Predictors of Early Reading Skill in 5-Year-Old Children With Hearing Loss Who Use Spoken Language

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ABSTRACT

This research investigated the concurrent association between early reading skills and phonological awareness (PA), print knowledge, language, cognitive, and demographic variables in 101 five-year-old children with prelingual hearing losses ranging from mild to profound who communicated primarily via spoken language. All participants were fitted with hearing aids (n = 71) or cochlear implants (n = 30). The participants completed standardized assessments of PA, receptive vocabulary, letter knowledge, word and nonword reading, passage comprehension, math reasoning, and nonverbal cognitive ability. Multiple regressions revealed that PA (assessed using judgments 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/nonwords) after controlling for variation in receptive vocabulary, nonverbal cognitive ability, and a range of demographic variables, including gender, degree of hearing loss, communication mode, 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 reading and did not generalize to another academic ability, math reasoning. Additional multiple regressions showed that letter knowledge (names or sounds) was superior in children whose mothers had undertaken postsecondary education and that better receptive vocabulary was associated with less severe hearing loss, use of a cochlear implant, and earlier age at implant switch-on. Earlier fitting of hearing aids or cochlear implants was not, however, significantly associated with better PA or reading outcomes in this cohort of children, most of whom were fitted with sensory devices before 3 years of age.

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 judgments of phonological similarity or difference. Segmentation is the process by which larger phonological units, usually words or nonwords, 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 nonwords (e.g., /f/ + /æ/ + /n/ = *fan*). Finally, judgments of phonological

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similarity or difference 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 subsyllabic units of onset (the initial consonant or consonant cluster) and rime (the vowel and any following consonants), such as /m/ + /æn/ and /sp/ + /æn/.

Since the publication of a seminal study by Bradley and Bryant (1983), numerous investigations have found evidence for a positive association between PA and early reading skill in children with typical development (e.g., Oakhill & Cain, 2012; Tunmer, Herriman, & Nesdale, 1988; Wagner, Torgesen, & 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 nonword 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.

In an alphabetic language, such as English, this association between PA and early reading is presumably underpinned by the child'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 (Cupples & Iacono, 2000). There are, however, several points of controversy regarding the exact nature of the association between PA and reading.

One controversial issue is the direction of the causal relationship between the variables. Although this issue is yet to be resolved, evidence from carefully designed training studies (e.g., Lundberg, Frost, & Peterson, 1988; Schneider, Küspert, Roth, Visé, & Marx, 1997) and comprehensive meta-analyses (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, namely, 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. However, 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 realization that phonological units such as onsets, rimes, and phonemes exist) or with the nature of children's underlying lexical-phonological representations (e.g., Melby-Lervåg et al., 2012; Snowling & Hulme, 1994; Swan & Goswami, 1997). According to the latter view, superior performance on PA tasks reflects the establishment of segmentally based lexical representations (or ordered sequences of phonemic segments), which are thought to 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).

A second question is whether PA is associated specifically with early reading skills or with cognitive ability and/or academic performance more generally. If 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 generalization, 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 these individuals.

Some researchers have emphasized the nature of reading as building on knowledge of spoken language, especially phonology (e.g., Mayer, 2007; Perfetti & Sandak, 2000; Wang, Trezek, Luckner, & Paul, 2008).

According to this view, phonological decoding processes (or the use of grapheme–phoneme rules to sound words out) are important for the development of reading skills in children with hearing loss, as they are for children with normal hearing. Children with hearing loss may, however, acquire these processes through modalities other than audition and speech. 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 labeled the qualitative similarity hypothesis, predicts a positive association between PA and reading in children with hearing loss.

In contrast with this view of reading as building on knowledge of spoken language, other researchers have suggested that proficiency in the use of a natural sign language might provide "the linguistic and cognitive underpinnings for successful use of written language" (McQuarrie & Parrila, 2009, p. 151). Proponents of this theoretical perspective have claimed that "the role of phonology in reading is currently being overstated" (Miller & Clark, 2011, p. 464). Research consistent with this view has documented the use of effective, alternative reading strategies in individuals with hearing loss, which reduce their reliance on phonological decoding skills and PA, such as through increased attention to visual, orthographic, morphological, and syntactic information (e.g., Allen et al., 2009; Clark, Gilbert, & Anderson, 2011; Mayberry, del Giudice, & Lieberman, 2011; McQuarrie & Parrila, 2009; Miller, 2010; Miller & Clark, 2011). 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 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, & Connor, 2008; Harris & Beech, 1998; Spencer & Tomblin, 2009).

Spencer and Tomblin (2009) reported a study of 29 children with prelingual profound hearing loss who were ages 7;2–17;8 (years;months) at the time of testing. All of the children had cochlear implants (CIs), which they received at ages ranging from 1;6 to 10;8. PA was assessed using two subtests from the Comprehensive Test of Phonological Processing (CTOPP; Wagner, Torgesen, & Rashotte, 1999), elision and blending words, and a rhyme judgment task adapted from a study by James et al. (2005). Elision and blending scores were both significantly correlated with reading ability in the form of nonword decoding and written word comprehension. The authors did not, however, investigate whether variation in some other variables (e.g., vocabulary knowledge) might have mediated the observed associations.

A study by Dillon et al. (2012), which also focused on profoundly deaf children with CIs, was not subject to this potential weakness. A total of 27 participants was included. They were between 6.2 and 14.0 years old (mean = 9.1) at the time of testing, having received their CIs at ages ranging from 1 to 6 years old. Bivariate correlations revealed a strong positive association between PA and several measures of reading, including oral reading of nonwords and sentence–picture matching. Dillon et al. 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. In contrast, 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.

Both Spencer and Tomblin (2009) and Dillon et al. (2012) found a positive association between PA and reading despite a difference in their participants' communication modes. Participants in Spencer and Tomblin's study were exposed to total communication ("the combined use of aural, oral, and manual modalities"; p. 4), whereas Dillon et al.'s participants used spoken English to communicate. In an earlier study by Dyer et al. (2003), a significant association between PA and reading was also reported for a sample of 49 teenagers with severe or profound hearing loss, who did not have CIs, and who used sign-supported English and British Sign Language to communicate. It might have been expected that this group of participants would be less likely to show an association between PA and reading because of a potentially greater reliance on visual than sound-based reading processes. The generalizability of Dyer et al.'s findings might be questioned, however, on the grounds that participants were selected to have at least a 6-year-old level of reading ability.

Further evidence for a positive association between PA and reading in children with hearing loss came from a longitudinal study by Colin et al. (2007). They reported an investigation of 21 French-speaking children with severe to profound prelingual hearing loss who were assessed in kindergarten (at mean age 6;2) and then approximately one year later (at mean age 7;2). The children, who were fitted with hearing aids (HAs)

(n = 13) or CIs (n = 8), were exposed to oral French and varying amounts of cued speech. The results showed that rhyme awareness in kindergarten predicted children's ability to recognize written words in first grade. Colin et al. did not include a measure of vocabulary in their assessment battery, however, so the observed relationship between PA and reading might have been mediated by vocabulary knowledge.

Colin et al.'s (2007) finding of a positive association between early PA and later reading is consistent with, although not necessarily indicative of, a causal relationship between the variables. In 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). They reported longitudinal associations among reading, hearing loss, productive vocabulary, PA, and speech reading in 29 English-speaking children with severe to profound prelingual hearing loss (22 with HAs and seven with CIs). Their participants differed from those in Colin et al.'s study in that most (22 out of 29) preferred to communicate using British Sign Language or total communication. Assessments were conducted when children were 7;10, 8;10, and 10;11. The results showed that earlier measured 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. However, word reading and sentence comprehension measured at 8;10 accounted for significant unique variance in PA measured at 10;11 after removing the variance associated with hearing loss and earlier PA.

The findings reported by Kyle and Harris (2010) and Colin et al. (2007) are inconsistent regarding the longitudinal nature of the association between PA and reading. This inconsistency might reflect methodological differences, for example, in the majority of participants' preferred communication mode and/or the number and type of demographic and other variables accounted for in statistical analyses. Nevertheless, when considered in combination with the other studies described previously, they provide support for the qualitative similarity hypothesis in revealing a positive association between PA and reading in diverse, although relatively small (most Ns < 30), samples of children with hearing loss. The literature also contains empirical studies that are 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 between 6;2 and 7;10 old. 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. The scoring procedure used by Izzo reflected this fact, with children's retellings scored for "the inclusion of story structure elements and for sequence" (p. 23). It is perhaps not surprising, therefore, that a significant association with PA was not observed.

McQuarrie and Parrila (2009) also 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 as their preferred communication mode. The students, who were between 6;6 and 18;10 old (mean = 13;1), were classified into two groups according to reading ability. Their performance was examined on a task requiring them to judge words' phonological similarity at the level of syllable, rhyme, and phoneme. Neither group achieved better than chance performance, leading the authors to conclude that "reading abilities…ranged from poor to very skilled despite similar insensitivity to spoken language phonological structure across all participants" (p. 151). It should be noted, however, that more than half (31 out of 52) of the participants in McQuarrie and Parrila's research achieved reading scores below a 9-year-old level despite a median chronological age of 13;1 across the entire sample. It is possible that an association between PA and reading might have emerged in this study had there been more participants with age-appropriate or better reading skills.

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 and reading in the same sample of children who were 7;10 old (range 6;8–8;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 nonsignificant in a reading–age matched sample of children without hearing loss.

In a related vein, Johnson and Goswami (2010) analyzed data from 39 children ages 5–15 years, all with CIs, 20 implanted early (before 3;3) and 19 implanted late (after 3;7). Multiple regression analyses using reading accuracy and comprehension as dependent variables showed that PA was a significant predictor of children's reading when entered into the regression equation before receptive vocabulary. After removing the variance associated with vocabulary, however, PA was no longer significant (see also James, Rajput, Brinton, & Goswami, 2009). These results, along with those of Kyle and Harris (2006), highlight the need to understand and control for the influence of relevant demographic and cognitive-linguistic variables to obtain an accurate understanding of the association between PA and early reading skill in children with hearing loss.

To summarize, previous research investigating 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 (for a recent meta-analysis, see Mayberry et al., 2011). This inconsistency could stem partly from a failure to control for the full range of variables that have been shown to influence children's PA and/or reading outcomes. To address this evidence gap, it would be necessary to draw on a participant sample large enough to allow examination of a potential link between PA and reading ability while controlling for the influence of variables such as 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), socioeconomic status (e.g., Geers, 2003), cognitive ability (e.g., Geers, 2003; Harris & Beech, 1998), and gender (Geers, 2003). In a study of oral reading, communication mode (oral or signed) may also be of particular importance given that written English encodes spoken language.

There would be further advantages if children were evaluated at 5 years of age, when they are just beginning formal schooling. First, it would address the paucity of evidence relating to the development of children with hearing loss during the emergent literacy period (Mayer, 2007; Williams, 2004). Second, it would help control for the confounding effects of systematic instruction in alphabetic reading to which children are exposed at school (see Kyle & Harris, 2010). Third, it would ensure that participants were homogeneous with respect to chronological age, thereby maximizing the likelihood of their being at a similar, early stage of reading development.

Research Aims and Hypotheses

The primary aims of this study were (a) to investigate the concurrent association between PA and early reading skill in 5-year-old children with hearing loss who communicated primarily using spoken language and (b) to identify the demographic and cognitive-linguistic variables associated with the children's PA, reading, and related outcomes.

Given the conflicting findings reported in the literature, our 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 (e.g., gender, degree of hearing loss, communication mode, type of sensory device [HA or CI], age at fitting of sensory devices, level of maternal education). Furthermore, we predicted that the association with PA would be specific to early reading and would not generalize to another academic skill, namely, mathematical ability. Finally, and in line with previous research, we hypothesized 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 who communicated primarily using spoken language.

Method

Design

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

Participants

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 called the Longitudinal Outcomes of Children with Hearing Impairment (LOCHI) study (see Ching et al., 2013). 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.

Participants were included in the current study if they had 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 standardized tests could be administered in spoken English according to instructions provided in the respective test manuals. Exclusion criteria were presence of additional disabilities, non-English language background, nonuse of hearing devices, or hearing within normal limits ($n = 25$).

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, namely elision, blending words, and sound matching. A further 79 cases met the inclusion criteria, but 29 of those children were unavailable for all or part of the assessment interval. 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 majority of these participants were also unable to attempt or complete the primary reading assessment, the Woodcock–Johnson III Diagnostic Reading Battery (WJ–III DRB; Woodcock, Mather, & Schrank, 2004). For 34 of the 50 participants, the WJ–III DRB either could 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 achieved a score on all three included subtests, 12 were unable to read any real words or nonwords correctly (although in some cases they were able to provide the names or sounds associated with individual letters), and three were able to read just one word. The final child read six real words, but his failure to complete any subtests of the CTOPP 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 (for further details, see Ching et al., 2013). Audiological information was collected from the databases of Australian Hearing and relevant intervention agencies.

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). Across the cohort, hearing loss at 5 years of age ranged from mild to profound (mean = 72.1, SD = 35.2, range = 24–120). On average, children had been diagnosed with a hearing loss at 11.0 months of age (SD = 10.9, range = 0–36) and first fitted with HAs approximately three to four months later (mean = 14.7, SD = 11.1, range = 1–36). 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 (mean = 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 three (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.

TABLE 1
Participants' Background Information (N = 101)

Variable	Number of participants (percentage)
Gender	
Male	60 (59.4%)
Female	41 (40.6%)
Degree of hearing loss	
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%)
*Maternal education (*n *= 99)*	
University qualification	42 (42.4%)
Diploma or certificate	28 (28.3%)
12 years or less of schooling	29 (29.3%)
*Paternal education (*n *= 92)*	
University qualification	37 (40.2%)
Diploma or certificate	32 (34.8%)
12 years or less of schooling	23 (25.0%)
*Communication mode at home (*n *= 100)*	
Oral only	95 (95.0%)
Simultaneous communication	3 (3.0%)
Bilingual	2 (2.0%)
*Communication mode in early intervention (*n *= 97)*	
Oral only	88 (90.7%)
Simultaneous communication	9 (9.3%)

Note. Due to missing data for some variables, scores are based on different numbers of participants as specified.

Children's socioeconomic 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, 2006). 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. The majority of children in the current cohort lived in more advantaged areas, with

70.3% of the cohort scoring 7 or above on the IRSAD (median = 8.0, mode = 10.0, range = 1–10). Parental education was measured using a 3-point scale. Both female and male caregivers were fairly evenly divided among those who had a university qualification, those with a diploma or certificate, and those with 12 years or less of school attendance (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 used oral communication only, with just a handful of children using simultaneous communication. A similar pattern of results was obtained for mode of communication used in early intervention (see Table 1). More specifically in regards to spoken language, all of the children used English at home. A subgroup of 19 included children (18.8%) reported use of another spoken language as well (most frequently Arabic). It is important to note that this subgroup of children achieved similar English vocabulary scores on the Peabody Picture Vocabulary Test 4th edition (PPVT–4; Dunn & Dunn, 2007) as children who were exposed only to English. Mean raw scores were 63.6 versus 70.0, respectively: $t(97) = 1.09$, $p = .28$. As noted earlier, children with a non-English language background were excluded from the sample.

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 PPVT–4 was used to evaluate children's receptive language, particularly 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 reported in the test manual are excellent, in the vicinity of .93 to .97 for children in the target age range (5;0–6;5). In this study, children's performance was measured in terms of their total number of correct responses (raw score) and their percentile rank.

PA

Three subtests from the CTOPP 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 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 asked the child 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 (four out of seven 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 α, as reported in the test manual, indicates good reliability for each of the three subtests, with values ranging from .88 to .93 for children ages 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 (.86) was reported in the test manual for a group of 35 children with a mean age of 5;4 (range = 4;5–5;8). Good split-half reliability was reported by Muter, Hulme, Snowling, and Stevenson (2004) for a group of 90 children tested initially at age 4;9 (.96) and then one year later (.89).

Other aspects of reading were evaluated using three subtests from the WJ–III DRB. Letter–word identification assessed children's ability to recognize 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 onward. Word attack measured children's ability to recognize and produce sounds associated with single letters (items 1–3) and read nonwords aloud (item 4 onward). 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 of 5 to 6 years, with values of .98 to .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 recognizing 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 out of 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 math 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 math 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 the use of quantities less than a whole and the use of theoretical and experimental probability to make predictions and answer questions. Good split-half reliabilities for the math reasoning subtest are reported in the test manual for children ages 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 ages 4;0–7;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 recognizable object. The final subtest is a recognition memory task. The child is shown a geometric design for three 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 = 57–68 months for PPVT–4 and 60–73 months for CTOPP, PAT, WJ–III DRB, and WIAT–II Australian), most of the assessments measuring language, PA, reading, and mathematical ability (95.0%) were conducted between 60 and 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 (mean = 70.7, *SD* = 10.4). Even for this assessment, however, the majority of children (75.5%) were tested within an 18-month time span (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, early intervention or preschool settings, or schools. 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. Agreement was high, with only a handful of errors (<1%) detected and corrected.

Statistical Considerations and Preliminary Data Analysis

In line with our primary aim of investigating the concurrent associations among 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 variables were included in the correlation analysis, primarily because they measured related characteristics. Thus, maternal education level was included in preference to both socioeconomic status and level of paternal education because level of maternal education was more evenly distributed across the participant sample than was socioeconomic status, and it was significantly correlated with level of paternal education (r [N = 92] = .44, $p < .001$) but with fewer missing data points. 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, level of maternal education, communication mode, sensory device (HA or CI), 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 nonzero score on sound matching, with a majority managing three or more correct responses. In contrast, just 54.4% achieved a nonzero 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 onward from the WJ–III DRB letter-word identification subtest), and WJ–III DRB word attack (letter and nonword 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 math 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 $\alpha = .01$ (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 (mean = 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.

PPVT–4 scores show that children knew about 69 words on average, although there was marked variability among 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–4 scores that placed them in the bottom 27% of the normative distribution (see Table 2). Developmental delay was also apparent with respect to math reasoning ability, with half of the sample achieving scores that placed them in the bottom 19% of the normative distribution. In 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 (mean = 104.3, SD = 12.1, median percentile rank = 61.0).

Regarding reading, the majority of children were in the early stages of development as intended. They

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: Peabody Picture Vocabulary Test 4th edition	99 (61.3)	68.83 (22.51)	4–112	27.0
Phonological awareness: Comprehensive Test of Phonological Processing				
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: Phonological Abilities Test letter knowledge	100 (61.6)	11.98 (8.88)	0–26	25.0
Reading: Woodcock–Johnson III Diagnostic Reading Battery				
Letter–word identification	97 (61.8)	8.20 (6.05)	0–40	47.0
Real-word reading	97 (61.8)	0.67 (2.89)	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
Math reasoning: Wechsler Individual Achievement Test—second edition, Australian standardised edition	94 (61.7)	8.56 (4.13)	0–21	19.0
Cognitive ability: Wechsler Nonverbal Scale of Ability full-scale IQ	94 (70.7)	104.34 (12.10)	74–132	61.0

Note. Real-word reading represents an alternative, nonstandardized scoring method for data collected from the Woodcock–Johnson III Diagnostic Reading Battery letter–word identification subtest. It is the number of correct recognition and oral reading responses to real-word test items (item 10 and items 15 onward).
[a]Mean age at testing in months.
[b]Means were computed using raw scores for all assessments except the WNV, where standardized (full-scale IQ) scores were used.
[c]Percentile ranks are medians.

knew the names or sounds associated with just under half the letters of the alphabet on average (mean = 11.98, *SD* = 8.88 for PAT letter knowledge), were generally able to read aloud three or four simple words at most (mean = 0.67, *SD* = 2.89 for real-word reading), and in over 95% of cases were unable to decode any simple C–V–C nonwords, although they could provide some of the sounds associated with single letters (mean = 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 previously, 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

As an initial step in examining the relationships between variables, a bivariate correlational analysis was conducted. The results are presented in Table 3. As

TABLE 3
Bivariate Correlations (Pearson's *r*) Between Demographic Variables and Formal Assessment Measures (and the number of paired observations)

	Device	Gender	MatEd	4FAHL	AgeHA	AgeSO	PPVT−4	Elision	Blend	Match	PATLK	WordID	RWRead	WordAtt	Comp[n]	Math	NVIQ
Mode	.01 (100)	.20 (100)	−.11 (98)	−.02 (100)	−.09 (100)	.09 (29)	−.07 (99)	−.05 (100)	.04 (100)	.06 (100)	.10 (99)	.15 (96)	.16 (96)	.00 (95)	.01 (97)	−.05 (93)	.10 (93)
Device		.23 (100)	.06 (98)	.89*** (100)	−.37*** (100)	—a	−.34*** (99)	−.20 (100)	−.18 (100)	−.12 (100)	.03 (99)	.05 (96)	.03 (96)	−.03 (95)	.01 (97)	−.31** (93)	−.20 (93)
Gender		1 (100)	.00 (98)	.22 (100)	−.20 (100)	−.14 (29)	−.08 (99)	−.08 (100)	−.17 (100)	−.12 (100)	.04 (99)	.02 (96)	−.11 (96)	−.13 (95)	−.08 (97)	−.04 (93)	.09 (93)
MatEd			1 (98)	−.02 (98)	.12 (98)	−.02 (27)	−.19 (97)	−.19 (98)	−.20 (98)	−.26** (98)	−.36*** (97)	−.35*** (94)	−.18 (94)	−.25 (93)	−.23 (95)	−.21 (92)	−.25 (91)
4FAHL				1 (100)	−.32*** (100)	—b	−.44*** (99)	−.24 (100)	−.19 (100)	−.14 (100)	.03 (99)	−.02 (96)	−.03 (96)	−.08 (95)	−.01 (97)	−.35*** (93)	−.11 (93)
AgeHA					1 (100)	.46 (29)	.07 (99)	.03 (100)	.04 (100)	.13 (100)	−.07 (99)	.01 (96)	.13 (96)	−.02 (95)	−.13 (97)	−.05 (93)	.03 (93)
AgeSO						1 (29)	−.38 (29)	−.31 (29)	−.13 (29)	−.28 (29)	.24 (28)	.16 (28)	.02 (28)	.02 (28)	−.01 (28)	−.24 (27)	−.01 (28)
PPVT−4							1 (99)	.63*** (99)	.42*** (99)	.34*** (99)	.33*** (98)	.37*** (95)	.26** (95)	.36*** (94)	.21 (96)	.65*** (92)	.34*** (92)
Elision								1 (100)	.41*** (100)	.53*** (100)	.36*** (99)	.34*** (96)	.47*** (96)	.50*** (95)	.15 (97)	.48*** (93)	.26 (93)
Blend									1 (100)	.53*** (100)	.28** (99)	.40*** (96)	.52*** (96)	.47*** (95)	.08 (97)	.44*** (93)	.32** (93)
Match										1 (100)	.31** (99)	.42*** (96)	.62*** (96)	.52*** (95)	.15 (97)	.34*** (93)	.32** (93)
PATLK											1 (99)	.88*** (95)	.52*** (95)	.63*** (94)	.14 (96)	.38*** (92)	.16 (92)
WordID												1 (96)	.70*** (96)	.61*** (95)	.12 (96)	.31** (92)	.19 (89)
RWRead													1 (96)	.66*** (95)	.01 (96)	.29** (92)	.20 (89)
WordAtt														1 (95)	.13 (95)	.44*** (91)	.19 (88)

(continued)

TABLE 3. *(continued)*

	Device	Gender	MatEd	4FAHL	AgeHA	AgeSO	PPVT–4	Elision	Blend	Match	PATLK	WordID	RWRead	WordAtt	Comp[n]	Math	NVIQ
Comp[n]															1 (97)	.25 (93)	.16 (90)
Math																1 (93)	.47*** (86)

Note. 4FAHL = 4 frequency average hearing loss in the better ear. AgeHA = age at hearing aid fitting. AgeSO = age at cochlear implant switch-on. Blend = Comprehensive Test of Phonological Processing (CTOPP) blending words raw score. Comp[n] = Woodcock–Johnson III Diagnostic Reading Battery (WJ–III DRB) passage comprehension raw score. Elision = CTOPP elision raw score. For device, 1 = hearing aid, and 2 = cochlear implant. For gender, 1 = male, and 2 = female. Match = CTOPP sound matching raw score. MatEd = maternal education (1 = university; 2 = diploma/certificate; 3 = 12 years or less schooling). Math = Wechsler Individual Achievement Test—second edition, Australian standardised edition math reasoning raw score. Mode = communication mode in early intervention (1 = oral; 2 = simultaneous communication). NVIQ = Wechsler Nonverbal Scale of Ability full-scale IQ. PATLK = Phonological Abilities Test letter knowledge raw score. PPVT–4 = Peabody Picture Vocabulary Test 4th edition receptive vocabulary raw score. RWRead = number of real words read correctly for test items 10 and 15 onward on the WJ–III DRB letter–word identification subtest. WordAtt = WJ–III DRB word attack raw score. WordID = WJ–III DRB letter–word identification raw score.

[a]Age at switch-on applies only to children with cochlear implants.

[b]4FAHL = 120 for all children with cochlear implants.

$^{**}p \leq .01$. $^{***}p \leq .001$.

shown, three demographic variables were significantly correlated with children's assessment outcomes:

1. Children whose mothers had higher levels of education achieved better outcomes in sound matching and reading (PAT letter knowledge and letter–word identification).
2. Children with more severe levels of hearing loss and children with CIs achieved poorer outcomes in receptive vocabulary and math reasoning. The correlations involving type of sensory device were, however, driven entirely by the strong positive association between device and severity of hearing loss (see Table 3). First-order partial correlations with device type were small and nonsignificant once the level of hearing loss was controlled (r [df = 96] = .13 for vocabulary; r [df = 90] = −.01 for math reasoning).

None of the remaining demographic variables (communication mode, gender, age at HA fitting, or age at CI switch-on) was significantly associated with outcomes. Earlier fitting of HAs was, however, associated with the presence of a more severe hearing loss and use of a CI. There was also 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

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 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 five demographic variables: communication mode, device, gender, maternal education, and 4FA HL; 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

TABLE 4
Multiple Regression Summary Table for Outcomes in Early Word and Nonword Reading

Predictors	Dependent variable		
	Letter knowledge	Real-word reading[a]	Word attack
		R^2 *change*	
Gender, 4FAHL, device, communication mode, maternal education	.14*	.10	.11
AgeHA, AgeSO[b]	.02	.03	.00
Cognitive ability (WNV)	.01	.04*	.03
Receptive vocabulary (PPVT–4)	.12***	.04	.07**
Letter knowledge (PAT)	—[c]	.18***	.25***
Phonological awareness (CTOPP sound matching)	.04*	.16***	.07***
Total R^2	.32***	.54***	.53***
N	99	96	95
		Regression coefficients	
Gender (reference male)	0.859	−0.319	−0.337
4FAHL	0.069	−0.006	−0.005
Device (reference hearing aid)	−1.932	0.884	0.357
Communication mode (reference oral)	2.565	0.658	−0.252
Maternal education (reference university):			
Certificate or diploma	−3.494	0.045	−0.095
12 years or less	−4.503*	0.248	0.056
AgeHA	−0.055	0.016	−0.011
AgeSO	0.325*	−0.004	−0.001
Cognitive ability (WNV)	−0.079	0.005	0.004
Receptive vocabulary (PPVT–4)	0.157***	0.000	0.005
Letter knowledge (PAT)	—[c]	0.067***	0.087***
Phonological awareness (CTOPP sound matching)	0.600*	0.232***	0.150***

Note. 4FAHL = 4 frequency average hearing loss in the better ear. AgeHA = age at hearing aid fitting. AgeSO = age at cochlear implant switch-on. CTOPP = Comprehensive Test of Phonological Processing. PAT = Phonological Abilities Test. PPVT–4 = Peabody Picture Vocabulary Test 4th edition. WNV = Wechsler Nonverbal Scale of Ability. Regression coefficients are for the final model containing all predictor variables. The letter knowledge subtest is from the PAT. The word attack is from the Woodcock–Johnson III Diagnostic Reading Battery (WJ–III DRB).
[a]Real-word reading = number of correct reading responses to real words (test items 10 and 15 onward) on the letter–word identification subtest of the WJ–III DRB.
[b]Because age at switch-on was available only for participants with cochlear implants, there were numerous, nonrandom, 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.
* $p \leq .05$. ** $p \leq .01$. *** $p \leq .001$.

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.

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, 16% in real-word reading, and 7% in word attack when added to the final regression model (i.e., when controlling for all other predictors). These percentages increased to 24.9% for real-word reading and 15.6% 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 0.600, real word reading by 0.232, and word attack by 0.150.

An analogous multiple regression was conducted with math reasoning as the dependent variable. Predictors 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 nonsignificant regression coefficient of .103 (see Table 5). The predictor variables that accounted for the most variance in math reasoning were nonverbal cognitive ability and receptive vocabulary, both of which

TABLE 5
Multiple Regression Summary Table for Outcomes in Math Reasoning, Receptive Vocabulary, and Phonological Awareness

Predictors	Dependent variable		
	Math reasoning	Receptive vocabulary	Sound matching
		R^2 *change*	
Gender, 4FAHL, device, communication mode, maternal education	.18**	.27***	.10
AgeHA, AgeSO[a]	.02	.03	.04
Cognitive ability (WNV)	.13***	.08***	.08**
Receptive vocabulary (PPVT−4)	.16***	—[b]	.02
Letter knowledge (PAT)	.03*	.09***	.04*
Phonological awareness (CTOPP sound matching)	.00	.00	—[b]
Total R^2	.53***	.48***	.28***
N	93	99	100
		Regression coefficients	
Gender (reference male)	−0.091	−0.308	−0.875
4FAHL	−0.009	−0.489***	−0.019
Device (reference hearing aid)	−1.000	19.722*	1.748
Communication mode (reference oral)	−0.876	−11.420	0.448
Maternal education (reference university):			
Certificate or diploma	0.068	1.824	−0.142
12 years or less	0.303	−3.398	−1.110
AgeHA	−0.062	−0.007	0.053
AgeSO	0.014	−0.737**	−0.090
Cognitive ability (WNV)	0.077*	0.495**	0.069*
Receptive vocabulary (PPVT−4)	0.078***	—[b]	0.013
Letter knowledge (PAT)	0.078	0.789***	0.085*
Phonological awareness (CTOPP sound matching)	0.103	0.457	—[b]

Note. 4FAHL = 4 frequency average hearing loss in the better ear. AgeHA = age at hearing aid fitting. AgeSO = age at cochlear implant switch-on. CTOPP = Comprehensive Test of Phonological Processing. PAT = Phonological Abilities Test. PPVT−4 = Peabody Picture Vocabulary Test 4th edition. WNV = Wechsler Nonverbal Scale of Ability. Regression coefficients are for the final model containing all predictor variables.
[a]Because age at switch-on was available only for participants with cochlear implants, there were numerous, nonrandom, 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.
[b]This model does not apply because a dependent variable cannot be used to predict itself.
**p* ≤ .05. ***p* ≤ .01. ****p* ≤ .001.

were significant in the final model with regression coefficients of .077 ($p < .05$) for nonverbal cognitive ability and .078 ($p < .001$) for receptive vocabulary.

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, level of maternal education, communication mode, and sensory device were always entered as a block in the first regression model. They accounted for significant variance in receptive vocabulary, math reasoning, and letter knowledge (see Tables 4 and 5). The individual predictors responsible for these effects were level of maternal education (for all three outcome measures) and degree of hearing loss (for receptive vocabulary). 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 simultaneously controlled for all predictors), three significant effects were evident.

1. Children whose mothers had completed postsecondary education knew more letters on average than did children whose mothers had 12 years or less of formal schooling (regression coefficient = −4.503, $p < .05$; see Table 4).
2. Children with more severe hearing losses (4FA HL) achieved inferior receptive vocabulary scores (regression coefficient = −0.489, $p < .001$; see Table 5).
3. Children with CIs achieved better receptive vocabulary scores than did children with HAs (regression coefficient = 19.722, $p < .05$; see Table 5).

Inspection of Tables 4 and 5 shows further 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. Earlier age at switch-on was associated with better outcomes in receptive vocabulary as expected (see Table 5), whereas later age at switch-on was associated with better outcomes in letter knowledge (see Table 4).

Discussion

This research investigated the concurrent association between PA and early reading skill in 5-year-old children with hearing loss who communicated primarily using spoken language. Three specific questions were addressed:

1. Would PA be associated with early reading skill 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 generalize to another academic skill, namely, math 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 question, 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, gender, degree of hearing loss, type of sensory device, communication mode, level of maternal education, and age at fitting of sensory devices. This relationship was evident when reading was measured in terms of (a) knowledge of letter names or sounds, (b) the ability to recognize or read single words aloud, and (c) the ability to recognize and produce sounds associated with single letters and to read nonwords aloud. A further multiple regression was conducted to address our second research question. It showed convincingly that PA did not account for significant unique variance in math 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 in predicting children's outcomes across the range of PA, reading, and related assessments. None of the demographic variables directly predicted real-word reading or word attack after all other variables were controlled. For math reasoning and PA, the only demographic variable to account for significant unique variance was cognitive ability. However, less severe hearing loss, use of a CI, and earlier age at CI switch-on were all associated with better outcomes in receptive vocabulary. This finding for age at CI switch-on is consistent with a comprehensive analysis of the LOCHI participants at 3 years of age (Ching et al., 2013) and suggests the benefit of early auditory stimulation for spoken language acquisition over the first few years of life. Finally, better outcomes in letter knowledge were associated with higher levels of maternal education as predicted but also with later CI switch-on, a finding that seems to contradict the results for receptive vocabulary. It is important to remember, however, that children typically begin to develop their letter knowledge around 4 years of age, by which time all of the participants with CIs in this study were already using their devices.

Our finding of a positive association between PA and reading in this sample of children with hearing loss is consistent with a number of previous investigations (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 16% of unique variance in real-word reading and 7% in word attack.

Despite this general similarity, the current findings also differed from those of Mayberry et al. (2011), who reported that language ability accounted for a greater proportion of the variance in reading ability than did phonological skills (35% on average) in a subset of seven studies that investigated the role of both variables. In 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 different pattern of results probably reflects 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 summarized by Mayberry et al. employed measures of reading comprehension and focused on older children, adolescents, or adults. Previous longitudinal research with children who have normal hearing has revealed that phonological processing skills and other language-related abilities had their strongest association with reading ability at different developmental stages. Phonological skills played their most important role in the earliest stages of reading development, whereas other language-related abilities were important at later stages (e.g., Frost, Madsbjerg, Niedersoe, Olofsson, & Sörensen, 2005; Storch & Whitehurst, 2002).

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 young and homogeneous with respect to age. In contrast, many previous studies spanned a wide range of ages and reading abilities (e.g., Dillon et al., 2012; Johnson & Goswami, 2010; Spencer & Tomblin, 2009). By restricting our participants' age range, we ensured that the majority were in the earliest stages of reading development; that is, they could provide names or sounds for 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 math reasoning ability as compared with 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 generalize to other academic skills; however, most previous studies of children with hearing loss have not tested this assumption directly. In contrast, the findings obtained in this investigation 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 math reasoning skill. The observed specificity of the association between PA and reading is all the more noteworthy given that children's math outcomes were predicted by concurrent levels of receptive vocabulary, presumably reflecting the verbal nature of the problems used for assessment (for a similar view, see Purpura, Hume, Sims, & Lonigan, 2011).

As discussed previously, 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 on older children. 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., Johnson & Goswami, 2010; Kyle & Harris, 2006). 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, although it is possible that a gender difference might emerge as children get older. Geers (2003) reported better reading outcomes for females than males in a large sample of 8–10-year-olds.

A different pattern of results was obtained for age at CI switch-on. In line with expectations, earlier CI switch-on was associated with significantly better outcomes in receptive vocabulary; however, this observed benefit did not extend to reading and PA outcomes as documented in some previous studies (e.g., Connor & Zwolan, 2004;

James et al., 2008; Johnson & Goswami, 2010). In fact, a small but significant effect in the opposite direction was obtained for letter knowledge, such that children with later CIs achieved better outcomes. In reconciling our findings for age at CI switch-on with those from previous studies, we note that in the current investigation, all children with CIs had their devices switched on before 4 years of age, well in advance of beginning formal reading instruction at school. In this regard, our sample is representative of the population of children whose hearing loss was detected via newborn hearing screening and who received early intervention. In contrast, implant ages ranged from 2 to 7 years old in the study by James et al., from <3 to 14 years old in Connor and Zwolan's study, and from 1.5 to 9 years in Johnson and Goswami's investigation. It may be expected that inclusion of children with a range of CI switch-on ages much wider than that in our study would increase the likelihood of revealing a benefit of earlier CI switch-on for the development of reading and PA skills (Ambrose, Fey, & Eisenberg, 2012).

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 when holding all other variables constant. However, degree of hearing loss was not linked to either early reading or PA outcomes at 5 years of age. The effect of severity of hearing loss on spoken language ability is unequivocal (Ching et al., 2013), and whether its effects on early PA and oral reading may manifest as children progress in their formal schooling remains to be investigated.

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 postsecondary education knew more letters' names or sounds than did 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 the children's learning shifts from letters to words, sentences, 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. 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 nonwords 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 segmentalized nature of their lexical-phonological representations (e.g., Metsala, 1999; Walley, 1993). One might argue that the latter interpretation is less likely, however, on the grounds that segmentalized 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 several 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 nonword reading, thus confirming the reliability of the findings.

Limitations

Despite these strengths, a number of limitations and suggestions for extension and improvement are also apparent. First, the results cannot be generalized beyond the population of children who are fitted with HAs before 3 years of age and communicate using primarily spoken language. Although the effect of communication mode used in early intervention was not significant in this research, fewer than 10% of participants used a combined mode of communication, and none used sign only. Further research would be necessary to enable generalization to these populations of children. Second, the findings cannot be generalized to measures of reading skill that reflect comprehension processes because our focus was on aspects of early reading related to the recognition and oral reading of single words, nonwords, and letters. Third, because 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.

This study used three subtests from the CTOPP to measure PA: elision, blending words, and sound matching. Performance in these tests and any other tests of spoken English relies on children's ability to hear spoken stimuli. Furthermore, in two of the subtests (elision and blending words), children were required to respond orally. The impact of these potential confounds was reduced or effectively eliminated in the current investigation through our use of sound matching as the measure of PA in multiple regression analyses. In this subtest, reliance on ability to hear speech is reduced through the use of pictorial stimuli to accompany presentation of spoken words. In addition, use of a picture-selection response eliminates the need for children to respond orally. Nevertheless, a question remains regarding the potential for use of an orthographic strategy in sound matching (McQuarrie & Parrila, 2009; Sterne & Goswami, 2000)—that is, the possibility that children might base their similarity judgments on shared letters rather than shared sounds (Harris & Beech, 1998). Use of such a strategy would seem unlikely in the current investigation, however, given the absence of printed word stimuli, the incomplete nature of children's letter knowledge, and their early stage of reading development.

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 who communicated primarily using spoken language. In contrast, the results 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 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 (Storch & Whitehurst, 2002). 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: (1) that even children in the normative sample perform poorly in reading tasks at 5 years of age and (2) 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 that we have observed between PA and reading would generalize 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 through subsequent emphasis on visual-orthographic processes in word recognition.

NOTES

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