledge (PAT)	**.....**[c]	**.20*****	**.26*****
PA (CTOPP Sound matching)	**.04***	**.18*****	**.07*****
Total R^2	**.31*****	**.52*****	**.53*****
N	99	96	95
		Regression coefficients	
Gender (reference male)	1.135	-0.216	-0.363
4FAHL	0.042	0.004	-0.001
MatEd (reference Uni)			
Certificate or Diploma	-3.464	0.136	-0.089
12 years or less	**-4.899***	0.280	0.100
AgeHA	-0.053	0.013	-0.011
AgeSO	**0.329***	0.000	0.000
Cognitive Ability (WNV)	-0.061	0.003	0.001

Receptive Vocabulary (PPVT)	**0.145*** **	0.000	0.006
Letter Knowledge (PAT)	**......[c]**	**0.070*** **	**0.087*** **
PA (CTOPP Sound Matching)	**0.606***	**0.240*** **	**0.150*** **

Note. Regression coefficients are for the final model containing all predictor variables; Letter knowledge subtest is from the PAT; Word attack is from the WJ III® DRB.

[a]Real word reading = number of correct reading responses to real words (test items 10 and 15 onwards) on the letter-word identification subtest of the WJ III® DRB.

[b]Because age at switch-on was available only for participants with CIs there were numerous, non-random, missing data points, which were replaced with the average value for this variable. This strategy leaves the regression coefficient unchanged from a model in which the data are missing.

[c]This model does not apply because a dependent variable cannot be used to predict itself.

* = $p < .05$, ** = $p < .01$, *** = $p \leq .001$.

Table 5

Multiple regression summary table for outcomes in maths reasoning, receptive vocabulary and PA

	Dependent Variable		
Predictors	Maths Reasoning	Receptive Vocab	Sound Matching
		R^2 change	
Gender, 4FAHL, MatEd, Device	**.17****	**.24*****	**.10***
Age at HA fit, Age at CI on	.03	.04	.04
Cognitive Ability (WNV)	**.12*****	**.06****	**.07****
Receptive Vocab (PPVT-4)	**.18*****	.....	.03
Letter Knowledge (PAT)	**.02***	**.09*****	**.04***
PA (CTOPP Sound Matching)	.00	.01	.....
Total R^2	**.52*****	**.43*****	**.27*****
N	93	99	100
		Regression coefficients	
Gender (reference male)	-0.220	-0.994	-0.754
4FAHL	-0.020	**-0.265*****	0.001
MatEd (reference Uni)			
Certificate or Diploma	-0.041	2.688	-0.003
12 years or less	0.282	-0.932	-0.988
AgeHA	-0.057	-0.068	0.046
AgeSO	0.010	**-0.740***	-0.084
Cognitive Ability (WNV)	**0.079****	**0.399***	**0.062***

Receptive Vocabulary (PPVT)	**0.078*** **	**.....**	0.016
Letter Knowledge (PAT)	0.075	**0.790*** **	**0.087***
PA (CTOPP Sound Matching)	0.094	0.611	.....

Note. Regression coefficients are for the final model containing all predictor variables.

* = $p < .05$, ** = $p < .01$, *** = $p \leq .001$.