CHARACTERISTICS OF PHONOLOGICAL PROCESSING, READING, ORAL LANGUAGE, AND AUDITORY PROCESSING SKILLS OF CHILDREN WITH MILD-TO-MODERATE SENSORINEURAL HEARING LOSS

By

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To my Godly wife, Mina;
and to a bright future for my precious little princess, Hayoung.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Abstract of Dissertation Presented to the Graduate School
of the University of Florida in Partial Fulfillment of the
Requirements for the Degree of Doctor of Philosophy

CHARACTERISTICS OF PHONOLOGICAL PROCESSING, READING, ORAL LANGUAGE, AND AUDITORY PROCESSING SKILLS OF CHILDREN WITH MILD-TO-MODERATE SENSORINEURAL HEARING LOSS

By

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The principle aim of the study was to examine the effect of mild to moderate SNHL on 19 children's performances on a range of spoken language, phonological processing skills, and literacy (reading and spelling). Performances of two controls groups (29 normally developing and 30 dyslexic children), matched for age, grade, and non-verbal intelligence were also analyzed to investigate the HI group's relative weaknesses and strengths in phonological processing ability and its relation to their literacy skills.

It is well known that a lack of natural and complete linguistic input in early childhood contributes to significant language delays even in children with mild to moderate hearing loss. Although they may be helped by hearing aids, these children usually remain unable to extract enough auditory information to develop spoken language with the ease and efficiency of a normally hearing child. Due to this, the development of appropriate phonological processing skills which are necessarily required for the early reading development is a considerable challenge for children with hearing loss. This study was planned with an assumption that literacy development would require the same acquisition of phonological processing skills, whether a child's hearing is impaired or normal.

A set of MANCOVAs revealed that HI group's performances on the measures of spoken language (receptive and expressive vocabulary and morphosyntactic knowledge) and phonological processing tasks were significantly delayed when compared to their normal controls. The HI group's phonological processing skills were *selectively* depressed such that only phonologically-based tasks (phonological awareness and phonological short-term memory) were seen significantly lower than the normal controls but their rapid naming skills were seen preserved despite hearing loss. This finding suggests that auditory perceptual distortion due to SNHL can only affect phonologically-based component and would not have negative impact on *extraphonological* processing ability (RAN).

It was found that the HI group's literacy skills were significantly lower than their normally hearing controls. The necessary role of phonological processing skills was also confirmed by the correlational and regression analyses which suggest that phonological processing skills are important correlates and predictors of hearing-impaired children's reading and spelling as well. The strongest predictor of reading and spelling was the *Elision* subtest on the CTOPP. These findings contradict previous studies which argued that reading skills of hearing-impaired would not necessarily require the support from phonological processing ability. Impressively, RAN measures were not associated with any of *untimed* reading tasks, but had significant correlations only with *timed* reading tasks. RAN also additively contributed independent variance to timed reading measures after phonologically-based variables were controlled for.

Lastly, assuming that hard-of-hearing individuals, like hearing individuals, will also benefit from direct phonological instruction, the findings imply that effective programs and strategies for teaching hearing-impaired children these skills may be the key to obtaining higher levels of reading achievement for this population.

CHAPTER 1
INTRODUCTION

Background of the Study

The purpose of this study is to investigate the strengths and weaknesses of skills in reading, phonological processing, and oral language of children with congenital mild to moderate sensorineural hearing loss in comparison to those of dyslexic and normal readers with intact hearing ability.

It is widely acknowledged that the critical requirement of written language skills is the acquisition and development of language and concomitant cognitive skills at as early an age as possible. Among various tiers of linguistic knowledge, the phonological component is now known as the most important foundation for the development of early literacy skills. Over the last several decades, an intense research focus has been placed on relations between phonological processing capacities and reading performances measured by word recognition, reading comprehension, reading fluency, and spelling. Evidence from both typically developing and atypically developing children demonstrates that the quality of a child's phonological representations is important for their subsequent progress in literacy. This relationship has been found across all languages studied, for both persons with typical reading ability (e.g. Bradley & Bryant, 1983; Hoien, Lundberg, Stanovich, and Bjaalidet, 1995; Siok & Fletcher, 2001), and persons with reading disabilities (e.g. Bradley & Bryant, 1983; Bruck, 1992; Landerl, Wimmer, & Frith, 1997; Porpodas, 1999). It is generally accepted that dyslexia is characterized by developmental weaknesses in establishing phonological representations of speech sounds.

The *'phonological core deficit'* theory (Stanovich, 1988) argues that children with dyslexia find it difficult to represent mentally the sound patterns of the words in their language in a detailed and specific way. Research to date has supported the causal connections between phonological representation and reading acquisition. Thus, research supports that the presence of normal phonological processing capacity is a hallmark characteristic of good readers while its absence is a consistent characteristic of poor readers (Hurford, Darrow, Edwards, Howerton, Schauf, & Coffey, 1993; Mann, 1993).

Based upon the phonological core deficit hypothesis of literacy development, if children's phonological representations are adversely affected for some reason, we can hypothesize deficits in their phonological skills will result in deficiencies in reading skill. Many students with congenital hearing impairment can have problems with reading and writing because of their difficulty in acquiring and/or manipulating the structural characteristics of phonological component of language. It is assumed that hard-of-hearing children have constrained access to the input of speech sounds of their first language during the early critical period of language acquisition. Because of the possible distortion of the incoming acoustic signal, it is hypothesized that the phonological processing capacity of the children with hearing loss and the emerging literacy-related cognitive skills resulting from it would also be negatively affected (Briscoe, Bishop, & Norbury, 2001; Nittrouer, 1996; and Nittrouer and Burton, 2005).

According to Nittrouer and Burton (2005), early auditory experience associated with normal hearing capacity facilitates the development of language-specific perceptual weighting strategies, which are believed to be critical for accessing phonetic entities of a given language and constructing a language-specific phonological structure. In turn, this knowledge of a language's phonemic inventory and phonological structure, based on normal auditory perception, will allow for the appropriate development of phonological processing skills such as efficient temporary storage (verbal working memory), lexical retrieval from long-term memory, and a variety of meta-phonological skills. In this respect, peripheral hearing loss which is assumed to result in alteration or distortion of auditory input, can provide a way of testing the phonological processing deficit hypothesis. That is, can the theory of phonological core deficit be applied to hearing impaired children, for whom possible phonological depression may be associated with a peripheral auditory deficit?

Rationale and Significance of the Study

Links between hearing loss, language, and reading performance have been widely investigated in children with conductive hearing loss caused by otitis media with emission (OME) (Friel-Patti & Finitzo, 1990; Mody, Studdert-Kennedy, & Brady, 1997). Researchers tried to address the effects of frequent OME on children's speech, language, and reading abilities. However, findings are inconsistent across studies. Also, there is a large body of research investigating oral and written language of children with SNHL, but most of this research focuses on children with severe to profound losses who rely heavily on visual information. Thus, scant research efforts have been directed to studying the contribution of phonological processing skills to literacy development in children with mild to moderate levels of SNHL.

To date, only a few studies have investigated the effect of potentially impaired phonological skills in children with mild-to-moderate SNHL on reading and related cognitive skills (Briscoe et al., 2001; Delage & Tuller, 2007; Gibbs, 2004; Halliday & Bishop, 2005). Furthermore, the results of previous research are contrary to our expectations based on findings from other populations. That is, hard-of-hearing children with depressed phonological processing skills do *not* show the pervasive difficulties with language and literacy. For example, Briscoe et al. (2001)'s study shows that even with significantly depressed phonological skills associated with hearing loss, reading skills are possible to some degree. In Briscoe et al.' study, nineteen children with mild and moderate SNHL were merged together to comprise a single experimental group and their reading and phonology skills were compared with those of children with specific language impairment (SLI). However, among the total 19 children in this group, 13 children had mild hearing losses and only three children had moderate SNHL. This skewed distribution of hearing loss levels would not adequately represent the population of children with mild-to-moderate SNHL. As expected, this might be the reason the subjects' reading performance was comparable to that of normally hearing children.

Seemingly, due to this limitation, statistical analyses conducted for group comparisons may not have captured the potential adverse effects of phonological depression associated with hearing impairment. Gibbs (2004) also reported a similar pattern. Fifteen children with mild-to-moderate bilateral SNHL were compared to normally hearing controls on reading performance. The reading abilities of the children with SNHL were indistinguishable from their hearing peers and reading abilities were not significantly associated with the degree of hearing impairment. However, their phonological skills were inferior to those of the normally hearing controls even though they had a significant negative correlation with hearing loss level. Gibbs concluded that reading might be possible even without well developed phonological skills. Thus, further research strictly focusing on the literacy and reading-related cognitive skills in children with mild-to-severe SNHL with appropriate methodology is warranted.

In these studies, the hearing-impaired children's success with reading in spite of depressed phonological processing skills was notable and unexpected in the theoretical framework of phonological core deficit. These unexpected findings raise a critical question regarding the precise role of phonological skills in written language acquisition. That is, according to the 'phonological processing deficit hypothesis', impaired phonology would lead to compromised literacy ability since phonological capacity is regarded as a necessary, although not a sufficient condition for reading. Moreover, no previous studies compared hard-of-hearing children's phonological and literacy skills to the same skills in children who have dyslexia. Such a comparison could provide insight into the cognitive skills of two groups of children with reading disabilities due to different etiologies.

In addition, very few studies investigated the effects SNHL has on phonological, language, and reading skills using a wide range of tests. To provide a more precise view of the developmental characteristics of hearing impaired children's reading and phonological skills, a comprehensive battery of tests was used in this study. That includes: (1) oral language (receptive and expressive vocabulary, grammatical knowledge), (2) phonological processing (phonological awareness and short-term memory, verbal working memory, rapid naming), (3) reading skills (word recognition and nonword decoding in both timed and untimed manner, paragraph reading accuracy/speed, reading comprehension, and spelling). Finally, auditory processing tasks were also used to determine if hearing impaired children's reading skill is associated with low-level auditory perceptual processing, a skill needed to perceive speech events for brief temporal durations.

Study Objectives

- Objective 1: To provide a comprehensive data set on a range of oral language, phonology, auditory processing, and literacy skills in hard-of-hearing children.
- Objective 2: To investigate the strengths and weaknesses in reading, phonological processing, and oral language of hearing-impaired children and to compare their abilities to those of children who are typical readers and children who have dyslexia, a specific reading impairment.
- Objective 3: To overcome some methodological limitations mentioned earlier by collecting a set of data which well represent the population and by using a better statistical approach for analysis.
- Objective 4: To address the universality of phonological core deficit theory. The theory is that *the contributive and necessary role of phonological processing* capacity for literacy found in normal hearing children will also be observed in children with hearing loss, that

is, the theoretical framework known as the phonological deficit hypothesis predicts that the more severe the initial hearing loss, the more impaired reading skills will be. This issue is of great theoretical importance in understanding associations between impaired phonological processing skills and reading achievement in children with hearing loss. Clinically, if this hypothesis is supported in this study, the results will serve to guide principles for reading programs for hearing-impaired children in school settings.

Brief Definition of Terms

Research literature in the area of phonological processing and phonological awareness entail highly technical language. The following definitions can be used as a guide for the subsequent discussion of these complex concepts.

- Phonological representation: Use of arbitrary symbols (oral or written) to represent experience or concepts (e.g., words or graphic symbols like "$").

- Phonological processing: The use of phonology or sounds of language to process verbal information in oral or written form in short- and long-term memory (Wagner & Torgesen, 1987). Components include awareness and coding (i.e., coding sounds for storage in memory and retrieval of sounds from memory codes) of verbal information only (Cornwall, 1992; Hurford et al., 1993; Torgesen et al., 1990; Vellutino & Scanlon, 1987a; Wagner & Torgesen, 1987).

- Phonological coding: "The representation of information about the sound structure of verbal stimuli in memory" (Torgesen et al., 1990, p. 236).

- Phonological recoding: Translation from either oral or written representation into a sound-based system to arrive at the meaning of words in the lexicon (stored vocabulary) in long-term memory (Wagner & Torgesen, 1987).

- Phonological units: Refers to the size of the sound (e.g., phonemes, onset-rimes, syllables, word).

- Phonetic recoding: Translation of verbal information into a sound-based system for temporary storage in working memory for processes such as decoding unfamiliar words in fluent reading, or during the beginning reading processes of blending and segmenting.

- Phonological awareness: Conscious awareness of the sound segments in language (e.g., syllable, shared rimes, or phonemes) and ability to manipulate sound (e.g., move, combine, and delete).

- Phonemic awareness: Awareness of phonemes, discrete individual sounds that correspond to individual letters. Spector (1995) pointed out that many terms have been used for this ability, including phonemic awareness, phonetic analysis, auditory analysis, phonological reading, phonological processing, and linguistic awareness. Typically, phonological awareness is used as a general term and phonemic awareness is used to refer specifically to awareness at the phoneme level.

- Decoding: Translating individual letters and/or groups of letters into sounds to access the pronunciation of a word.
- Lexical access: Access to internal dictionary in memory.
- Retrieval: Accessing coded information from short-term or long-term memory.
- Phonemes: Individual sounds, smallest unit of sound.
- Grapheme: Written symbols or letters of the alphabet; arbitrary, abstract, and usually without meaning; the written equivalent of phonemes.
- Grapheme-to-phoneme correspondence: Linkages between discrete phonemes and individual letters or graphemes.
- Onset-rime**:** Two-part division of words into units that are smaller than syllables; onset is the first division of a single phoneme or consonant cluster (e.g., /br/ in bright), rime is the last division with multiple phonemes (e.g., /ight/ in bright).
- Alphabetic understanding: Understanding that letters represent sounds and that whole words have a sound structure consisting of individual sounds and patterns of groups of sounds.

CHAPTER 2
LITERATURE REVIEW

Introduction

The primary goal of this chapter is to provide a review of previous studies related to the phonological core model of reading disabilities is provided.

The nature of weakened phonological processing and its possible causal role to later literacy development is considered through a review of current explanatory models or theories of the interface between reading and phonology. Theories reviewed will include: (i) Phonological representation hypothesis and lexical restructuring hypothesis; (ii) double-deficit hypothesis, and (iii) auditory processing deficit hypothesis. Integrated summary of each theory will be provided in each section. The chapter also reviews studies dealing with language and reading development of hearing impaired children. Before that, a brief theoretical framework of phonological processing is given in the first section.

Phonological Core Deficit Theory

Developmental dyslexia (DD) refers to the inability to acquire proficient reading skill and is a prevalent learning disability affecting between 5 and 15% of children in school. Vellutino (1979), one of the earliest studies in reading disorder, reported that children with reading problem have systematic difficulties on tasks with verbal demands, whereas they performed at the similar level with normal readers on non-verbal tasks.

Over the last two decades, a large body of converging evidence now indicates that dyslexia stems from an underlying deficit in the phonological processing system, suggesting that deficits in processing the sounds of language explain a significant proportion of beginning reading problems and correlated problems with older readers even though debates still remain regarding whether a *single, phonological core deficit* or *other cognitive deficits* lead to reading failure

(Beitchman & Young, 1997; Mody, 2003; Shaywitz, 1998; Snowling, Nation, Moxham, Gallagher & Frith, 1997) or underspecified, poor phonological representations (Elbro, 1996; Fowler, 1991; Hansen and Bowey, 1994; Metsala, 1997; Snowling, Goulandris, Bowlby, & Howell, 1986; Swan and Goswami, 1997a,b).

The strong association between the phonological deficits and dyslexia led Stanovich (1986) to propose that dyslexia should be defined as a core phonological deficit. In the phonological core-variable difference model of dyslexia (Stanovich & Siegel, 1994), poor phonology is related to poor reading performance, irrespective of IQ. An important advantage of the core phonological deficit definition of dyslexia is that it makes sense in terms of what is known about the normal acquisition of reading. That is, it has been known that phonological awareness skills measured in preschool is an excellent predictor of later literacy performance, even after the substantial effects of IQ are controlled. It is well understood that the ability to reflect upon the sound structure of words at the phonemic level is critical to the development of the alphabetic principle that allows children to decode novel words that they have not seen before.

There is now converging evidence that the core deficit in reading disability is at the level of phonological awareness, letter-sound decoding and limitations of verbal short-term memory (Ehri, Nunes, Willows, Schuster, Yaghoub-Zadeh, & Shanahan, 2001; Fletcher, Shaywitz, Shankweiler, Katz, Liberman, Stuebing, Francis, Fowler, & Shaywitz ,1994; Foorman, Francis, Beeler, Winikates, & Fletcher, 1997; Morris, Stuebing, Fletcher, Shaywitz, Lyon, Shankweiler, 1998; Scanlon & Vellutino, 1997; Shaywitz et al., 1999; Stanovich, 1988, 1993; Stanovich & Siegel, 1994; Torgesen, Wagner, & Rashotte, 1997; Vellutino, Fletcher, Snowling, & Scanlon, 2004). Shaywitz (2003) describes phonological awareness as an inclusive term that "…includes all levels of awareness of the sound structure of words. It also is used to refer to the earliest stages of developing an awareness of the parts of words, such as sensitivity to rhyme or noticing larger parts of words such as syllables" (p.144). Letter-sound decoding is the process of converting the written symbols on the page to the smallest unit of speech sounds called phonemes (Shaywitz, 2003). There is also evidence that dyslexic children have trouble with long-term verbal learning and the retrieval of phonological information from long-term memory. Word-finding difficulties are often seen clinically and deficiencies in lexical retrieval can be manifested by rapid naming tasks.

In a recent summary of what has been learned about dyslexia in the past four decades, Vellutino et al. (2004) reviewed the support behind a number of theories that have been proposed as the underlying cause of dyslexia. Citing findings from the research literature, Vellutino et al. found that there is "…growing consensus that the most influential cause of difficulties in learning to read is the failure to acquire phonological awareness and skill in alphabetic coding" (p.12). More specifically, weak phonological coding has been identified as the central cause of reading disability in most impaired readers (Archer, Gleason, & Vachon, 2003; Ehri et al., 2001; Lyon, Shaywitz, & Shaywitz, 2003; Ramus, Rosen, Dakin, Day, Castellote, White, & Frith, 2003; Vellutino et al., 2004).

Components of Phonological Processing

Phonological processing is defined as the use of phonological information (i.e., the sounds of one's language) in processing written and oral language. *Phonological processing* is defined as the use of phonological information (i.e., the sounds of one's language) in processing written and oral language (Wagner & Torgesen, 1987). It sometimes has been used interchangeably with phonological awareness, but these two concepts are best seen as distinct from one another. Three major components of phonological processing deficits have been identified: (a) phonological awareness, (b) phonological recoding in lexical access, and/or (c) phonetic recoding to maintain information in working memory (Wagner & Torgesen, 1987).

More specifically, research with school-age children has identified three interrelated phonological processing abilities that are important for reading and writing: phonological awareness, phonological memory, and efficiency of phonological access to lexical storage. How the various phonological processing abilities are related to each other and what roles they play in literacy development are issues of considerable theoretical and practical importance.

Phonological awareness (PA) refers to one's ability to detect or manipulate the sounds in his or her oral language (for review, see Anthony & Francis, 2005). PA encompasses phoneme awareness, the ability to manipulate individual sounds (phonemes) in words, and rudimentary phonological awareness skills, such as judging whether two words rhyme. Phonological memory (PM) refers to the coding of information in a sound-based representation system for temporary storage. PM is utilized during all cognitive tasks that involve processing sound information. Individuals' PM capacity is often operationalized by auditory span tasks, like digit span. Rapid naming (RAN) refers to the efficiency of retrieving phonological codes from memory. Individual differences in efficiency of retrieving phonologically stored information from memory are typically measured by performance on rapid autonomic naming tasks in which individuals verbally identify common objects, letters, or numbers as quickly as possible.

Phonological Awareness

Stanovich viewed phonological awareness, as "conscious access to the phonemic level of the speech stream and some ability to cognitively manipulate representations at this level" (1986, p 362). Basically, phonological awareness is a multilevel skill of breaking down words into smaller units (Hoien, Lundberg, Stanovich, & Bjaalid, 1995). It refers to an individual's awareness of or sensitivity to the sound structure, or phonological structure, or segments of differing level in spoken words. Torgesen (1997) defines phonological awareness as the ability to notice, think about, or manipulate the sounds in language.

Dimensions of phonological awareness

Based on recent phonological theories focusing on the hierarchical sound structure of a word, phonological awareness can be described in terms of different phonological tiers such as syllable, onset-rime, and phonemes. Stanovich (1994) viewed phonological awareness as the ability to deal explicitly and segmentally with sound units ranging from syllable, onset-rime, and phonemes. Gillon (2004:5-9) subdivided it into three subtypes; syllable awareness, onset-rime awareness, and phonemic awareness (Figure 2-1).

A variety of measures have been used to assess individual's knowledge of these three differing levels such as auditory discrimination, blending, segmenting, deletion, isolation, rhyming, substitution, sound categorization, tapping, reversing order of sounds, and word to word matching. Especially, regarding phoneme-level of awareness, Adams (1990) describes five different types of manipulative skill in terms of abilities: (i) To do oddity tasks (comparing and contrasting the sounds of words for rhyme and alliteration); (ii) to hear rhymes and alliteration as measured by knowledge of nursery rhymes; (iii) to blend and split (segment) syllables; (iv) to perform phonemic segmentation (such as counting out the number of phonemes in a word), and (v) to perform phoneme manipulation tasks (such as adding, deleting a particular phoneme and regenerating a word from the remainder).

Similarly, research has shown that phonological awareness dimensions can be validly and reliably measure through a variety of tasks (Yopp, 1988). According to Yopp, the dimensions of phonological awareness are represented by a range of difficulty. From easiest to hardest the range of difficulty is as follows: (a) rhyme, (b) auditory discrimination, (c) phoneme blending,

(d) word-to-word matching, (e) sound isolation, (f) phoneme counting, (g) phoneme segmentation, and (h) phoneme deletion.

Factors related to order of difficulty

A number of properties of phonological units have been found to affect the degree of difficulty of phonological awareness tasks including: (a) the position of the unit in words (i.e., first, middle, or last); (b) degree of abstraction; (c) characteristics of tasks used; and (d) size of sound unit and related acoustic features.

- Position: Research points to the differential difficulty for initial, medial, and final positions, with initial and final positions being easier than middle (Byrne and Fielding-Barnsley, 1989).
- Presence of semantic content: Degree of semantic abstraction also affects difficulty. Different from phonemes or rhymes, real words are less abstract entity due to their semantic entity. Thus, words are recognized and manipulated naturally without less instruction. Instead, phonemes are: (a) the smallest phonological unit, (b) not acoustically pure (not easily isolated), (c) independent of meaning, and (d) abstract and arbitrary.
- Task characteristics: The characteristics of tasks involved decide difficulty as well. Adams (1990) indicated that most young children can rhyme but not delete.
- Size of unit: Differential difficulty among units of varying size can be explained by their acoustic features. Spector (1995) conjectured that we do not hear discrete pure phonemes because they overlap in speech chain; rather, we hear in syllables. Therefore, tasks that require sensitivity to phonemes may be more complex and necessarily more difficult than those that require manipulation of syllables. Similarly, syllable segmentation is easier and often develops without instruction in contrast to phoneme segmentation. Liberman & Shankweiler (1985) reported that in groups of four-year-old children, none could segment by phoneme whereas about 50% could segment by syllables
- Processing memory: *Memory* capacity also contribute to difficulty related to phonological awareness since each phonological awareness task requires a certain amount of *memory* capacity to temporarily hold material for later processing. For example, phonemic awareness tasks can be divided into different categories depending on the memory processes and the number of operations required. For example, when asked what sounds are heard in fish (segmentation), only one operation of pulling apart sound is needed (i.e., /f/, /i/, and /sh/) while holding the word in short-term memory. In contrast, when asked to delete the first sound from 'fish' (deletion), a child should (1) segment the sounds, (2) identify the beginning sound, and (3) creating a new chain of phonemes using the remaining sounds filling the memory slot previously occupied by the omitted sound.

Phonological Memory

Phonological memory refers to recoding visually (letters) or orally (speech) presented words into a temporary phonological buffer to maintain efficiently for subsequent verbal tasks such as rote repetition of words/nonwords or conscious manipulation of parts of a word. This process is called verbal short-term storage or temporary retention of phonological representation. Baddeley and his colleague figured out human memory model which best fits various cognitive behaviors. They extended the previous short-term memory, a 'passive storage of verbal input', to a more active working space (i.e., working memory) serving lots of cognitive tasks such as phonological awareness, sentence analysis, retrieval of lexical information from a LTM, or decoding of words.

Old research on short-term memory (STM) has focused on temporary holding of information, rather than on the processes or transformation of information in general cognition. However, for tasks which require more than simple retention of information, a different memory module is needed. For Baddeley and Hitch (1974), the working memory is a 'workspace' and its capacity can be divided between 'processing' and 'storage'. The *storage* portion was referred to as the 'phonemic buffer' or 'phonological loop' and the *processing* portion was referred to as 'central executive'. Tasks such as verbal rehearsal which extracts the information from the phonemic buffer, segmenting, blending, reordering, and substitution were all regarded as the functions attributed to the central executive, a processing system. Figure 2-2 is a simplified display of Baddeley (1986)'s tripartite framework, which had consolidated the position of the working memory model in cognitive psychology. The frame consists of two modality-specific, limited-capacity storage systems called '*slave systems*' and a limited-capacity general processing system called '*central executive*'. Repetition of words, nonwords, or sentence and digit span tasks (i.e., serial recall of digits) are used to measure the efficiency of phonological recoding in working memory (i.e., they measure phonological short-term memory). Among these, nonword repetition is seen as the best measure of short term memory since semantic cues would be available to facilitate rote repetition of nonsense words.

Rapid Naming

A great deal of research over the past 30 years on children's phonological awareness has brought us virtually everything we need to know about identifying children who lack phonological awareness and teaching them to develop this knowledge. However, another capacity was shown significantly compromised in dyslexic children; slow lexical access (rapid automatized naming, RAN in short). Wagner and Torgesen (1987) used a specific terminology for this process: *phonological recoding in lexical access*. It is defined as getting from a written word to its lexical referent by converting the graphemes into sound-based representation system. In general, coding process involves translating stimuli from one form to another (e.g., from letters to auditory). For efficient word recognition, phonological coding ability should be automatized or fluent.

Since Wagner and Torgesen (1987)'s study, a new line of research have suggested that automatized lexical access and retrieval may significantly affect ease of reading acquisition. Rapid naming and lexicality tests are two tasks commonly used to measure ability to fluently code letters into phonological representations. O'Connor, Jenkins, Leicester, & Slocum (1993) reported that significant difference on reading and spelling measures between low- and high-skilled readers could be explained by differences in rapid letter naming. Cornwall (1992) similarly indicated that students that had rapid rates of letter naming did better in word identification and passage reading speed and accuracy than those with lower rates of rapid naming. Wren (2005) indicated that impaired skills in RAN is not easy to identify at younger age, and improving RAN and visual processing speed is considerably more difficult than helping children develop PA. To the theorists, it has been an important question whether the phonological awareness and the impaired RAN represent the so-called double-deficits or whether they are two manifestations of the same underlying disorder (Tijms, 2004). Unfortunately, less is known about cognitive processing model of RAN.

First of all, visual stimuli (letter sequence or pictures) should be converted into a sound representation to get access to permanent lexical item (retrieval). According to Ramus (2001b), after visual or auditory signal is processed to form sub-lexical phonological representation, with which no lexical, semantic information is yet linked, retrieval system will start to find a lexical target of which the phonological form is well matching with the sub-lexical phonetic entity. After retrieval is successfully executed, semantic component of the target item will be activated or pulled out to temporary working memory space and used for subsequent verbal tasks such as comprehension.

Cognitive Model of Phonological Processing

Figure 2-3 provides is a cognitive model of phonological processing and word recognition, which is a refined version of Levelt (1989)'s model of speech production and Ramus' (2001b) model of lexical access. This model integrated 'orthographical lexical access' (reading), 'visual lexical access' (object recognition), and 'auditory lexical access' (speech-based word recognition) to explain reading.

Each box stands for distinct levels of representations and arrows stand for a specific conversion, or translation between different modules. Mental lexicon is divided into three parts (lexical meaning, phonological form, and orthographical form). When children perceive ambient speech signal, it is first encoded as non-specific manner, that is, as non-speech signal (arrow 1). In the model, this non-specific signal is called 'acoustic representation'. At a later stage, this must be encoded as a speech signal (arrow 2). Since no lexical entry is accessed yet, the model uses a term of 'sub-lexical phonological representation' at this level. This sub-lexical representation has also to be converted into a phonological representation for a specific lexical item. So, the arrow 3 between sub-lexical and phonological form represents '*auditory word recognition'*. Auditory word recognition requires the finding of lexical item whose phonological form matches the sub-lexical sound representation. As indicated by Ramus (2001a:201), the phonological lexicon is a permanent, long-term storage for word forms (LTM), whereas the sub-lexical phonological representation is a short-term storage for whatever can be represented in a phonological manner, that is, words or non-sense words. In this regard, Ramus' model can be extended into a new framework, in which the loci of the phonological memory (STM/LTM) and awareness can also be established.

When a word is very familiar to a listener (i.e., *cat*), a procedure called '*whole-word recognition'* will happen without any rehearsal in working memory area, that is, the child may not have to manipulate or rehearse the input sequence of sounds to figure out the ultimate target in lexicon and will instantly map the sub-lexical sound form with the corresponding phonological form (arrow 3). However, when the incoming sub-lexical phonological representation is new or unfamiliar (*e.g., peruse*), the child needs to analyze it into smaller parts (syllable, intra-syllable, or phonemes) and use this parsing information (*e.g. per* + *use*) for lexical retrieval by manipulating or processing them. Since these manipulation tasks are quite different from rote repetition usually done in STM, we need working or processing memory, as a functionally separate module. Working memory is a locus where retention and phonological manipulation (awareness tasks) occur. The input from the STM in *sub-lexical* component can be sent to WM for further manipulation or phonological rehearsal need to process unfamiliar words or non-words (arrow 4). WM also receives its input from the lexical representation. From the *mental lexicon,* phonological form of a lexical item can be sent to WM for further awareness tasks (arrow 5), but WM is not a place for permanent storage like lexical storage. For phonological awareness tasks, WM consists of its own 'retention resource' needed for temporary processing (storage capacity) and 'manipulation function' (processing capacity). In this respect, WM is displayed as separated from sub-lexical and lexicon. Of importance is the fact that phonological processing components (sub-lexicon, WM, phonological awareness skill) are the main gate which incoming auditory signal must enter for successful lexical access and acquisition.

Theories on Impaired Phonology

One of the robust findings in literacy development research is that children with impaired reading skill show concurrent weakness in meta-phonological skills (phonological awareness tasks). Indeed, a child's PA knowledge has been described as the best single predictor of reading performance (Lieberman, Shankweiler, & Liberman, 1989). Because of this, it was assumed that weak phonological awareness is a *'causal' factor* in reading and spelling difficulties. Logically, however, a strong predictive power of a relevant factor does not necessarily imply its causal relation to a resulting condition. Rather, it is still quite unclear in what way aspects of weakened phonological awareness skills are 'causally' linked to reading impairment.

Of equal significance is the fact that deficits in other two areas of phonological processing skills have been also identified in children with reading disorder: (1) inefficient activation of long-term phonological coding in lexicon for rapid naming tasks, and (2) impaired short-term memory skills necessary for immediate or rote repetition of sequences of words or sentences. Considering these general impairments in phonological components, research pointed to a more central phonological module as the possible source of dyslexia (Brady, 1997; Mody, 2003; Snowling, 2001; Swan & Goswami, 1997a).

Thus, the precise nature of the phonological processing difficulties in reading disorder is a central topic of current psycholinguistic research on dyslexia (Elbro & Jensen, 2005). Various hypotheses have been suggested about the nature and origin of phonological processing difficulty in dyslexia. How these problems relate to each other (interrelation), the extent to which weakened phonology is a cause of reading difficulty (causality) continue to be explored, but the exact mechanisms by which dyslexics' weakened phonological processor impact each relevant skill of oral or written language skills such as impaired decoding or spelling, delayed word recognition, and reading comprehension is not clearly documented.

In this section, three theoretical approaches will be shortly reviewed regarding the possible causes of impaired phonological skills in dyslexic population: phonological representation deficit, lexical underspecification hypothesis, double-deficit hypothesis, and auditory perceptual deficit theory.

Phonological Representation Hypothesis

One suggestion is that the dyslexic readers' phonological representations of lexical items may be less well specified than normal children (Katz, 1986; Fowler, 1991; Elbro, 1996; Foy & Mann, 2001; Griffith & Snowling, 2002). Problems related to establishing 'complete', 'full', 'clear', or 'precise' phonological representations in children's speech-based coding system or long-term lexical memory have frequently been mentioned as a possible cause of diverse phonological difficulties of dyslexia.

This hypothesis derives from theories of the development of spoken word recognition and production. When children first begin to acquire lexical items during infancy, each word is coded in terms of certain semantic and phonological features. For example, for them, 'Daddy' may refer to a person of a certain sex/size and it would appear different from 'doggy'. These features will be more fine-grained, specified, and augmented over time. So, children will soon understand the difference between 'Daddy' and 'doggy' or 'Debbie'.

Phonological distinctness refers to the magnitude of the difference between a representation and its neighbors and it is an aspect of the static quality of phonological material. This hypothesis states that a lack of distinctness and/or segmental specificity in dyslexic children's developing phonological representations supporting spoken word recognition and production is causally linked to their impaired phonological processing skills (Goswami, 2000; Snowling et al., 1986, Elbro, 1996). Thus, it should be distinguished from *dynamic* phonological processes such as conscious manipulation, verbal rehearsal, phonological retrieval, and articulation, all using phonetic segments already represented.

For example, due to the poor phonological encoding skill, only parts of the phonetic material of the input can be stored in lexicon (e.g. 'sub' for *subway* or 'croco' for *crocodile*), or relatively full but not complete representation can be provided (e.g. 'cro?dile'), where the question mark indicates that any unspecified segment can be inserted which fits with the phonotactic rules of English (e.g. *crowdile, cropodile*). To sum, inaccurate, underspecified, indistinct, or low-quality phonological representation of incoming sounds may hinder higher level of phonological processing (Snowling, 2001; Swan & Goswami, 1997b; Tijms, 2004).

Lexical restructuring theory

A few evidence for weakened phonological representation come from a theory of lexical learning strategy. Metsala and Walley (1998) and other studies suggested a theory of lexical maturation, 'lexical reconstruction' theory (Fowler, 1991; Walley, 1993). This theory suggests that children's phonological representation of words is re-presented a number of times in terms of different aspects, that is, from whole words to syllables, and phonemes.

It is interesting to note that children's word recognition strategies change with the increase of vocabulary; as vocabulary grows, initial 'holistic representations' are gradually re-structured, and ultimately, phonemes. In this process, frequent or familiar or early-acquired words will be encountered many times and so will experience more re-structuring than less frequent words. Also, children should have more experience for phonologically ambiguous words, that is, words with many similar-sounding neighbors than words with few phonological neighbors.

Another important aspect of this theory with regard to phonological under-specification is that the phoneme would not be an integral aspect until certain period of language growth (Eimas, 1974), but rather it emerges as a representation unit via continuing spoken language experience as children experience further lexical restructuring processes. So, the degree to which segmental (i.e., phoneme-mediated) representation has taken place will be in turn thought to determine children's abilities in phonological awareness, which is essential for phoneme-based decoding process and resulting word-level reading. It is assumed that each child's lexical restructuring would be different in terms of rate and accuracy. Thus, based on a huge body of research on phonological awareness deficit in dyslexia, it is hypothesized that dyslexic children will show delayed or slow developing lexical restructuring.

Similarly, Snowling et al. (1986) and Metsala (1997) provided a few evidences. The former study reported that, when appropriate lexical contexts were provided, dyslexic children were better at recognizing phonologically ambiguous words, suggesting a more holistic lexical presentation. The latter study used a speech gating task, in which small segments from onset of words are presented via headphones (e.g., /f/, /fu/, or /fud/ for *fudge*). Dyslexic children needed more acoustic information than age-matched controls to recognize words when the target word had few similar-sounding neighbors, suggesting that their phonological representation is not totally decomposed into phonemes when compared to the controls. This was interpreted by Metsala (1997) to evidence a delayed segment-based specification of such words.

Application of representation hypothesis

The explanatory power of the phonological representation hypothesis is pronounced when it comes to weaknesses of other phonological tasks. First of all, poor phonological representation would easily explain dyslexic children's typical problems in phonological awareness. Since the child only knows that the sound after initial st- is consonant, but not which, he or she would not efficiently delete [r] and say *sting* when asked to say *string* without saying [r]. Or the child would not easily say *ring* by deleting *st-* when asked to say *string* without saying [st] since he or she is now aware of the actual consonant after *st-* (Elbro & Jensen, 2005). In general, phonemic manipulation tasks (segmenting, blending, etc.) would be very hard if incoming segments are underspecified or incorrectly specified.

Second, the *distinctness hypothesis* (or representation hypothesis) may also account for the picture naming speed deficits, a strong predictive factor of reading disorder. For successful lexical access, it is easier to get access to a phonological representation that is well specified and clearly separated from its neighbors than to unstable or underspecified representations (e.g., Katz, 1986, Bowers & Wolf, 1993). In this way, the representation hypothesis may explain the naming speed deficit.

Third, low phonological distinctness may also be linked to the delayed decoding capacity of dyslexic children. Decoding involves the following steps and each step has its own requirement for successful decoding.

- **Step 1.** Consecutive grapheme-to-phoneme conversion: each letter should be converted into its corresponding phoneme (i.e., p→[p], r→[r], i→[i], n→[n], t→[t]).
- **Step 2.** Representation accuracy (distinct coding): each sound linked to a certain orthographical pattern should be accurately coded in the decoder's phonological representation in a fixed order.
- **Step 3.** Short term memory: every phoneme obtained from step 2 should be held in a phonological buffer temporarily, waiting to be blended to produce a whole word print.
- **Step 4.** Blending (phonological manipulation): each phoneme will be ultimately put together to form a final representation of a word.

If any of these procedures are impaired, decoding problem can occur. Especially, efficient short term retention and blending process would be totally dependent upon the quality of phonological representation of each phoneme converted from input letters. It is expected that step 3 and step 4 will be damaged by underspecified input. Likewise, all phonology-based tasks utilizing underspecified input representation will be deteriorated in a differing degree. These chain-like negative effects of inaccurate phonological representation on related phonological tasks are summarized in the Figure 2-4.

A challenging observation

Based upon the fact that dyslexic children's low performances on phonological processing tasks are related to processing *incoming* sound information, Goswami (2000) indicated that the input-based representation is the major obstacle for further literacy development. So, low scores on input measures of speech perception should differentiate dyslexic children from controls; Dyslexic children should find it more difficult to discriminate between different phonemes in speech (phoneme perception), they should find it difficult to recognize spoken words (auditory lexical decision), and they need more phonological information or clearly articulated input for accurate spoken words (speech gating).

However, lots of studies found that such speech recognition-related skills do not consistently characterize individual dyslexic children even though all these difficulties have been reported in group or population studies (Manis, Doi, & Bhadha, 1997; Mody, Studdert-Kennedy & Brady, 1997). Instead, one consensus has been documented that dyslexic children showed significantly impaired scores on tasks tapping their *production* skills such as word finding difficulties (rapid naming), rote repetition of non-words (STM for nonsense word repetition), and less distinctness of vowel production (See Figure 2-5).

This subtle observation raises some challenges to the theory of phonological representation deficit. Is dyslexia an input-processing deficit (representation deficit)? Or, are other factors necessary for phonological production such as insufficient verbal memory resource or phonological awareness capacity associated with dyslexia (post-input processing deficit)? In spite of the above observation, Goswami (2000) argued that it would be logically possible that our current measures are failing to tap the main representation deficits causing underspecified representation, or that compensation for early representation deficits have already occurred in some children after remediation.

Even though this theory is right, the fundamental difficulties measuring children's inner phonological representation in their mental system would make experimental design hard. According to Elbro (1998), studies of the quality of phonological representations are scarce. In addition, with a good deal of possible evidence for representational or auditory perceptual deficit hypothesis, the fine-grained explanation of the relationship between underspecified phonological representation and associated phonological tasks (phonological awareness, working memory, lexical retrieval) still remains to be resolved to reveal the exact mechanism responsible for the apparent impairment seen at the production level as indicated.

A critical summary

There is now strong and highly convergent evidence in support of weak phonological coding as an underlying cause of dyslexia. Dyslexic children's impaired phonology-based skills such as phonological awareness and alphabetic decoding are believed to be due to the weak coding skill. Other problems such as slow lexical storing and/or lexical access, impairment seen in short-term memory tasks are also viewed as stemming from the phonological underspecification (Vellutino et al., 2004). In turn, difficulties in word storing and retrieval can impair the beginning reader's ability to establish a stable connection between the sublexical phonological codes constructed from oral or graphical stimuli and permanent phonological codes in the lexicon, which will ultimately impede the reader's efficient word identification. Fluency in word identification is a critically important prerequisite for adequate reading comprehension (Perfetti, 1985). Compromised short-term phonological memory can also impair the reader's decoding capacity, for which each phoneme converted from letters needs to be blended in an orderly manner. Thus, phonological coding weakness was hypothesized to be a core deficit which could cause a collection of phonology-based difficulties observed in dyslexics such as word identification (retrieval), phonological awareness, decoding of letter sequences, rapid naming, vocabulary learning, and nonword repetition.

This hypothesis now raises an essential question of why dyslexia is associated with underspecified phonological representation. Very little work has been done on the possible causes of poor representation. Metsala (1999)'s well-known 'lexical restructuring theory' is in line with the phonological representation hypothesis. In this theory, the unit of phonological representation gets smaller starting from whole utterance to phrase, words. For some unknown reason, this lexical restructuring appears to take place at a lower rate in dyslexic children than others. But, this hypothesis also does not readily explain why dyslexics' weak phonological awareness is sustained after their vocabulary grows at a near normal rate and the theory itself does not provide the root cause of delayed lexical restructuring in dyslexic children.

Double-Deficit Hypothesis

Deficits other than phonological ones characterize individuals with dyslexia. Impaired performance on rapid serial naming tasks distinguishes individuals with dyslexia from those with other developmental disorders, like attention-deficit disorder (Felton, Wood, Brown, Campbell & Harter, 1987; Felton & Wood, 1992).

Research suggests that for most children, there are two main aspects that drive the development of fluent decoding skills (Lovett, Steinbach, & Frijters, 2000). First, children should have good meta-phonological awareness skill to identify or manipulate sounds within speech. Secondly, children should be able to process visual or orthographical information very rapidly to be a good reader. This skill is a part of rapid automatic naming (Torgesen, Wagner, Rashotte, Burgess, & Hecht, 1997) and it is reported that children with slow retrieval time for pictures or objects have similar delayed naming with letters or printed words. This slow processing of visual information to activate lexical storage will put some students at a disadvantage when it comes to reading (Lovett et al., 2000).

RAN as a phonological processing skill

Many research studies have demonstrated that RAN makes a contribution to reading that is independent of the contribution of other predictors of reading ability such as phonological awareness and memory (Bowers, 1989; Bowers, Steffy, & Tate, 1988). Nonetheless, RAN has often been placed within the phonological processing domain, along with phonological awareness (both synthesis and analysis) and verbal working memory (Wagner et al., 1994; Torgesen, Wagner, Rashotte, Burgess, and Hecht, 1997). This idea is based on Denckla and Rudel (1974)'s early suggestion that RAN is basically a phonological processing skill. Those who believe that RAN is a component of phonological processing, alongside phonological awareness and memory, define RAN as the "efficiency of phonological code retrieval" (Wagner, Torgesen, Laughon, Sommons, & Rashotte, 1993; Vellutino, Scanlon, Sipay, Small, Pratt, Chen, & Denckla, 1996). Torgesen and his colleagues regarded naming speed into "a part of the phonological family" (Torgesen et al, 1997b). Researchers who conceptualized naming speed as a phonological process suggested that naming speed, like any other linguistic tasks (e.g., expressive vocabulary), involves accessing and retrieving a phonological code stored in long-term memory. One of the reasons for this approach is associated with sufficient amount of correlation between serial naming and performance on other phonological processing tasks and based on that, it is argued that serial naming tasks should be included as part of assessment of children's phonological processing abilities.

However, others have argued that deficits in visual naming speed and phonological processing are distinct and dissociable aspects (Bowers & Wolf, 1993; Wolf & Bowers, 1999). For them, RAN is not a subsidiary component of phonological processing and the evidence based on correlations between speed naming and other phonological skills is insufficient reason to categorize and subsume naming speed under phonology. This opinion that RAN represents functions separate from the phonological processing domain stems from the facts that: (1) RAN consistently makes a unique contribution to reading beyond phonological awareness and memory; (2) some group of poor readers show a specific clinical characteristics (i.e., adequate decoding skill, but slow reading speed).

Three subtypes

Impaired RAN skills, about which there is more controversy, concerns deficiencies in visual naming speed, that is, impairments in rapidly accessing and retrieving names for visually presented symbols (letters, numbers, pictures of objects, or animals) even though the names are quite well known to the child. Wolf and Bowers (1999) proposed a neurocognitive model of reading disability, the Double Deficit Hypothesis (DDH), along at least 2 dimensions of dyslexia subtypes with unique causes of reading failure. According to the DDH, these subtypes are classified according to the presence or absence of phonological and naming-speed deficits, where one subtype exhibits both deficits.

- *Readers within the phonological deficit subtype* are characterized by marked difficulty decoding words and exhibit little phoneme awareness of the sound structure of words. Such individuals have special difficulties with pseudo-word reading. They are typically identified by significantly low scores on tests requiring blending phonemes into words or pronouncing parts of words by removing one or more phonemes (phoneme elision tasks).
- Readers within the second, *naming-speed-deficit subtype* are markedly slower at serially naming a sequence of visually presented stimuli, such as letters or numbers. This deficit is believed to encompass problems with the automatic or rapid word retrieval necessary for the development of fluent reading and ultimately comprehension.
- Readers with problems on both *phonological and naming speed tasks* (i.e., more than one standard deviation below average) fall within a double-deficit subtype. These individuals regularly represent the most severe cases of reading failure.

According to the DDH, as compared with phonological processing ability, rapid serial naming speed contributes unique variance to reading rate and fluency measures (Bowers, 1995), and is a stronger predictor of reading ability in more orthographically transparent languages like German (Wimmer, 1993) and Dutch. These findings suggest a unique role for the processes underlying the rapid recognition and retrieval of visually presented linguistic stimuli, and that they may not be subsumed under the phonological core deficits of dyslexia.

Differentiation from phonology

Intrinsic cognitive complexity of RAN: The rationale for emphasizing the difference between naming speed and phonology is based on the complexity of cognitive procedure involved in them. Wolf, Bowers, and Biddle (2000), using a model of simple letter naming task, argued that serial naming and its internal complexity go beyond phonological processes. For them, visual naming represents a demanding array of attentional, perceptual, conceptual, memory, lexical, and articulatory processes and all of these components places heavy emphasis on precise time requirements.

The following is a simplified version of the model they used to illustrate the complex processes involved in visual naming (Figure 2-6)

- Step 1 (Activation of attention system): Naming task requires the participants to focus on the task with high level of attention.
- Step 2 (Visual processes): Based on adequate level of attention, the letter's visual information will be processed and this will allow for identification process by integrating information about the present stimulus (letter 'B') with known mental, visual representation.
- Step 3 (Integration processes): After Step 2, lexical information will be integrated with accumulated visual information.
- Step 4 (Lexical access/retrieval): Lexical information, especially the target letter's phonological code, will be accessed and retrieved.
- Step 5 (Production): Motor planning and articulation will translate this phonological information into an articulated name.

This model exemplifies both the importance of access to the phonological code in naming and the fact that phonological processes represent only one subset of the multiple processes involved in naming. Also, the authors emphasized the importance of speed requirement needed for fast naming and this is marked as PSR, which is required in every step of whole model. Different from single letter recognition, serial letter naming add to this model the extra demands of rapidity, maintenance of attention, and serial processing. In sum, the model's inherent complexity, the extent of processing speed demands, and the addition of rapid rate and seriation make naming-speed task a quite different cognitive task from phonology (Wolf, Bowers, & Biddle, 2000:393).

Other reasons for differentiation: In addition to the cognitive difference, there are other evidence supporting the differentiation between naming speed and phonology. First, the correlation found between phonological measures and RAN tasks are modest. There is variability in this finding; it is reported that correlation is higher in younger readers and it gets weaker in relatively older readers since naming speed approaches somewhat automatic rates in average readers between Grade 1 and 2 (Biddle, 1996).

Secondly, there are different patterns of relationships with reading subskills that characterize naming speed and phonological variables. Bower and her colleagues found that phonological tasks strongly predicted word/nonword decoding, but not word and text reading speed. Rather, naming speed predicted latency (response time) of word identification and speed of text reading (Bowers, 1993; Bowers & Swanson, 1991). In Bower (1995), only naming speed contributed to speed on reading measures. After finding similar results, Cornwall concluded that "naming speed may represent unique aspects of the reading process as opposed to an overall phonological ability" (1992:537). Given this evidence, to subsume naming speed only under phonology will obscure its separate role in predicting reading disorder.

Linkage between RAN and reading process

The relation between phonological processing skills (awareness, memory) is easily understandable. Specifically, learning to decode through grapheme-to-phoneme conversion requires an acute awareness of and an ability to analyze or blend the sounds within words. For this to be successful, normally developing memory skill must be associated with age-appropriate decoding skills. In contrast, no such straightforward conceptualization exists to explain how the processes underlying naming speed affect word identification and nonword decoding. Wolf et al. (2000) proposed two speculative hypotheses on the possible roles of orthographic processing.

- Orthographic pattern recognition: Slow naming speed can prevent the appropriate amalgamation of the connections between phonemes and orthographic patterns at sublexical level. When a reader does not efficiently merge phonemes decoded from each letter due to slow access to phonological codes, it will surely reduce the efficiency of word recognition.

- Second route involves the importance of the learned association between letters in the development of orthographic representation. That is, if a beginning reader is slow in identifying individual letters (as indexed by RAN), then single letters in a word will not be activated in sufficiently close temporal proximity to allow the child to become sensitive to the knowledge about orthographic (letter) patterns (Bowers, Golden, Kennedy, and Young, 1994). Similarly, Bowers and Wolf (1993) and Wolf & Bowers, 1999) suggested that deficits in visual naming speed disrupt reading acquisition by inhibiting growth in the connections between phonemic and orthographic patterns at word and subword levels of representation during word identification learning. The possible delay and inefficiency in establishing this relationship is believed to reduce the quality of orthographic codes in memory.

Not all scholars seems to accept the view that reading-related cognitive deficits are caused exclusively or primarily by phonological limitations. Double deficit theory suggests that naming speed deficits are caused by disruption of a ‘precise timing mechanism’ that may influence temporal association of visual and phonological counterparts, thereby impairing the child’s ability to detect and represent orthographic pattern. This compromised connection between visual and phonological pattern of a word cannot be explained only by indistinct phonological representation. As discussed above, more *general cognitive problem* such as visual pattern matching may be involved in impaired RAN

Current research may not be able to establish a *unifying* framework with regard to the differences in the psycholinguistic mechanism and underlying causes between these two components. By positing two separate deficits (DDH) cognitive pathways (visual vs. decoding-based), the single-deficit approach (phonological representation theory) may not be the ultimate answer. It may have to be posited that there are multiple causes of reading disorder and there are other cognitive areas that cross many domains including visual, auditory, and, possibly, motor processing. All of these functions need to be developed simultaneously with a normal phonology for successful literacy.

Auditory Perceptual Deficit Hypothesis

Researchers on the opposite side suggested that phonological deficit should be understood in the context of more *general 'sensory' or 'learning impairments'* (Nicolson and Fawcett, 1990; Tallal, Miller, & Fitch, 1993). This 'auditory perceptual theory' has been proposed by Tallal and her colleagues (Tallal, 1980; Tallal et al., 1993). They have argued that dyslexic children have particular difficulties in processing rapidly changing or transient acoustic events, and that the ability to process rapid successive information is fundamental to setting up the phonological system. It is posited that children with language-learning disabilities and dyslexia process sounds more slowly than the average children and this may diminish their ability to distinguish phonemes.

Evidence for this theory comes from studies that measure how much time (inter-signal interval, known as ISI) children need between two sounds before recognizing that there is more than one sound. The children showed deficits in comparison to controls when one stimulus rapidly followed another in both a temporal *order judgment paradigm* (TOJ) and a *same-different discrimination* paradigm. Similar deficits were then observed in 8 out of 20 dyslexic children (Tallal, 1980). ISI is called 'timing threshold' and it is interpreted as the time it takes for nerve cells to fire and process a sound's acoustic features and then recover to pick up the next sound. While the average child has an average timing threshold in the tens of milliseconds range for simple tones, children with reading disabilities have time thresholds measuring hundreds of milliseconds. For example, because the difference between 'ba' and 'ad' occur within tens of milliseconds, children who need longer time to detect changes may not hear the difference. If they cannot discriminate phonetically similar sounds, this may cause underspecified phonological representations of words in lexicon. Theoretically, it was argued that a rapid processing deficit could affect literacy because efficient processing of transient information is critical for phoneme perception and fully specified phonological representation of words in permanent lexicon. This stable, correct phonological specification is regarded as the basis of competent phonological processing (phonemic awareness, short tem retention, and lexical access), which are necessary for successful reading.

This 'auditory processing deficit' theory has become so dominant that a remediation package based on the elongation of brief perceptual cues has been developed and is administered to thousands of children (Merzenich, Jenkins, Johnson, Schreiner, Miller, & Tallal, 1996). However, this theory has lost favor despite its logical appeal (Goswami, 2003). Common criticisms are that: (i) positive findings are difficult to replicate; (ii) that only sub-groups of dyslexics are affected; (iii) that when positive relationships are found they are more robust in control groups, (iv) and that when auditory deficits are found they tend to be small (Ramus, 2003; Rosen, 2003). In response to the criticism, the proponents of this theory argue that, by the time children are diagnosed with dyslexia around age 9, their brains may have compensated for the auditory deficit, but early deficit may have laid the foundation for trouble with other subtle phonological processing skills such as phonemic awareness.

Hearing loss, Phonology, and Literacy

It is now a well established consensus that phonological representation capacity plays a crucial role in language development and language-based cognitive functions such as verbal memory, speech perception, metalinguistic awareness, and literacy in normal hearing children. If, for some reason, children's phonological representation is adversely affected, it is hypothesized that skills mentioned above closely associated with appropriate phonological foundation would be compromised. As far as hearing loss is concerned, the most important question is to what extent children's phonological capacity will be damaged by limited auditory input (Leybaert, 1998).

It should be mentioned that most of previous research have focused on children with profound hearing loss and very few is known about the literacy or literacy-related cognitive skills in children with mild-to-moderate hearing loss. Allen & Schoem (1997) reported that even hard-of-hearing children, that is, children with only mild-to-moderate hearing loss, read at lower median levels than do hearing children. Another limitation of the previous research on the literacy development of heard-of-hearing children is that evaluations of reading skills were done in very limited areas. Thus, understanding the developmental change of a wider and comprehensive range of literacy and related cognitive skills is not yet seen in the current literature.

Phonological Processing, Language Skills, and Hearing Loss

Children's poor word learning can be explained by either misrepresented phonological features or insufficient memory resources (Ramus, 2001b). The quality of incoming auditory input will be limited in children with hearing losses and this might cause the phonological component to be affected especially during the so-called 'sensitive' or 'critical' period of language acquisition. This time-specific delay in phonological component may be the cause of persistent language impairment and later literacy weakness in children with HL. Under-specified phonological input or lack of enough storage capacity can adversely affect normal lexical growth. If a child has a permanent or temporary limitation of auditory input, his overall phonological processing skills can be impacted by way of various routes. Therefore, different from normal-hearing children, hard-of-hearing children's compromised phonological processing skills can have a negative impact on later vocabulary, grammatical knowledge, and overall language competence.

Otitis media with effusion (OME)

Fluctuating conductive hearing loss associated with repeated episodes of otitis media with effusion (OME) occurs most often during the first three years of life, a time that is most important for age-appropriate language development. OME is the presence of the fluid in the middle ear that is not infected. OME typically causes a mild-to-moderate hearing that lasts as long as the fluid persists and the variability in auditory input due to OME has been hypothesized to disrupt children's ability to code phonological information accurately into their phonological representation system (working memory), building up inaccurate sound representation in the lexical storage (long-term memory).

Several studies have tried to relate an early history of OME to language development during the first 3 years of life to examine the effect of OME, which usually occur during critical period of spoken language acquisition. It is posited that early normal auditory functions would facilitate the acquisition of language-specific speech perceptual strategy. In turn, normal access to incoming sounds would also facilitate: (1) the phonological coding via high-quality resolution of acoustic features; (2) stable formation of phonological representation of a word in lexical memory; (3) efficient word retrieval, and (4) enhanced phonological short-term memory (Nittrouer and Burton, 2005).

One correlation study reported that children with OME episodes during the first 2 years of life scored slightly lower in expressive language, but caught up by second grade (Roberts, Burchinal, & Zeisel, 2002). Early impact of OME (first 2 years) on expressive language skills seems to shed light on the importance of "critical time window" for language acquisition, beyond which children do not show fast developmental rate. But, this possible delay in expressive language skills seems to be resolved as children enter 2nd grade level if children are provided appropriate audiologic or speech-language intervention. This suggests that OME's effect on language development is not substantial.

Similar observation can be found in a very recent study. Majerus, Amand, Boniver, Demanez, Demanez, & Linden (2005) reported that 8-year-old children with OME had strictly normal performance for (1) expressive/receptive vocabulary, (2) verbal STM (new word learning/serial words recall), but (3) slight decrease of performance was found in phonological processing/ awareness level (nonword repetition, a rhyme judgment task) when compared with normal-hearing controls. In Roberts et al. (2002)'s study, students caught up with the hearing peers' language skills by the second grade and this period approximates to the mean age of 8, which was reported to be the chronological age when no continuing language delay was documented in Majerus et al. (2005).

However, different observation was documented in Nittrouer et al. (2005). This study analyzed 5-year-old children's phonological awareness, verbal short-term memory, and sentence comprehension. Children with OME showed impaired phonological awareness and verbal working memory. Different from other previous studies, which reported no significant risk for language development (cf. Majerus et al., 2005, Briscoe et al., 2001), this research found *significant delay in language* (sentence comprehension) and indicated that impaired phonological processing was associated with later language delay (syntax). Nittrouer and her colleagues suggested that this different result should be reinterpreted in the context of methods used. It is indicated that most of previous studies reporting no significant language impaired in children with OME used parental checklists (e.g., MCDI), or non-in-depth standardized assessment tools (e.g., CELF), which they say may not assess in-depth language skill. With this in mind, it can be expected that Majerus et al. (20015's documentation of normal language skills found in children with impaired phonological processing skills might be changed if we use in-depth language tests.

Nittrouer and the colleagues also suggested that no group difference between normal-hearing and hard-of-hearing children might be explained by the fact that the majority of children in both OME and non-OME groups came from low-SES group. Because of high correlation between SES and language skills, the possible language difference might have been masked by similarly low language skills in both groups. For this reason, careful control of the SES factor is required for exact evaluation of later language, or literacy capacity. Finally, the mean age of participants also appears to be an important factor for this outcome discrepancy.

As mentioned in Majerus et al. (2005), overall evidence for residual STM impairment in children with OME remains equivocal depending upon different tasks used and subject-related factors such as family supportiveness, quality of later audiologic, speech-language intervention, and socio-economic status (SES), which usually were not reflected in a measurable way.

According to Majerus et al. (2005), hearing loss can affect verbal STM or long-term lexical memory in three different ways: (1) residual perceptual deficit might reduce the accuracy of phonological coding (initial representation in the model) in STM area; (2) this poor phonological coding can cause poor phonological memory because of insufficient acoustic resolution; or (3) limited perceptual input during infancy may lead to less structured phonological form in mental lexicon, which is related to later weak vocabulary level. Phonological representation of a lexical item with weak and low acoustic resolution would hinder efficient both short-term memory tasks and fast lexical retrieval for age-appropriate comprehension/production.

Majerus et al. (2005) reported that OME does not have adverse effect on verbal STM, and phonological processing ability would be subtly impaired. They went on to say that this might indicate the delay of phonological processing tasks in children with OME cannot be related to their normal verbal STM capacity. In this study, nonword repetition skill was shown to be slightly impaired, but it is not sure why this task was not classified as verbal STM. In Norbury, Bishop, & Briscoe (2001) and Baddeley et al. (1998), it is clearly indicated that nonword repetition is best understood as a measure of the capacity of the phonological short-term memory. If we follow this standpoint, the data in this study confirm that part of verbal STM skill (nonword repetition) is significantly decreased. In this respect, further in-depth analysis of the memory skills tapped into by different tasks is strongly recommended, without which it is meaningless to discuss the effect of hearing loss on phonological verbal memory (i.e., STM, WM, or LTM).

Interestingly, verbal STM skill in children with a history of OME was shown significantly delayed or quite normal according to the age of participants. In contrast to Majerus (2005), Nittrouer et al. (2005) reported delayed verbal STM. The average age of participants in this study was 5 (age range: 4;11-5;11 months) and the mean age of subjects in Majerus et al. (2005)'s study, which reported 'normal' verbal STM capacity, was 8 years. Considering the fact that the subjects in Majerus and colleagues' (2005) study showed strictly normal vocabulary skill, it is conceivable that limitation in verbal STM in early ages reported does not seem to have negative impact on later language functioning. That is, early history of OME can have adverse impact on initial verbal STM capacity and this prompt loss of memory skill seems to be recovered. This could be the reason why children's language does not show significant delay later on (Majerus et al., 2005; Briscoe et al, 2001) at the age of 7 to 8 years (cf. second grade). It could be that intensive audiologic or speech-language therapy combined with good family support and SES helped children to catch up with the language skills of normal-hearing peers.

Sensorineural hearing loss

To date, substantial amount of research has been conducted to investigate the effect of OME on later language. Thus, much less is known about the development of phonology and language in children with permanent mild-to-moderate SNHL (Stelmachowicz, Pittman, Hoover, & Lewis, 2004; Briscoe et al., 2001; Gilbertson & Kamhi, 1995; Plapinger and Sikora, 1995; Davis et al., 1986).

Briscoe et al. (2001) assessed three phonological processing skills: phonological discrimination, phonological awareness (onset-rime detection), and STM (nonword repetition) in 4 groups of children (SLI, SNHL, and 2 control groups). Children with SNHL showed scored significantly weakened phonological processing and phonological STM skills than a control group matched on chronological age. But, no difference was observed in SNH and CA control groups on vocabulary and sentence comprehension (syntax). Impressively, considerable individual variation within the SNH group was found; nearly 50% of the SNH group classified 'impaired group' showed phonological impairment associated with poorer vocabulary than remaining children who had no impaired phonology and vocabulary, but both groups' language skills were within normal range.

It is notable that the 'unimpaired' group showed relatively milder hearing loss. This might suggest a causal link between the degree of hearing loss (impaired phonology) and the resulting decrease in language skill in the 'impaired' subgroup. But, the overall result is that impaired phonological processing due to SNHL can occur without clinically significant deficits in language. As criticized by Nittrouer et al. (2005), this might be related to shallow assessment of language skills, which may not find existing language difference in deep level.

Gilbertson and Kamhi (1995) were concerned about phonological skills and new word learning in children with SNHL. Substantial variability was found on measures of vocabulary and word learning, that is, half of the children with SNHL showed normal development and the other half of the children (n=10) performed more poorly than the first group. Based on this observation, they argued that children with SNHL can be divided into two distinct subgroups: (1) one lower-functioning group with impaired word learning, vocabulary; (2) one higher functioning group with normal language ability. They went on to say that hearing level was not significantly related to word-learning or measures of language skills since the higher-functioning group had poorer SRT scores than the lower-functioning group. It is argued that the higher-functioning group's better language (lexical) skill is related to their better phonological memory (new word learning, word repetition). This had led them to the conclusion that one out of every two children with a hearing loss might be considered as language-impaired.

However, for the following reasons, this seemingly important conclusion needs to be carefully interpreted. First, the data show that low-functioning children have better rapid naming skill which is a measure of phonological long-term memory, but this observation was not discussed at all. In contrast, the better STM function (word repetition) of the higher-function group was regarded as a crucial factor for efficient lexical acquisition. Secondly, the scores in grammatical understanding test did not yield a significant language gap between two groups. Also, the small number of subjects in both groups (n=10 and 9) also needs to be considered in terms of statistical power. Thirdly, it is argued that this intra-group difference is not related with the severity of hearing loss, but no explanation regarding the possible link between hearing loss and lower functioning group's impaired phonological memory (STM) was provided. Lastly, as noted by the authors, substantial amount of variance was observed in the performance of children. The delayed vocabulary in their lower-functioning group may have resulted from a set of other extraneous factors such as poor family factor (responsiveness, supportiveness), low quality of intervention, inappropriate educational program, higher age of identification, short duration of hearing aid wearing, low SES, and so on. All of these factors might have contributed to the group difference. Considering the inappropriate data interpretation and the variance seemingly linked to other uncontrolled factors, vocabulary difference may not be a definitely reliable criterion for suggesting that one out of every two hearing impaired children has concomitant language disorder.

Hearing Loss and Literacy

Conductive hearing loss

Links between audition, language, and literacy have been widely studied in children with conductive hearing loss caused by OME (Friel-Patti, 1990; Mody, Schwartz, Gravel, & Ruben, 1999). Despite a considerable number of studies conducted during the past three decades on whether children with frequent OME score lower on measures of speech, language, and reading than children without such a history, the literature is still controversial. Moreover, there are very few comprehensive studies on the effect of OME-related hearing loss on literacy development and the results of research, if any, are quite heterogeneous. One problem of most of studies is that very limited areas of reading or underlying skills of reading are assessed. For example, one longitudinal study with subjects from second graders measured only one area for reading assessment: letter-naming (identification) skill and concluded that no correlation was found between a history of OME occurred up to 4 years of age and literacy (Roberts et al., 2002). This is surely a problem since the subjects in this study were at age range of 5 to 7 years of age, when most of children would master letter naming.

Peters (1994) conducted a longitudinal study testing the effect of middle ear infection on reading and spelling. Subjects were tested on non-word reading, word recognition, reading comprehension, and sentence identification at ages of two, four, and seven. The results indicated that ear infections had a significant effect on spelling, but *not* on reading. Some authors reported difficulties with phonological skills with unimpaired general language skills in children with OM (Peters, 1994), but others did not reveal any difference (Roberts, Burchinal, & Zeisel, 2002). A recent meta-analysis by Roberts, Rosenfeld, and Zeisel (2004) reported no significant difference a number of standardized language measures at preschool age and OME-related hearing loss.

Share and Chalmers (1986) is also a longitudinal study on the relationship between ear infection and reading. They reported *no* significant effect of middle ear infection on reading ability. Hemmer and Ratner (1994) studied the impact of middle ear infection on literacy using six pairs of twins through a longitudinal observation. One of each pair had a repeated ear infection and one did not. Middle ear infection was shown to have a negative effect on vocabulary skill, but had no effect on speech, other linguistic skills, and reading. Abu-Rabia (2002) sampled 49 first graders all from low SES families and 11 children with a history of at least one episode of middle ear disease were assessed for a wide range of phonological awareness skills and pseudo words reading. No significant differences were found on the phonological awareness tasks, and non-word reading task. These findings accord with the above results, suggesting that middle ear infection does *not* adversely impair children's phonological sensitivity and reading development.

In contrast, different result was reported by Nittrouer (2005), in which four groups of second graders participated. It is asserted that conductive hearing loss may have adverse effect on language when it occurs in association with other social or health risk factors. In this study, one group, the control, was from the middle class and had no ear infection; the second group, also from the middle class, had a history of ear infection; the third and the fourth groups of low SES, was with or without ear infection history, respectively. The rationale of the study was that middle ear infection causes temporary hearing loss, which Nittrouer expected would affect the amount of exposure to language. Nittrouer hypothesized that limited language experience would account for the variance in phonological awareness skills.

As stated above, the underlying hypothesis of this study was that phonological awareness can only be developed via explicit exposure to acoustical speech sounds. Significant difference in the performance on phonological awareness tasks was found between the two groups from the middle class, but no differences was reported between groups with low SES, i.e., both groups from low SES families performed at a low level. Nittrouer explained that this lack of group difference in samples from low SES families is due to the fact that slight exposure to print of these children in their homes provided a negative environment against normal phonological and reading development. So, regardless of the hearing status, the possible group difference might have been masked by simultaneous impairment due to the low SES. Similarly, Yoshinaga-Itano (1999) reported adverse overall language outcomes for children attending early intervention services even when the loss was classified as mild, with outcomes more strongly related to age of diagnosis than to severity of loss. Similarly, Davis, Elfenbein, Schum, and Bentler (1986) reported receptive vocabulary, verbal ability, and reasoning to be more than one standard deviation below the mean, even in children with 'mild' hearing loss.

As seen from the literature, the effects of fluctuating hearing loss related to middle ear infection, more specifically the OME, on phonology, language, and literacy are still not explicitly determined. However, the overall impression is that mild or moderate conductive hearing loss does *not* severely impair children's phonological skills. Based on this observation, it can be expected that skills of language and literacy associated with conductive hearing loss would not be significantly compromised. However, reflecting upon possible delay though not statistically significant, it is strongly suggested that further studies include the assessment of wider and deeper range of phonological capacities, reading, and cognitive skills underlying reading process in the children with mild or moderate conductive hearing loss for evidence-based intervention design.

Sensorineural hearing loss and literacy

Reading development in children with permanent SNHL has received relatively much less attention than conductive hearing loss related to middle ear disease. In contrast to children with fluctuating hearing loss, very scant research efforts have been directed to literacy development in children with permanent SNHL. Although there is a large body of research documenting the language and literacy outcomes of children with SNHL, most of this was concentrated on children with profound hearing impairment. So, much less is known about literacy development for these children, even thought it can affect not only hearing level thresholds, but also frequency discrimination (Moore, 1995) and further research strictly focusing on the reading and reading-related cognitive skills in this population is warranted.

Briscoe et al. (2001) compared 5- to 10-year-old children with mild-to-moderate SNHL, children with specific language impairments and children with no hearing or no language-learning difficulties. In common with the SLI group, mean scores of children with hearing loss were significantly poorer on tests of phonological STM (non-word repetition), phonological discrimination, and phonological awareness than chronological age controls. But, no differences were observed in SNH and age control group on language (vocabulary, sentence comprehension), digit/sentence recall (STM), and literacy (reading comprehension, nonword decoding, and word recognition). That is, while the data revealed *little* overall difference of the reading abilities between the hearing impaired and normally hearing children, the hearing impaired children’s phonological skills were significantly inferior to children in the age-control group.

Interestingly, Briscoe and colleagues’ study also reported that there was considerable individual variation within the SNH group. That is, nearly 50% of the SNH group showed phonological impairment associated with poorer expressive and receptive vocabulary and literacy. In addition, this subgroup showed higher hearing thresholds than remaining children without phonological impairment. Thus, it was suggested that there was a link between vocabulary (language) and literacy and phonological skills associated with hearing loss. Strikingly, all three areas of reading (word/nonword reading, comprehension) were shown quite normal (99.5, 91.6, and 95.3, respectively), revealing no significant between impaired and unimpaired subgroups. Overall, this study suggested that major problems in nonword repetition and depressed phonological component occurred *without* clinically significant deficits in wider language and literacy abilities in children with mild-to-moderate SNHL.

Impaired phonology in children with hearing loss

In Briscoe and her colleagues’ (2002) study, it was hypothesized that children with hearing impairment might show phonological impairment similar to those seen in SLI and this was well observed. But, this expected link between compromised damaged phonology and other language and literacy measures was not found in children with SNHL.

The hearing impaired children’s success with reading in spite of depressed phonological processing skills is very notable. It was suggested that even though slight language deficiencies (receptive/expressive vocabulary) were observed, phonological depression linked with auditory limitation would not impede reading skills of children with mild-to-moderate SNHL and at least *some* reading may be possible even without closely associated phonological skills (Gibbs, 2004). This led the authors to conclude that auditory deficit can compromise phonological skills, but impaired phonological skill does not necessarily lead to serious impairments in the reading performance of hearing impaired children.

Theoretically, this argument poses a very important aspect of impaired phonological component found in children with hearing loss since the argument itself is the converse of numerous studies of children with dyslexia, which all agree in indicating that poor phonological capacity will compromise the development of word reading.

A very similar phenomenon was reported in Gibbs (2004)'s study. Fifteen children with mild-to-moderate bilateral SNHL were compared to normally hearing controls on their performance on reading and underpinning skills. Gibbs showed that hearing impaired children's reading abilities were indistinguishable from their hearing peers, while showing phonological skills that were not as good as the controls. So, Gibbs (2004) supports the findings of Briscoe et al. (2001) and offers a similar challenge to the *necessity* of phonological skills in the development of early reading and the *universality* of phonological core deficit theory.

Summary

The following is a short summary of current literature about the effect of hearing loss on phonology, language, and literacy.

Conductive hearing loss

- While there have been a substantial number of studies of profoundly deaf children's reading, the literacy of children with mild-to-moderate fluctuating conductive and permanent SNHL has relatively not received enough attention.
- Results from the studies conducted during the past three decades on the effect of OME-related hearing loss on speech, language, and reading are still controversial.
- However, the overall impression is that mild or moderate conductive hearing loss does *not* impair children's phonological and linguistic knowledge in a way that their reading level is significantly delayed or depressed. Thus, we anticipate that skills of language and literacy associated with conductive hearing loss would not be significantly compromised.

Permanent SNHL

- In contrast to children with fluctuating hearing loss, very scant research has been directed to literacy development in children with permanent SNHL. So, much less is known about literacy development in this population. Further research strictly focusing on the reading and reading-related cognitive skills in this population is warranted.

- The data revealed little difference of language and reading abilities between the hearing impaired and normally hearing children, but the hearing impaired children's phonological skills were significantly inferior to children in the age-control group. The hearing impaired children's success with reading in spite of depressed phonological processing skills was noted.

- Thus, it is assumed that even though slight language deficiency (receptive/expressive vocabulary) was observed, phonological depression linked with auditory limitation would not impede reading skills of hearing impaired children. Furthermore, possible weakness in parts of language areas (receptive vocabulary) does not seem to have significantly adverse impact on later reading capacity in this population.

- Based on this, phonological strength would be regarded as a *sufficient condition* for normal literacy, but *not* as a necessary condition for age-appropriate written language development in hearing-impaired children.

- Children with less significant hearing loss or those with relatively more auditory access to phonemes did not readily use phonological information for reading words in the same way as hearing readers. This preferential use of the visual route was manifested by more dependence upon sight word recognition strategy in children with mild or moderate hearing loss. Further studies which can investigate hearing impaired children's use of sight word use would reveal an interesting fact, which would be of clinical importance.

- To tap children's phonological memory skills (STM, WM, and LTM), a consistent, theory-based theoretical framework should be used to categorize each memory task. Without this, the interpretation of data could be misleading.

- A further recommendation is that the socio-economic status factor should be considered as an influential factor for reading achievement.

- Finally, two issues can be mentioned regarding the research design. First, a longitudinal study design with longer period of observation for reading development is quite warranted to see the trend of literacy development in children with hearing loss. Second, children's hearing levels (aided or unaided) should be representative of the population to be studied. That is, the possible group difference associated with hearing level effect can be obscured when the distribution of hearing loss is skewed.

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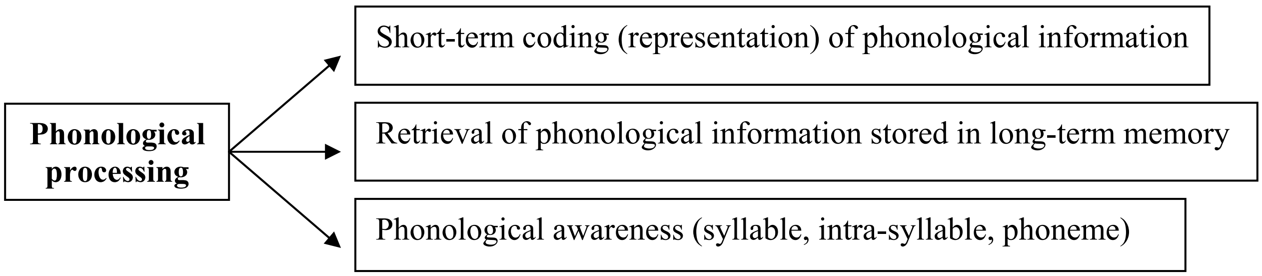

Figure 2-1. Three different areas of phonological processing (Gillon, 2004).

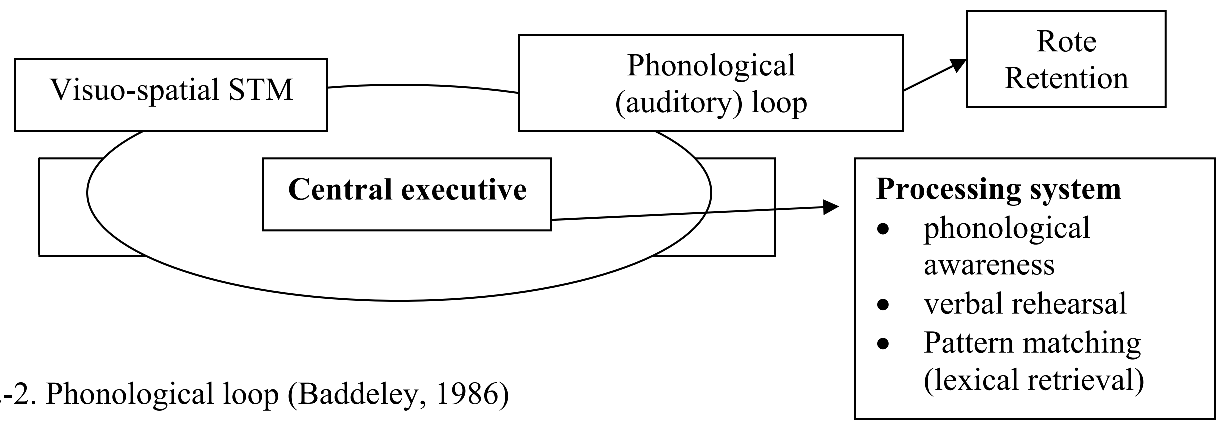

Figure 2-2. Phonological loop (Baddeley, 1986)

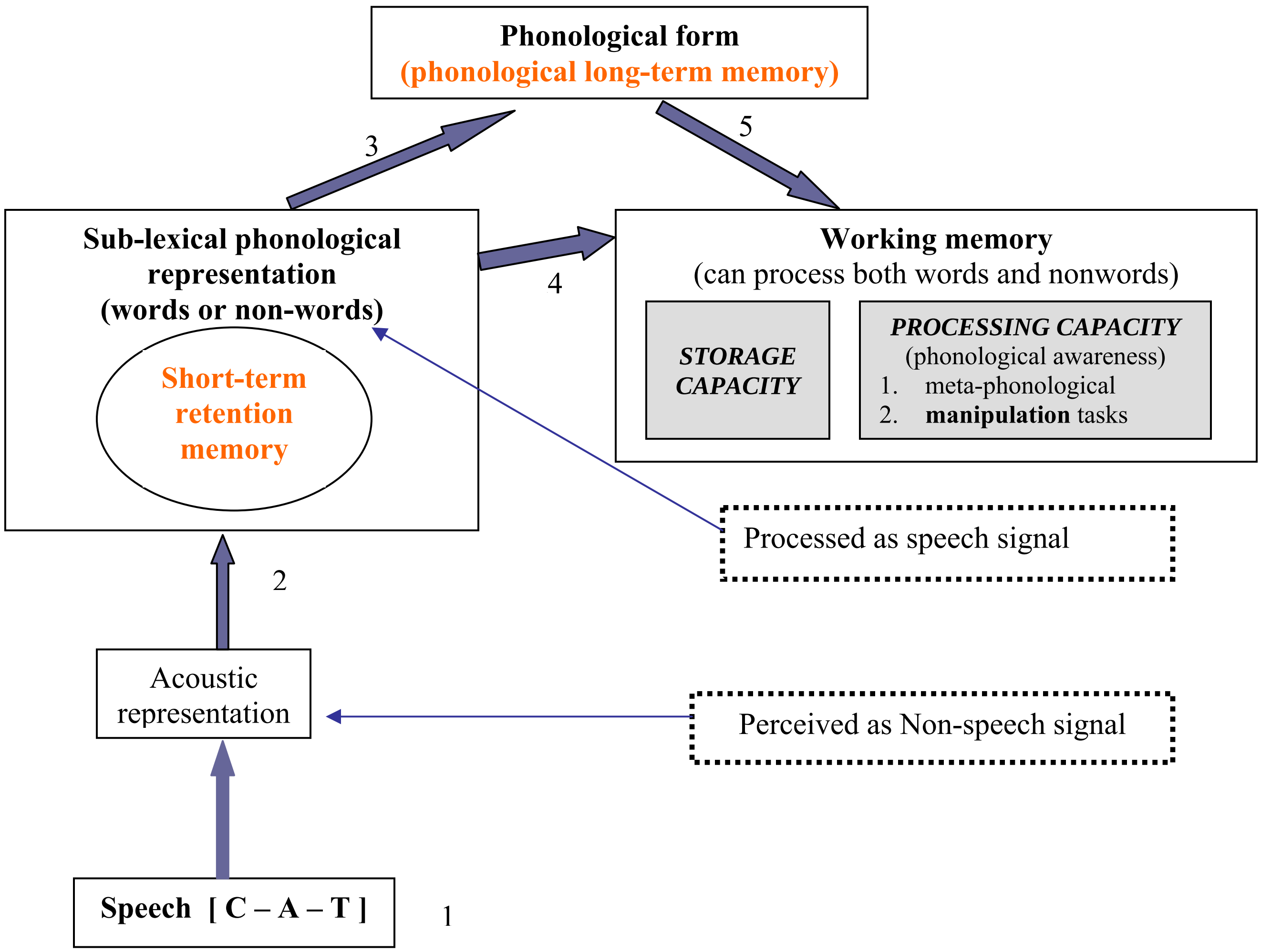

Figure 2-3. Word recognition through phonological route (revised from Ramus, 2001)

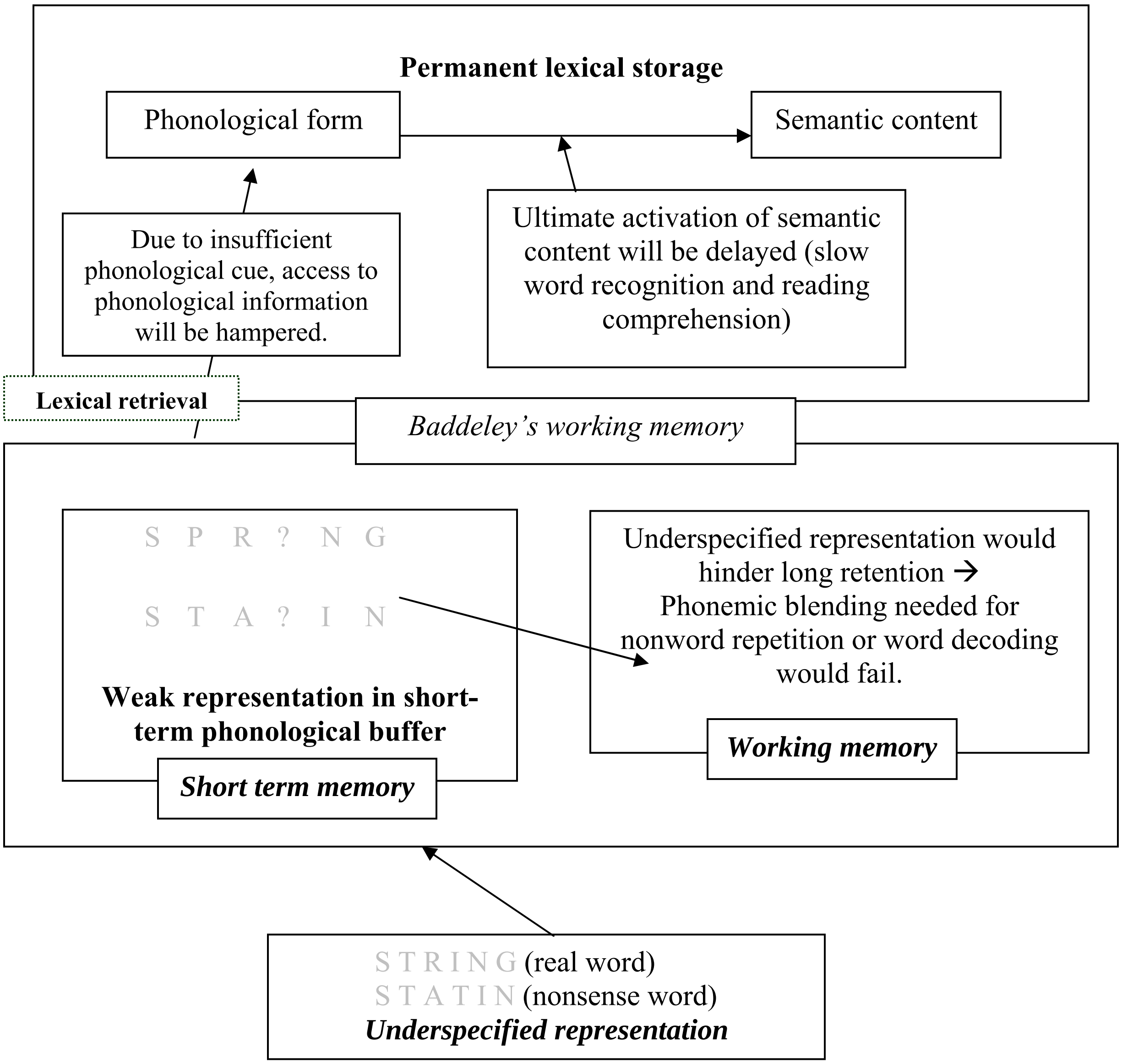

Figure 2-4. Model of (underspecified) phonological representation

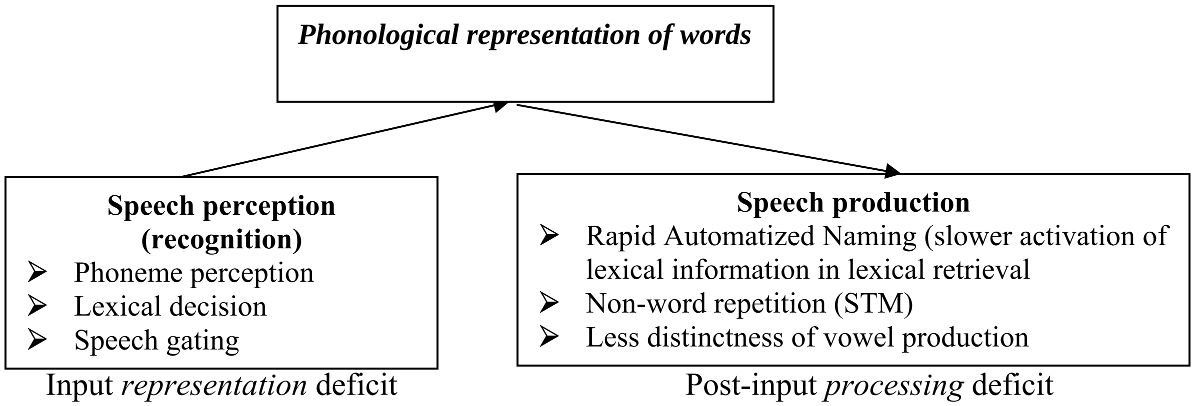

Figure 2-5. Two different aspects of phonological representations (Goswami, 2000).

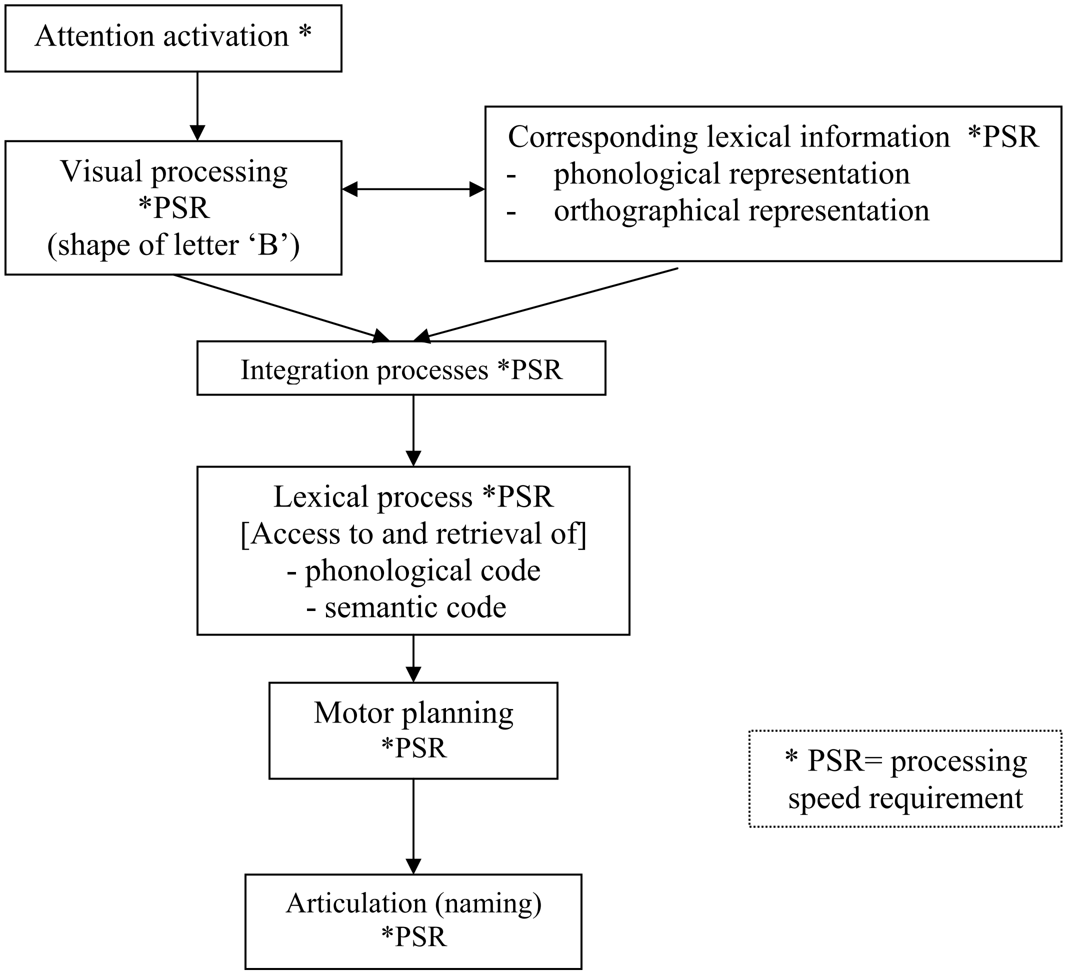

Figure 2-6. Simplified model of visual naming (Wolf et al, 2000:394)

CHAPTER 3
METHODS AND MATERIALS

Introduction

Despite the substantial number of empirical studies on phonological development and phonology-based reading skills in children with deafness, little is known about hard-of-hearing children's skills in similar areas. Most previous studies concur that hearing impaired children's phonological processing skills could be adversely affected during the critical period of language development possibly due to decreased acuity of peripheral audition related to congenital hearing loss. However, impaired phonological processing skill has not been reported to negatively impact reading and related cognitive skills (Briscoe et al., 2001; Gibbs, 2004). This study is designed to further explore relationship between phonological processes, spoken language, and reading.

This cross-sectional study addressed the following primary research question: *What are the effects of mild to moderate sensorineural hearing loss on the phonological processing skills, oral language, and reading ability?* It was hypothesized that hearing loss would affect phonological awareness, rapid naming, verbal memory, vocabulary and grammar, and reading skills (reading fluency and comprehension). To investigate this question, the investigator used a theoretical framework of 'phonological core deficit hypothesis,' established in the study of developmental reading disorders.

A wide range of tests in the areas of reading and spelling, oral language, phonological processing skills, auditory processing ability, and basic auditory skills was used to accomplish this objective. Reading skills were measured for word reading under timed and untimed conditions, spelling, oral reading fluency, and reading comprehension. Also, a range of phonological processes were measured, including (1) phonological awareness (blending and deletion), (2) phonological short-term memory (digit span, nonword repetition), and (3) rapid naming skills (digits and letters). Further, auditory processing skills were investigated using a subset of tests from a screening test of central auditory processing ability. Basic auditory skills were checked by obtaining thresholds for stimuli consisting of pure-tones and speech signals.

The research methods presented in this section are addressed under the headings of recruitment setting, participants and selection criteria, procedures, treatment of the data, and research questions.

Setting and Participants

The purpose of this section is to describe the instructional settings where the study took place and to provide a description of the participants. Demographic and audiologic characteristics of the participants are provided for three groups of subjects.

Recruitment Setting

Three groups of children between 7 to 12 years of age, were recruited for the study: (1) 19 children with mild to moderate hearing loss measured by their better ear's pure-tone average (PTA); (2) 29 children with normal hearing and reading skills; and (3) 30 dyslexic children with normal hearing ability. The University of Florida Institutional Review Board (IRB-02) approval (UFIRB 2006-U-0535) was received to recruit participants and conduct the research. Data were collected from October 2006 through October, 2007. For the group of children with hearing loss, 2,500 flyers and recruiting letters containing information about the study and contact information were sent out to public elementary schools located in the following ten counties in north central Florida region: Alachua, Clay, Duval, Gilchrist, Lake, Marion, Orange, Putman, St. Johns, and Volusia Counties. Around fifty parents or guardians of hearing impaired students expressed interest in the study through reply letters, emails, or phone calls. All students were enrolled in public elementary schools in the central Florida area. Participants with hearing loss were recruited from several sources, including contracts with the Exceptional Student Education department (ESE) of each county, advertisements posted at hospitals and several churches located in Gainesville, FL., and personal acquaintances. For the hearing impaired subjects, directors of ESE department were contacted to help distribute recruiting letters to schools which had special program for hard-of-hearing children. Letters were sent to the families through classroom teachers. Of the 69 (2.8%) children who returned permission forms or expressed their interests, 50 (70%) were qualified to participate in the study. All participants with normal hearing and reading ability were recruited from twelve elementary schools located in Gainesville, FL through the department of research at the Alachua County School Board.

Selection Criteria

Potential participants were required to satisfy the following criteria.

- Each participant must be a native speaker of American English.
- Each participant's non-verbal intelligence screened by the Test of Nonverbal Intelligence-3 (TONI-3, Brown L., Sherbenou R. J., & Johnsen S. K., 1997) must be equal to or more than 80.
- All participants were required to have normal tympanograms and no signs of middle ear infection at the time of testing.
- All parents of participating children were required to read and sign the informed consent letter.
- Children's hearing loss must be binaural sensorineural and not associated with any other sensory impairments, neurological and/or neurodevelopmental disturbances. When potential subjects were identified, children with monaural SNHL and/or cochlear implant devices were excluded.
- Hearing loss must be congenital and the participants must wear hearing aids for both ears at the time of testing. Exception was allowed only when the hearing loss was very mild (26 dB HL to 30 dB HL) and the participant's word recognition scores for both ears were 100% at the most comfortable level (MCL).
- All hearing-impaired participants were required to attend a mainstream school and use speech mode as their primary communication mode.

Participants

Parental consent was obtained for each child participant at the onset of the investigation. When a family agreed to have their child participate in the study, the child's parent or guardian provided informed consent as required by the course of the study and a completed questionnaire (Appendix A). The information in this form was used to check the subject's language and reading ability, the status of hearing loss, age at identification of hearing loss, age at initial audiologic intervention, duration and frequency of speech language services, developmental change of patterns or types of hearing loss, family history of hearing loss, and any known etiologic cues. Children were not compensated for their time. Instead, the participants were provided a letter of test scores within three weeks.

The participants in the present study initially consisted of two groups of students between 7 and 12 years of age: (1) A sample of 29 normally developing children, and (2) a sample of 19 children with mild to moderate binaural SNHL. Ethnicity representation for the students in the HI and the NH groups was predominantly Caucasian (n=38), followed by Asian American (n=5), Hispanic (n=3), and African-American (n=2). After the data collection of these two groups was over, an additional archival data set of thirty dyslexic children was incorporated for the purpose of comparison and formed a third experimental group.

Participants with normal hearing and reading skills (NH group)

For the control group of children with normal hearing ability and reading skills, thirty eight potential participants responded. After removing nine students who did not satisfied all inclusive and exclusive criteria for the following reasons, the group was reduced to twenty nine (boys=16, girls=13). None of the children participating in the control group were known to have histories of speech, language, or hearing problems, or any type of exceptional educational needs.

- Three students had bilingual background (one for Spanish and two for Korean language)
- According to the questionnaire form, four children were reported to have developmental reading difficulties. One of them actually completed the protocol for the study, but due to this problem, the data could not be included in the final data.
- Two students who also completed the protocol were excluded from the data since their ages were either lower or higher than the suggested research plan.

The mean age (in months) and mean grade (in years and months) of this NH group were 111;9 (SD= 14.0) and 3.8 (SD=1.15), respectively.

Participants with hearing impairment (HI group)

Thirty-one children with prelinguistic, sensorineural hearing loss were contacted. The children's parents or guardians were asked if their children had been or were currently receiving speech or language therapy. Only four participants who enrolled in the study were not receiving speech and language therapy. All subjects in HI group had binaural sensorineural hearing with better ear's hearing thresholds in the mild to moderate range (26 to 70 dB HL) as assessed by the pure-tone average (PTA). All children wore ear-level hearing aids, with only one subject aided monaurally.

Two categories of hearing loss were identified in this sample, on the basis of the child's PTA in the better ear. Mild hearing loss defined as having a PTA of 20 – 40dB HL and moderate hearing loss was defined as a PTA of 41–70 dB HL. Audiometric assessments revealed that 6 children had mild hearing loss, whereas 13 children met the criteria for moderate hearing loss.

Information about hearing loss, audiologic services received, and clinical histories were determined through interviews with at least one parent or guardian and/or a parental questionnaire form provided in the recruiting letter packet. Among these thirty-one potential participants, twelve children who did not satisfy the inclusive and exclusive criteria were excluded from the study.

- Four children were reported to have only monaural hearing loss.
- Three children had bilingual background and they were all Spanish-speaking participants.
- Three subjects were reported to wear cochlear implants for at least one ear.
- Two children completed the protocol for the study; however, their data were excluded from final data since their hearing losses were found to have developed after four and three years of age, respectively.

Nineteen hearing impaired children included in the final selection (mean age [in months] = 110.8, SD = 19.3, mean grade [in years and months] = 3.4, SD = 1.61, boys = 11, girls = 8) were designated as the experimental group (HI group). They were all enrolled in public elementary schools that provided oral programming for hard-of-hearing students and emphasized use of their residual audition for the development of speech and language skills.

Dyslexic group (RD group)

To enable a rigorous investigation of the strengths and the weaknesses of the HI group's performance on phonological processes and literacy skills, the investigator decided to add a third group of children with specific reading disorder who have no auditory perceptual limitations due to cochlear damage. That is, the HI children performances on phonological processing and literacy were compared to those of age and grade-level matched dyslexic controls of similar nonverbal ability.

Many dyslexic children have a history of language difficulty (Rutter and Yule 1975) and dyslexia is conceptualized either as a mild form of language impairment, affecting only the phonological system, or as a residual problem that remains when oral language difficulties have resolved (Aram, Ekelman, and Nation 1984; Scarborough and Dobrich, 1990).

Based on the fact that the auditory system is crucial for the development of language, many researchers have suggested that for at least some of the children with phonologic dyslexia, there may be a disorder within the auditory system that has disrupted normal acquisition of language.

However, unlike hearing impaired children, the disruption is not occurring at the periphery, but at certain point in the ascending auditory pathway or the cortical level, through intrahemispheric, interhemispheric or associative connections (Moncrieff, 2002). There is evidence to indicate that dyslexic readers have abnormalities within some of the auditory structures necessary for language development, including symmetry differences of the planum temporale (Hynd, Semrud-Clikemand, Lorys, Novey, and Eliopulos Hynd, 1990; Kushch, Gross-Glenn, Jallad, Lubs, Rabin, Feldman, and Duara, 1993; Larsen, Hoien, Lundberg, and Odegaard, 1990; Leonard, et al. 1993), abnormal portions of the corpus callosum (Duara, Kushch, Gross-Gleen, Barker, Jallad, Pascal, Loewenstein, Sheldon, Rabin, Levin, Lubs, 1991; Hynd, et al. 1995), and Heschl's gyrus in the right hemisphere (Leonard, et al. 1998; Musiek & Reeves 1990; Penhune, Zatorre, MacDonald, and Evens, 1996).

Therefore, these children with specific reading disorders would serve as an informative comparison group when investigating the impact of congenital *peripheral* hearing loss on the development of phonological processing and related literacy skills in comparison to the one associated with cortical or *central* disruption of auditory processing. Currently, there is no in-depth study that has looked at the different characteristics of hearing impaired and dyslexic children’s performances on phonology and reading measures.

Thirty dyslexic children’s data were selected from an archival data set that has been collected from 1999 to 2003 from the Dyslexia Clinic Program at the University of Florida Speech and Hearing Clinic (mean age[in months] = 116.6, SD = 20.3, grade[in years and months] = 3.96 , SD = 1.62, boys = 18, girls = 12). All subjects were diagnosed with dyslexia, a specific reading disability. Some parts of variables were not available for this RD group for the following variables: (1) basic audiometry (puretone and speech), (2) auditory processing measures, and (3) oral language measures. However, normal hearing abilities were confirmed for all dyslexic participants through hearing screen on the day of testing by a certified audiologist in UFSHC or by parent report of normal hearing based on previous testing.

Matching Variables

Normally developing (NH) and dyslexic subjects (RD) were selected to match age, grade, and sex of the hearing impaired subjects (HI). Statistical comparisons revealed that these variables were well matched on chronological age, grade, and gender for the groups (Age: $F[2,75] = .778$, $p = .463$; Gender: $F[2,75] = .011$, $p = .989$; Grade: $F[2, 75] = .818$, $p = .445$).

A non-verbal IQ measure was selected as a covariate in data analyses to reduce any existing effect of intelligence on reading skills. This test was only administered to children in the NH and HI groups. A criterion nonverbal IQ of 80 as assessed by the TONI-3 was required. Controlling for nonverbal IQ was deemed necessary because a univariate one-way ANOVA confirmed a significant group effect ($F[1,45] = 3.406$, $p = .042$). Therefore, controlling for this nonverbal IQ measure was justified (See Table 3-1).

Procedure

The experimental tasks were completed in two separate sessions in a quiet room in the UFSHC and the speech hearing clinic in the University of Central Florida. In the first session, which lasted for about 90 minutes, general information about the test and the test procedure was explained to students and their parents or guardians. Upon successful confirmation of eligibility, each participant signed a written consent for the data to be used for research purposes and completed all audiologic testing. In a second session that followed within two weeks, tests were administered in the areas of phonology, oral language, and reading for about 120 minutes.

Because of decreased speech intelligibility, hearing impaired children's responses on all of phonological processing tasks were recorded digitally using Olympus digital voice recorder (Model No. DS-40) and phonetically transcribed by the author for scoring.

The author and two other research assistants administered tests to all participants. Two research assistants were senior undergraduate students in speech-language pathology. Both assistants were trained by the investigator in test administration. For reading and language tests, the author provided specialized instruction to the assistants and 50% of training sessions were supervised by a certified speech pathologist. To ensure reliable test administration and scoring, whenever any deviation from the protocol occurred, additional instruction was provided until that assistant was able to demonstrate complete compliance with the testing protocols.

All audiologic tests were conducted by three doctoral students enrolled in the Doctor of Audiology program (AuD) of UF and one certified audiologist from UCF. All tests were administered in a soundproof suite using recorded material.

Materials

Each NH and HI participant was given tests individually in four separate domains, including (1) auditory function, (2) phonological processes, (3) oral language, and (4) reading and spelling from September 2006 through October 2007. However, RD subjects' data on auditory function and oral language were not available from the archival database. Table 3-2 is a list of all the tests that were used. Descriptions of the test instruments are presented in detail in the next section.

Audiologic Measures

All subjects were examined otoscopically to rule out the presence of fluid in the middle-ear-cleft. Each listener was tested in one 60-min session and received all tests in the above listed sequence. Both left and right ears were tested to determine the better ear. The audiologic test battery consisted of (a) a pure-tone threshold test at 250, 500, 1000, 2000, 3000, 4000, and 8000 Hz, (b) a speech recognition threshold test, (c) word recognition test, (d) two central auditory processing tests, and (d) tympanometry.

Puretone and speech audiometry

The hearing acuity of the children was assessed in a conventional manner since all of participants were 7 years or older. The air-conducted thresholds were examined in a sound proof booth at 0.24 - 8 kHz with a GSI 61 clinical audiometer calibrated according to the ISO-389 standards (1985), employing insert earphones (E-A-R-TONE® 3A Insert Earphone) and TDH-39 headphones.

A standard audiometric staircase procedure (5-dB step size; down 10 dB, up 5 dB rule) was used to obtain pure-tone air conduction thresholds. The intensity recorded as threshold was the lowest intensity at which two correct responses were given (response in the presence of a stimulus tone) out of four presentations. Children responded to test stimuli by hand-raising. Bone conduction thresholds were obtained in a similar manner if air conduction thresholds were 20 dB HL at any frequency. PTA (pure-tone average at the frequencies of 0.5, 1 and 2 kHz in the better ear; right ear if equal hearing) defined each participant's hearing threshold.

Speech reception thresholds and word recognition scores in percentile were measured via live voice using CID W-22 spondaic word lists (Audited Revised Auditory Tests CD). For the NI group, stimuli were provided at the most comfortable level (MCL) as determined in the speech reception thresholds (SRTs). For hearing impaired children, unaided thresholds were obtained. Listeners wore various hearing aids ranging from basic analog to high performance digital technology.

The subjects in the NH group had pure-tone thresholds of 15 dB HL or better at all octave frequencies from 250 to 8000 Hz with an exception of one male child, whose right ear pure-tone threshold for 2 KHz was 21 dB HL. All hearing subjects also had excellent word-recognition scores ranging from 880% to 100% for the CID W-22 word lists (M = 99.0, SD = 2.95). Hearing impaired subjects' pure-tone thresholds at 0.25, 1, and 2 kHz ranged from 0 to 13 dB HL and their word recognition scores measured at the MCL level were moderately good (Right ear: M = 75.2, SD = 29.6, Left ear: M = 86.0, SD = 21.9).

Auditory processing tests

Based on recommendations by Musiek & Chermak (1994), four commonly used central auditory tests were administered to all participants in the NH and HI groups: (1) One subtest, the *Dichotic Digit* test, was selected from the Central Auditory Processing Tests developed by Frank Musiek, and (2) three subtests were selected from the SCAN-C/A screening test for auditory processing disorders (SCAN-C for children aged 3 to 11 years, SCAN-A for subjects aged 12 and more). Musiek's (1983) *Dichotic Digits* test is a test of binaural integration in which pairs of digits are delivered simultaneously to each ear at the MCL, with each ear receiving a different digit pair. This test has good validity data and is simple and quick to administer and to score. Subjects were given three practice items to ensure their understanding of the task. All stimulus items consisted of monosyllabic digits from 1 to 10 (excluding 7) spoken by a male speaker of General American English. Stimuli were routed from a CD player through a two-channel audiometer meeting ANSI (1996) standards and were delivered via TDH-49 headphones at an intensity of 40 dB SRT. Twenty stimulus items consisting of four digits each were presented. The test was administered following standard clinical recommendations (Musiek, 1983) using a free-recall paradigm. Performance was scored as a function of percent correct for each ear. The minimum subject age for this test is 7 years (Musiek, 1983). Administration time was approximately 5 to 6 minutes.

The SCAN is a screening test for auditory processing disorders (Keith, 1986). It may be used to identify potential factors related to poor social skills, language use, and academic performance in children from 3 to 11 years of age. This test was developed to determine possible central nervous system dysfunction by assessing auditory maturation, (b) identify children at risk for auditory-processing or receptive language problems who may require additional audiological or language testing, and (c) identify children who may benefit from specific management strategies (Keith, Rudy, Donahue, & Katbamna, 1989).

For this study, first three SCAN subtests were given in the order stipulated by standard test format (*Filtered Words* ([FW], *Auditory Figure Ground* [AFG], *Competing Words* [CW]). In the *Filtered Words* subtest, the subject is asked to repeat words that sound muffled. The test stimuli consist of one syllable words that have been low-pass filtered at 500 Hz. Two practice words and 20 test words are presented to each ear. In the *Auditory Figure-Ground* subtest, the subject's ability to understand words in the presence of background noise is measured. One syllable words were recorded in the presence of multi-talker speech babble noise at the 0 dB signal-to-noise (S/N) ratio. Two practice words and 20 test words were presented to each ear. In the *Competing Words* subtest, the subject hears two words simultaneously--one word presented to each ear. The test stimuli consist of one syllable word pairs presented to the right and left ears. First, two practice word pairs and 15 word pairs are presented. The subject is instructed to repeat the words presented in each ear, repeating the word heard in the right ear first. Then, a second set of two practice word pairs and 15 word pairs are presented, with the subject repeating the word heard in the left ear first.

Middle ear function (tympanometry)

All participants were required to pass a tympanometry screening (i.e., type A with equal to or more than 0.2 ml compliance) to ensure normal eardrum and middle ear functions. Acoustic immittance measures used to determine middle ear function were obtained by using a commercially available middle ear analyzer (Grason Stadler, Model GSI-33). Tympanograms were obtained in both ears on all participants during the first session. Any tympanogram for which tympanometric width could not be calculated (i.e., no measurable peak) resulted in a rescheduling of the participant for testing at a later date. Children were considered to have normal middle ear function when their tympanometric width was 250 daPa in both ears (criterion based on Nozza, Bluestone, Kardatzke, & Bachman, 1994). Only one normally hearing participant had middle ear infection at the time of testing. One month later, this subject was retested after the infection had been treated.

Literacy (Reading and Spelling)

All subjects in the three groups (NH, HI, and RD) were administered exactly the same set of tests in the areas of phonological processing and literacy (reading and spelling). To test reading and spelling, eight standardized subtests from four published tests were used. To test phonological processing skills, six standardized subtests were taken from one published test. A description of each test is provided below.

Woodcock Reading Mastery Test – Revised (WRMT-R; Woodcock, 1987): Three subtests of the WRMT were administered to assess: (1) untimed phonemic decoding skills for real words and nonwords, and (2) passage reading comprehension. The *Word Identification* and *Word Attack* subtests comprise 106 and 45 pronounceable real and pseudo words of increasing complexity, respectively. Especially, in the *Word Attack* subtest, five unfamiliar words are presented at a time on one page, and the examinee is asked to read them aloud as accurately as possible. Pronunciation rules are provided for the examiner to determine the accuracy of the child's responses. This test is discontinued when six errors are made. The *Word Attack* subtest evaluates the child's ability to use phonic skills to determine the correct pronunciation of unfamiliar words while reading aloud letter combinations that form nonsense words. The *Passage Comprehension* subtest requires participants to read a segment of prose with a missing word and say word(s) to fill in the blank(s) in the printed paragraph.

The WRMT-R test record allows for raw scores to be converted to age equivalent scores, grade equivalent scores, and standard scores ($M = 100$, $SD = 15$). The WRMT-R was selected for two reasons: (a) to measure word and nonword reading normed on the same sample, and (b) to use large numbers of test items in order to reduce the likelihood of idiosyncratic word knowledge causing lack of reliability (Olson, Forsberg, Wise, & Rack, 1994). The WRMT-R has more items than other tests with a similar format. Content and concurrent validity are well documented in the test manual (Woodcock & Johnson, 1989). Internal reliability coefficients of the WRMT-R calculated based on split half reliability for 1st through 3rd grade ranged from .91 to .98 (M = .94; Woodcock, 1987).

Wide Range Achievement Test-3 (WRAT-3; Justas & Wilkensen, 1993): The WRAT-3 includes three subtests that measure reading, spelling, and arithmetic skills. The WRAT-3 is an academic achievement test that has been shown to have good correlation with the Wechsler Individual Achievement Test. For the purpose of this study, only the *Spelling* subtest was used to assess the ability to spell single words. Children were asked to write single words on test form after listening to the target word followed by a sample sentence. Children are asked to try as hard as they can to spell every word. For each item, target word is spoken first in isolation and then in a sentence in which the word is stressed. Finally, the word is spoken again. Standard scores ($M= 100$, $SD = 15$) are provided for 32 age groups. Internal consistency reliability figures in the range of $r = .86$ to .91 are reported for children ages 7 to 13 years. The inclusion of a spelling measure is based on the strong association between early spelling ability, phonological awareness, and beginning reading (Ehri & Wilce, 1987).

Test of Word Reading Efficiency (TOWRE; Wagner, Torgesen, & Rashotte, 1999): The TOWRE was given to measure ability to pronounce both sight words (*Sight Word Efficiency* subtest) and nonwords (*Phonemic Decoding Efficiency* subtest). In the *Sight Word Efficiency* subtest, 104 context-free single words of increasing complexity in terms of phonological structure are given. Participants were asked to read aloud as many words as possible in 45 seconds. Similarly, the *Phonemic Decoding Efficiency* subtest of the TOWRE was administered to quantify rapid nonword decoding skill. The subtest presents 63 pronounceable pseudo-words and participants were asked to read as many nonwords as possible in 45 seconds.

Gray Oral Reading Tests-4 (GORT-4; Wiederholt & Bryant, 2001)**:** The GORT-4, a measure of reading fluency (accuracy and rate) was administered individually to each participant to test reading fluency only. Both the child and the examiner were audio-recorded with an Olympus DS-40 Digital Voice Recorder for more accurate scoring procedure. Especially, recording was necessitated especially because of the decreased speech intelligibility of hearing impaired children in fast passage reading task.

The GORT-4 is designed for children aged 7;0 to 18;11 (in months). It consists of 13 passages. Each passage has one paragraph that is centered on a single topic. Across the test, there is an increase of length and complexity of paragraph, sentence, grammatical structures, and vocabulary content. The test yields raw scores, standard scores, percentiles, and grade-equivalent scores. The fluency assessment is a composite score of two components: a *Rate* (i.e., the time taken to read each passage) and an *Accuracy* (number of deviations from print). The mean for the two subtest components is 10, with a standard deviation of 3. They were instructed to read each story aloud as quickly and accurately as possible.

Phonological Processing Skills

Comprehensive Test of Phonological Processing (CTOPP**;** Wagner, Torgesen, & Rashotte, 1999). Phonological coding is an oral language skill and consists of the analysis and synthesis of phonemes converted from visual stimuli of letters. Beginning readers who have deficits in phonological coding seem to have difficulty naming letters of the alphabet, identifying sounds for alphabet letters, segmenting words into phonemes and syllables, and applying knowledge of letter-sound correspondence to decode words (Vellutino, et al., 1996). For example, phonological coding involves analysis such as recognizing that the first sound of the word ball (/b/) can be replaced with /t/ to produce the word tall. Phonological coding abilities associated with this process of changing 'ball' to 'tall' include: (1) letter-sound correspondence, (2) phonemic awareness and segmentation, and (3) working with information in phonological working memory. For this study, six subtests of the CTOPP were used, including the *Elision, Blending Words, Memory for Digits, Nonword Repetition, Rapid Letter Naming*, and *Rapid Digit Naming* subtests (Form A).

The CTOPP is an individually administered, norm-referenced measure that is used to evaluate a wide range of aspects of an individual's phonological processing. A three-part model, based on earlier studies in this area has been presented by the test developers (Torgesen & Wagner, 1998; Wagner & Torgesen, 1987). That is, three pairs of scores were combined to produce composite scores: *Elision* and *Blending Words* for *Phonological Awareness composite*, *Memory for Digits* and *Nonword Repetition* for *Phonological memory composite*, and *Rapid Letter Naming* and *Rapid Digit Naming* for *Rapid Naming composite* scores, respectively. The following is a short description of each of these components.

- Phonological awareness: analysis and synthesis of the sound structure of oral language. The order of progression of phonological awareness starts with syllables and moves toward smaller units of speech sounds (Adams, 1990). Phonological awareness provides individuals with the ability to break words into syllables and component phonemes, to synthesize words from discrete sounds, and to learn about the distinctive features of words (Torgesen & Wagner, 1998).

- Phonological memory: coding information phonologically for temporary storage in working or short-term memory. Phonological short-term memory involves storing distinct phonological features for short periods of time to be "read off" in the process of applying the alphabetic principle to word identification.

- Rapid naming: efficient retrieval of a series of names of objects, colors, digits, or letters from long-term memory. Rapid naming of verbal material is a measure of the fluid access to verbal names, in isolation or as part of a series, and related efficiency in activating name codes from memory (Wagner, Torgesen, & Rashotte, 1999).

The *Elision* subtest required participants to delete a phoneme in either the initial, final, or medial position from a real word and then produce a new word (e.g., “Say tiger without saying /g/.” [tire]). The *Blending* subtest required isolated syllables and phonemes to be combined into a word (e.g., “What word do these sounds make: /hæm/ /er/?” [hammer]). In the *Rapid Letter and Digit Naming* tests, children are shown a visual display of randomly presented items and asked to name them in sequence as quickly as they can. The *Rapid Digit Naming* test uses numbers 2, 3, 4, 5, 7, and 8. Seventy-two numerals are presented on two pages in four rows, with a space after each. The time in seconds to name the 72 items in the display is recorded. Standardized scores are provided for individuals ages 5 to 24 years on a scale ranging from 0 to 20, with an average of 10.

The authors were able to establish criterion predictive validity with a sample that represented ethnic, gender, and age variations. Reliability of the CTOPP was investigated using estimates of content sampling, time sampling, and scorer differences. Most of the average internal consistency or alternate forms reliability coefficients exceed .80 according to the test manual. The test/retest (time sampling) coefficients range from .70 to .92. It is known that the magnitude of the coefficients reported from all the reliability studies suggests that there is limited error in the CTOPP and that examiners can have confidence in the results. Reliability coefficients for the rapid-naming subtests are r = .82 for letter and r = .87 for digits.

Standardized Oral Language Tests

The Peabody Picture Vocabulary Test-III (L. M. Dunn & Dunn, 1997) and Expressive Vocabulary Test (Williams, l997) were administered to assess lexical knowledge and word retrieval. Both tests were administered according to the guidelines provided in the testing manual. The EVT and the PPVT-III were standardized on the same population of 2,725 examinees ranging in age from 2-6 to 90. All hard-of-hearing participants were wearing hearing aids for both ears and given the same oral instruction as hearing subjects. Throughout the data collection, no subjects had difficulty understanding the task.

Peabody Picture Vocabulary Test–III (PPVT-III, L. M. Dunn & Dunn, 1997): The PPVT-III is a standardized test of receptive lexical knowledge. Each easel page contains four pictures. Participants are required to choose the picture drawing from four choices on a page that best depicts a word orally presented by the test administrator. The normative sample included 2725 persons. And while the original PPVT was standardized only on white children from Tennessee, the normative sample of the PPVT-III was selected to match the data of the 1994 US Census. The sample was stratified with each age group by gender, race/ethnicity, geographic region, and SES. Only individuals who were determined to speak and understand English were included in the testing. The alpha reliabilities for the 25 standardized age groups were between .92 and .98 with a median reliability of .95 for both forms A and B. The split-half reliabilities for the 25 age groups ranged from .86 to .97, with a median of .94 for both forms. The alternate forms reliabilities range from .88 to .96 with a median correlation of .94.

The Expressive Vocabulary Test (EVT; Williams, l997**):** The EVT is a test of expressive vocabulary (lexical knowledge and word retrieval) requiring picture labeling and synonym tasks. For the 38 items, the tester points to a picture and asks a question. On the 152 synonym items, the examiner presents a picture and stimulus word(s) within a carrier phrase. The examinee responds to each item with a one-word answer. All stimulus pictures are in full color, carefully balanced for gender and ethnic representation. The EVT reliability analyses indicate a high degree of internal consistency. Split-half reliabilities range from .83 to .97 with a median of .91. Alphas range from .90 to .98 with a median of .95. And test-retest studies with four separate age samples resulted in reliability coefficients ranging from .77 to .90, indicating a strong degree of test score stability.

The Comprehensive Assessment of Spoken Language (CASL, Carrrow-Woolfolk, 1999*)* was used to measure the knowledge of grammatical knowledge. The CASL is an individually and orally administered oral language assessment battery for ages 3 through 21. This test measures four main areas of oral language such as (a) lexical/ semantic, (b) syntactic, (c) supralinguistic, and (d) pragmatic skills. In the Syntactic Tests, five subtests are included: Syntax Construction, Paragraph Comprehension, Grammatical Morphemes, Sentence Comprehension, and Grammaticality Judgment. For this study, the Grammatical Morphemes subtest was selected to investigate hearing impaired subjects' sensitivity to morphological markers and syntactic constituents for major grammatical information, including tense, voice, number, modality, person, pronoun, comparative, and lexico-conceptual knowledge. The examiner read one pair of words or phrases that demonstrated an analogy, then read the first word or phrase of a second pair. The examinee must complete the analogy of the second pair (e.g., Skate is to skated, as talk is to _____.).

The rationale for selecting this subtest is based on some previous theoretical suggestion regarding phonetic salience of grammatical morphemes in English language. For example, Leonard (1998) suggested that many inflections in English have low phonetic salience and that this factor in combination with reduced speed of processing underlies the problems with inflectional morphology described in SLI (Surface hypothesis). Even though the surface feature of phonetic salience alone cannot account for the difference in difficulty (Hayiou-Thomas, Bishop, & Plunkett, 2004; Rice & Wexler, 1996), it is well assumed that peripherally depressed hearing acuity would be a negative factor for efficient and normal perception of inflectional markers which have low phonetic salience. Thus, we hypothesized that hearing-impaired children's performance on this specific test would show significant difference from that of normally hearing subjects.

Interrater Reliability

To ensure test reliability, whenever any deviation from the protocol of test administration occurred, additional instruction was provided until that assistant was able to demonstrate stabilized skill. The test results and the background data were fed into SPSS for Windows package 15.0. The first author and two research assistants, who assisted in the test administration, score conversion and coding, met regularly to discuss any problematic matters. Interrater reliability procedures were conducted to determine the reliability of scoring and coding procedures.

To determine interrater reliability at the end of data collection period, a trained reliability coder, a doctoral student of speech pathology, checked on all scores (raw and standard scores) and coded data of 30 randomly selected participants (38% of the whole subjects). This coder independently obtained children’s raw scores on all tests, converted them to standard and percentile scores, and checked the coded numbers in the SPSS. The reliability coder and the test administrator were blind to each other's scoring. The coder and the test administrator conducted an item-by-item comparison of their respective responses to each item administered in the battery. A reliability score was calculated for all variables by dividing the number of agreements by the number of disagreements plus agreements and multiplying this score by 100. Interrater analysis showed 99% agreement for data coding (disagreement on 18 coding errors out of 2,100 numeric codes) and 97% agreement for score conversion (disagreement on 12 out of 420 standard scores).

Research Questions and Hypotheses

The following three main categories of research questions were investigated.

Category I (Group Effect)

Question: Are there any significant group effects on phonology, oral language, and reading skills?

Hypotheses: It was hypothesized that children with mild to moderately severe SNHL would demonstrate significantly lower performance than the comparison groups (NH and RD) on the measures of (a) auditory processing skills, (b) phonological processing (phonological awareness, verbal memory, and rapid naming), (c) oral language (receptive and expressive vocabulary and grammar) and (d) reading (word/nonword reading, passage reading fluency, and comprehension).

Category II (Relationships among Measures)

Question: What are the interrelationship among reading achievement, hearing ability, phonology, oral language skills, and auditory processing skills? Which phonological processes are the most strongly correlated with reading skills?

Hypotheses: It was hypothesized that there would be significant association among variables of phonological processing, oral language, and reading skills of hearing impaired subjects. This hypothesis was explored primarily using correlational analyses using a matrix of Pearson product-moment correlation coefficients between the variables.

Category III (Regression Question)

Question: What are the contributions of phonological and auditory processing skills in predicting hard-of-hearing children's reading achievement?

(1) Specifically, which measure of phonological processing skills is the best predictor of reading skills?

(2) How much of unique variance of reading performance (reading comprehension, reading fluency, word/nonword reading) is explained by phonological processing measures?

A full list of specific null hypotheses for the research questions to be tested in the study is presented in Table 3-3.

Treatment of the Data

All variables were entered into Microsoft Excel spreadsheets and analyzed with the SPSS 16.0. Descriptive statistics were calculated for all variables: demographic, audiologic, auditory processing, oral language, phonological processing, and reading/spelling skills.

Three statistical methods were used to analyze the data. First, to measure group effect, a series of multivariate analysis of covariance (MANCOVA) tests was carried out on the scores of auditory processing, phonological processing, and reading skills of the three groups (NH, HI, and RD) to investigate any significant group effect (Category I). A set of MANCOVAs was also conducted to compare oral language skills of children with normal and impaired hearing ability (NH and HI only). The grade scores (in months) and/or the non-verbal intelligence score (TONI-3) served as the covariates or control variables.

Secondly, to measure relationship among variables, a series of partial correlation analyses was conducted to determine significant relationships among variables.

Finally, to examine the unique variance explained selected exploratory variables, block hierarchical regression analyses were performed to determine which predictor variables could most effectively account for variance in the following dependent variables (4 word/nonword reading measures; 1 reading fluency measures; and 1 reading comprehension). The predictor variables examined were: (1) background information such as age, grade, and non-verbal IQ; (2) audibility, as measured by the pure-tone average; (3) auditory processing, as measured by the dichotic digits, and (4) six phonological processing measures from the CTOPP. For all multivariate statistical tests, correlation analyses and regressions were conducted with an alpha level set to .05.

Table 3-1. Matching variables (Grade, Age, Gender, and non-verbal intelligence)

	IQ				Grade[a]			Age[b]			Gender			
											Boys		Girls	
	Mean (SD)	Min	Med	Max	Mean (SD)	Min	Max	Mean (SD)	Min	Max	Freq	%	Freq	%
NH	112.52 (15.844)	88	110	150	3.8 (1.15)	2.1	5.9	111.9 (14.0)	89	134	16	55.2	13	44.8
HI	100.89 (12.918)	84	110	138	3.4 (1.61)	1.0	6.9	110.8 (19.3)	82	152	11	57.9	8	42.1
RD	No data				3.96 (1.62)	1.2	6.8	116.6 (20.3)	86	152	18	60.0	12	40.0
Total	107.92 (84-150)	84	107.9	150	49.1 (18.9)	12	92	113.4 (17.9)	82	152	45	57.7	33	42.3

Note: [a]: in year.months, [b]: in months, Freq: frequency, %: percentile

Table 3-2. List of tests used.

Area of measurement	Tests	Contents
Non-verbal intelligence		
	TONI-3	Non-verbal IQ
Oral language		
Receptive vocabulary	PPVT-III	Receptive vocabulary
Expressive vocabulary	EVT	Expressive vocabulary
Syntactic structure	CASL (*Grammatic Knowledge* subtest)	Grammatic knowledge
Phonological processing CTOPP)		
Phonological awareness	Elision, Blending	
Phonological memory	Memory for Digits, Nonword Repetition,	Short-term memory
Rapid naming	RAN-Digit, RAN-Letter	Lexical access and retrieval
Literacy		
Reading (Untimed)	WRMT-R (*Word Identification*)	Word Reading
	WRMT-R (*Word Attack*)	Nonword decoding
Reading (Timed)	TOWRE (*Word Efficiency*)	Word reading
	TOWRE (*Phonemic decoding efficiency*)	Nonword decoding
Spelling	WRAT-3 (*Spelling*)	Spelling words
Reading comprehension	WRMT-R (*Passage Comprehension*)	Silent passage comprehension
Reading fluency	GORT-4 (*Reading accuracy and rate*)	Passage reading fluency

Abbreviations: TONI (Test of Nonverbal Intelligence), PPVT-III (Peabody Picture Vocabulary Test), EVT (Expressive Vocabulary Test), CASL (Comprehensive Assessment of Spoken Language),CTOPP (Comprehensive Test of Phonological Processing), WRMT-R (Woodcock Reading Mastery Test – Revised), TOWRE (Test of Word Reading Efficiency), WRAT-3 (Wide Range Achievement Test), GORT-4 (Gray Oral Reading Tests).

Table 3-3. List of research hypotheses.

Statistical analyses	Hypotheses
MANCOVA	1. There will be statistically significant differences on a measure of receptive vocabulary (PPVT-3) among students in the NH and HI groups.
	2. There will be statistically significant differences on a measure of expressive vocabulary (EVT) among students in the NH and HI groups.
	3. There will be statistically significant differences on a measure of grammatical knowledge (CASL) among students in the NH and HI groups.
	4. There will be statistically significant differences on the measures of phonemic elision, deletion, rapid naming (letter and digit), and phonological short-term memory among students in the NH, HI, and RD groups (CTOPP).
	5. There will be statistically significant differences in untimed word and nonword reading skills (WRMT-R) among students in the NH, HI, and RD groups.
	6. There will be statistically significant differences in timed word and nonword reading skills (TOWRE) among students in the NH, HI, and RD groups.
	7. There will be statistically significant differences in spelling skill (WRAT) among students in the NH, HI, and RD groups.
	8. There will be statistically significant differences in passage reading comprehension (WRMT-R) among students in the NH, HI, and RD groups.
	9. There will be statistically significant differences in passage reading accuracy and rate (GORT-4) among students in the NH, HI, and RD groups.
Correlation	1. There will be significant correlations between hearing-impaired students' depressed phonology and reading.
	2. There will be significant correlations between hearing-impaired students' depressed phonology and hearing loss.
	3. There will be significant correlations between hearing-impaired students' depressed phonology and oral languages.
	4. There will be significant correlations between hearing-impaired students' auditory processing and reading.
	5. There will be significant correlations between hearing-impaired students' auditory processing and phonology.
Regression	1. Phonological awareness will significantly predict unique variance in word-level reading after controlling for cognitive ability, hearing acuity, and grade in both untimed and timed reading tasks.

Table 3-3. Continued

	2. Phonological short-term memory will significantly predict unique variance in word-level reading after controlling for cognitive ability, hearing acuity, and grade in both untimed and timed reading tasks.
	3. Rapid naming will significantly predict unique variance in word-level reading after controlling for cognitive ability, hearing acuity, and grade in both untimed and timed reading tasks.
	4. Auditory processing will significantly predict unique variance in word-level reading after controlling for cognitive ability, hearing acuity, and grade in both untimed and timed reading tasks.
	5. Phonological awareness will significantly predict unique variance in passage reading fluency after controlling for cognitive ability, hearing acuity, and grade in both untimed and timed reading tasks.
	6. Phonological short-term memory will significantly predict unique variance in passage reading fluency after controlling for cognitive ability, hearing acuity, and grade in both untimed and timed reading tasks.
	7. Rapid naming will significantly predict unique variance in passage reading fluency after controlling for cognitive ability, hearing acuity, and grade in both untimed and timed reading tasks.
	8. Auditory processing will significantly predict unique variance in passage reading fluency after controlling for cognitive ability, hearing acuity, and grade in both untimed and timed reading tasks.
	9. Phonological awareness will significantly predict unique variance in spelling after controlling for cognitive ability, hearing acuity, and grade in both untimed and timed reading tasks.
	10. Phonological short-term memory will significantly predict unique variance in spelling after controlling for cognitive ability, hearing acuity, and grade in both untimed and timed reading tasks.
	11. Rapid naming will significantly predict unique variance in word-level in spelling after controlling for cognitive ability, hearing acuity, and grade in both untimed and timed reading tasks.
	12. Auditory processing will significantly predict unique variance in word-level in spelling after controlling for cognitive ability, hearing acuity, and grade in both untimed and timed reading tasks.

CHAPTER 4
RESULTS

The primary goal of this study was to examine the effect of congenital mild to moderate SNHL on children's auditory processing, phonological processing, oral language, and literacy skills. The main focus of this investigation was twofold: (1) to examine differences among normally developing, hearing impaired students, and dyslexic readers in oral language, phonology, and reading skills (group effect) and (2) to investigate interrelationships between reading skills and phonology, auditory processing, and oral language abilities. The following questions were formulated and tested as follows.

- Are there any significant group effects for phonology, oral language, and literacy skills (reading/spelling) between the three groups?
- What interrelationships exist between reading and phonological skills, auditory processing and oral language ability in hard-of-hearing children?
- Do phonological processing skills make significant contributions to the literacy skills of children with hearing loss?

This chapter has four subsections. The first section presents results of the descriptive statistics for all of the variables investigated in this study. The second section deals with the group effect on oral language, phonology, audiologic function, and reading using a set of multivariate analyses of covariance. The third section provides the results of correlation analyses among variables based on the Pearson-product correlations. Descriptive statistics and first-order bivariate and partial correlation coefficients were used to estimate the children's performance in the measures and interrelationships among their performance in different measures. The final section investigates the results of multiple hierarchical regression analyses. The implications of these findings are discussed in Chapter 5.

Descriptive Statistics

Preliminary analyses were conducted to obtain descriptive information on the samples' demographic characteristics, audiologic ability, phonological process skills, oral language skills, and reading skills. Results of the measures on phonology, language, and reading are displayed in the next section where the outcomes of the MANCOVAs are reported.

Demographic Data

The demographic characteristics of the participants in the three groups, including age , grade, non-verbal IQ, and gender are provided in Chapter 3 (See Table 3-1).

Audiologic Ability Measures

Information related to the hard-of-hearing children's audiologic characteristics is displayed in Table 4-1. Demographic information was collated and included age, grade, gender, information about the history of audiologic invention (age at identification of hearing loss age at initial hearing aid fitting and length of hearing aid fitting), etiology, and basic audiometric results (unaided PTA, SRT, and WRS). A subject number was randomly assigned to each participant to ensure patient confidentiality.

Table 4-2 is a descriptive summary of the HI and NH groups' performance on the basic audiologic measures. The HI group's unaided PTA on the frequencies of 0,5 Hz, 1KHz, and 2 KHz ranged from 27 to 69 dB HL (mean better ear's PTA = 46.9 dB HL). Table 4-3 reports mean PTA of the HI and NH groups for every tested frequency. Figures 4-1 through 4-3 are graphical representations of this information. Figure 4-1 and 4-2 are error bar charts for each ear based on the standard errors of each mean threshold across tested frequencies, showing that, on average, the HI group had a symmetrical sloping binaural SNHL, with substantial variance within the group. Figure 4-3 is a histogram of better ear's pure-tone threshold for the HI group. Table 4-4 displays the means and standard deviations by hearing group (NH, HI) for the three subtests of the SCAN-A/C and the Dichotic Digits subtest of the CAPD test (Musiek, 1983).

Oral Language, Phonology, and Reading

Descriptive data of oral language, phonological processing, and reading measures are provided in the next section dealing with the MANCOVA questions.

Inferential Statistics

All scores used in the statistical analyses were norm-referenced standard scores. Multivariate analyses of covariance (MANCOVA), Pearson-product correlation analyses, and hierarchical block regression analyses were used to analyze the data to answer the research questions raised in the previous chapter. The results are organized to provide answers to three questions below:

1. What is the effect of decreased auditory sensitivity due to congenital SNHL on phonology, oral language, and reading skills? That is, is there any significant group effect in each measured area?
2. What is the relationship among hard-of-hearing readers' impaired phonology, reading, oral language, and hearing loss

Question Category I: Group Comparisons of Language, Phonology, and Reading

To compare the performance of the HI with the two control groups (NH and RD), multivariate analyses of covariance (MANCOVA) with grade (in months) and/or non-verbal intelligence as covariates were used for oral language, phonology, and reading measures. MANCOVA was selected in order to guard against Type I errors due to multiple univariate testing for each area.

Three separate MANCOVAs were conducted: (a) For oral language measures, three dependent variables from the PPVT-III (receptive vocabulary), EVT (expressive vocabulary), and a subtest of *Grammatical Knowledg*e from the CASL were analyzed (NH and HI groups only), (b) for the phonological tests, six subtests from the CTOPP were analyzed (NH, HI, and RD groups), and (c) thirdly, for the reading measures, standard scores of timed word/nonword reading (TOWRE), untimed word/nonword reading (WRMT-R), reading comprehension (WRMT-R), passage reading fluency (GORT-4), and spelling (WRAT) tests were included in the MANCOVA to investigate between-group difference on the literacy skills.

MANCOVA is appropriate for use with multiple dependent variables that differ in scales of measurement and fewer Type I errors occur with it than with a univariate analysis of variance (Gabriel & Hopkins, 1974). Other than maintaining overall Type I error at a constant level, MANCOVA also allows us to control the systematic group difference caused by covariates. Covariates are variables that are correlated with the dependent variables and are used to adjust for any differences in the scores affected by extraneous confounding factors. By using MANCOVAs, the effects of confounding variables such as non-verbal IQ, age, or grade, can be statistically removed, helping to ensure that the findings reflect true differences in phonology, oral language, and reading skills.

For the first MANCOVA, children's non-verbal intelligence and grade were used as covariate variables. For the second and third MANCOVAs, only grade (in months) was used as a covariate variable because the TONI scores were not available in dyslexic participants.

Hair et al. (1992) recommends that Wilk's lambda is the best statistical measure to assess whether an overall significant difference is found between groups. All multivariate statistical analyses were conducted with an alpha level set to .05. Good approximations for significance can be obtained from Wilk's lambda and can be transformed into an F-statistic. If any significant differences are identified in MANCOVAs, univariate analyses of covariance (ANCOVAs) are justified to investigate the direction and significance of specific dependent measures. ANCOVAs are run on the residuals after predictions of the dependent variable have been made from a set of covariates. In this type of analysis, a predicted dependent variable is computed. This predicted score is subtracted from the original dependent variable score. This difference or residual score is used in the ANCOVA (Meyer, 1993). Effect sizes for significant differences between groups, adjusting for covariates, are calculated as the difference between the estimated adjusted means for the two groups, divided by the root-mean-square error and reported as Cohen's d. Cohen (1988) designated an effect size of 0.2 as small, 0.5 as medium, and 0.8 as large.

For all ANCOVAs showing significant group effects, pairwise comparisons of groups are conducted. As a precaution against making Type I errors, the *p* value is adjusted with the Bonferroni method for all multiple pairwise comparisons.

MANCOVA for oral language measures

Performance on the oral language tests for the two groups of children (NH and HI groups) was compared to determine if differences in group performances were significant for overall measures of expressive/receptive vocabulary and grammatical knowledge. A one-way multivariate analysis of covariance (MANCOVA) was used with group membership (NH vs. HI) as the independent variable, standard scores from the PPVT-III, EVT, and CASL tests as the dependent variables, and grade (in months) and non-verbal intelligence as the covariates.

Two assumptions of the MANCOVA were tests: equal covariance and equal variance. MANCOVA assumes that for each group the covariance matrix is similar. Box's M statistic was used and the covariance assumption was not violated (F[6, 9896.2]) = 4.356, *p* = .673). MANCOVA also assumes that each dependent variable will have similar variances for all groups. According to the Levene's test, all three measures had equal variances in the two groups (PPVT-III: F[(1,46] = .325, *p* = .571; EVT: F[1,46] = 2.179, *p* = .147; and CASL: F[1,46] = 2.850, *p* =.098).

Results of the initial multivariate test using Wilks' Lambda (Λ) criterion indicated that the groups differed significantly in overall oral language measures (F[3,42] = 10.34, *p* = .000, partial η^2 = .425, and observed power = .997). Because significant differences between groups emerged for overall measures, it was necessary to examine specifically which of the tests were influenced across the two groups. That is, each of the oral language variables was examined individually through the use of three one-way univariate ANCOVAs. These follow-up univariate analyses indicated that differences between groups were significant for *all* language measures: (a) receptive vocabulary: F[1,44] = 16.123, *p* = .000, partial η^2 = .268, observed power = .975; (b) expressive vocabulary: F[1,44] = 8.694, *p* = .005, partial η^2 = .165, observed power = .822; and (c) grammatical knowledge: F[1,44] = 28.354, *p* = .000, partial η^2 = .392, observed power = .999.

Descriptive statistics for oral language measures along with estimated adjusted means and standard errors are reported in Table 4-5. Table 4-6 is the ANOVA table for these ANCOVAs displaying the result of univariate F-tests for between-group differences.

Table 4-7 is a summary of pairwise post-hoc comparisons. Finally, Figure 4-4 displays clustered box plots of oral language measures of the groups (NH, HI).

Pairwise comparison revealed that when controlling for non-verbal IQ and grade, the hearing impaired group performed significantly below the normal group both on the vocabulary and grammatical knowledge. Specifically, the differences of adjusted means of the PPVT-III and *Grammatic Knowledge* subset of the CASL test was 16.651 and 18.769, respectively, which were larger than one standard deviation (15.0). The EVT also showed substantial difference of 10.963. Notably, as seen in the adjustment mean difference, the effect size was biggest on the measure of grammatical knowledge (partial $\eta^2 = .392$).

MANCOVA for phonology

In order to determine whether there was a significant difference between the three study groups (NH, HI, and RD) on phonological processing measures, six dependent variables from the CTOPP representing components of phonological awareness, phonological memory, and rapid naming skills were submitted to multivariate analysis of covariance. MANCOVA was conducted with group membership as the independent variable and grade in months as the covariate.

Box's M statistic was used to check the covariance assumption, which was not violated: F[6, 11817.457] = 9896, $p = .831$), suggesting that the observed covariance matrices of the dependent variables were equal across groups. The Levene's test was used to test the equal variance assumption. All six measures had equal variances in the three groups ($df_1 = 2$, $df_2 = 75$): (1) *Elision*: F = .272, $p = .763$; (2) *Blending*: F = 2.102, $p = .129$; (3) *RAN-Digit*: F = .433, $p = .650$; (4) *RAN-Letter*: F = .005, $p = .995$; (5) *Memory for digit: F* = .202, $p = .818$; and (6) *Nonword repetition:* F = 1.344, $p = .267$.

The resulting MANCOVA was significant, yielding a main effect for group, F(12, 138) = 8.450, p <.001, showing a significant difference between the groups' overall performance on the phonological processing measures. The observed means, the observed standard deviations, and means adjusted after the statistical removal of the grade effect, standard errors, and observed powers for three groups appear in Table 4-8. Because of this significant difference in overall measures, a series of follow-up one-way univariate ANCOVAs were conducted.

Differences between groups were significant for every phonological measure after adjusting for grade in month ($df_1 = 2$, $df_2 = 74$): (1) *Elision* (F = 26.803, p = .000, partial η^2 = .420, observed power = 1.00); (b) *Blending* (F = 20.281, p = .000, partial η^2 = .354, observed power = 1.000); (c) *RAN for Digit* (F = 13.767, p = .000, partial η^2 = .271, observed power = .998); (d) *RAN for Letter* (F = 13.584, p = .005, partial η^2 = .269, observed power = .997); (e) *Memory for Digits* (F = 4.993, p = .009, partial η^2 = .119, observed power = .798); and (f) *Nonword Repetition* (F = 25.78, p = .000, partial η^2 = .411, observed power = 1.00).

The effect sizes for the *Blending* and *Elision* subtests were moderately large (*Elision* = .420, *Blending* = .354). In contrast, the effect sizes for rapid naming skill were smaller than those for phonological awareness skills (RAN-Digit = .271 and RAN-Letter = .269). A summary of six univariate ANCOVAs is shown in Table 4-9.

For all phonological processing measure showing significant between-group differences, a series of post hoc pairwise comparisons for the three groups (i.e., NH vs. HI, HI vs. RD, and NH vs. RD) based on Bonferroni adjustment was conducted to investigate how the groups are different across each of the dependent variables. Results are displayed in Table 4-10. Consistent with the previous literature (Cornwall, 1992; Cronin & Carver, 1998; Snyder & Downey, 1995; Wolf & Bowers, 1999; Wolf et al., 2002), on average, dyslexic children in this study were severely impaired on all reading measures when compared to the normal controls. Adjusted mean differences (NH minus RD) and *t*-scores on each measure were as follows: (1) *Elision:* 4.593, $t(57) = 6.917$, $p = .000$; (2) *Blending:* 2.645, $t(57) = 4.401$, $p = .000$; (3) *RAN-Digit*: 3.043, $t(57) = 5.247$, $p = .000$; (4) *RAN-Letter*: 3.281, $t(57) = 5.208$, $p = .000$; (5) *Memory for digits:* 1.999, $t(57) = 2.750$, $p = .022$; and (6) *Nonword repetition*:3.577, $t(57) = 5.478$, $p = .000$.

Similarly, HI subjects' phonological awareness and phonological memory skills were significantly lower than in the NH group. Adjusted mean differences (NH minus HI) and t-scores on each measure were as follows: (1) *Elision:* 3.500, $t(46) = 4.888$, $p = .000$; (2) *Blending:* 3.849, $t(46) = 5.949$, $p = .000$; (3) *Memory for digits:* 1.953, $t(46) = 2.494$, $p = .044$; and (4) *Nonword repetition:* 4.496, $t(46) = 6.395$, $p = .000$. Unexpectedly, however, no significant differences in the subtests of rapid naming were reported between the NH and HI groups. Adjusted mean differences (NH minus HI) and t-scores on rapid naming measures were as follows: (1) *RAN-Digit*: 1.302, $t(46) = 2.083$, $p = .122$ and (2) *RAN-Letter*: 1.245, $t(46) = 1.836$, $p = .211$.

Hence, these data have shown that hearing impaired students' lexical access and retrieval skills are well preserved. Additionally, our post hoc comparisons indicated that the HI group performed significantly better than the RD group on the two RAN subtests. While the HI group did not differ from the RD group on tasks of phonological awareness and phonological memory, when adjusted means (HI minus RD) for the *Nonword Repetition* and *Blending* subtests were used, RD subjects scored slightly higher with no significant difference. Adjusted mean, t-scores, and associated p-values on each measure were as follows: (1) *RAN-Digit*: 1.741, t(47) = 2.568, *p* = .033; (2) *RAN-Letter:* 2.035, t(47) = 2.803, *p* = .019; (3) *Elision:* 1.093, t(47) = 1.427, *p* = .473 (ns); (4) *Blending*: -1.204, t(47) = 1.737, *p* = .260 (ns); (5) *Memory for digits:* .047, t(47) = .056, *p* = 1.00 (ns); and (6) *Nonword repetition:* -.919, t(47) = 1.220, *p* = .679 (ns).

Overall, the HI group showed depressed phonological processing skills only in the areas of phonological awareness and phonological memory. No differences existed between the normal controls and the HI groups on the measures on rapid naming. In contrast, the RD subjects in this study showed deficiencies in all three phonological processing components (phonological awareness, phonological memory, and rapid naming). Descriptive results are displayed graphically in Figures 4-5 through 4-7 as clustered boxplots for each phonological component.

MANCOVA for literacy measures (reading and spelling)

For the reading and spelling measures, a one-way MANCOVA was used with group membership (NH, HI, and RD) as the independent variable and grade in months as the covariate.

Three out of eight dependent variables had statistically significant inequalities of variance based on the Levene's test for equality of variance ($p < 0.05$): (1) spelling: F[2,75] = 3.782, *p* = .027; (2) timed word reading (TOWRE): F[2,75] = 4.275, *p* = .017; and (3) passage reading rate: F[2,75] = 3.834, *p* = .026. However, according to Hair et al. (1992), a violation of this assumption has minimal impact if the groups (HI, NH, and RD) are approximately of equal size or if the largest group size divided by the smallest group size is less than 1.5. The ratio of dyslexic group size (n = 30) to the group of hearing impaired students (n = 19) was near to 1.50 (ratio = 1.579), hence, any violation of this assumption should have minimal impact. In light of the above findings, it is not surprising that the Box's M-test for multivariate homoscedasticity indicated significant differences as well (F = 1.544, df_1 = 72, df_2 = 11146.98, p = .002). This test is "notoriously sensitive" (Tabachnick and Fidell, 1996, p. 382), particularly given the large sample size involved. The group sizes in our data are not large and relatively equal to each other, so the impact should be minimal; all analyses of variance have been conducted assuming unique variance between groups.

The multivariate analysis results showed a significant difference between the three groups, when MANCOVA was carried out for the entire measures of reading and spelling (Wilks' Lambda = 0.228, F[16, 134] = 9.179, partial η^2 = .523, and p <.001). This significant differences in the analyses for overall tests justified further investigation of the significance of each dependent measure using univariate tests of ANCOVA. ANCOVAs showed significant group effects for *all* seven measures: (1) untimed word reading (F[2,74] = 58.610 , p < .001); (2) untimed nonword reading (F[2,74] = 42.430 , p < .001); (3) passage comprehension (F[2,74] = 35.084, p < .001); (4) spelling (F[2,74] = 40.899, p < .001); (5) timed word reading timed (F[2,74] = 68.634, p < .001); (6) timed nonword reading (F[2,74] = 73.415, p < .001); (7) passage reading rate (F[2,74] = 77.143 , p < .001); and (8) passage reading accuracy (F[2,74] = 59.777, p < .001).

Descriptive statistics such as means, standard deviations, and estimated adjusted means for all tasks are displayed in Table 4-11. Error bar charts and box plots based on these descriptive data are also seen in Figures 4-7 through 4-10. Significant group effects based on eight univariate ANCOVAs for all measures and the corresponding ANOVA tables are seen in Table 4-12 and Table 4-13, respectively.

Next, pairwise comparisons using Bonferroni's adjustment were conducted. Inconsistent with the previous literature (Briscoe et al., 2001; Gibbs, 2004), on average, reading and spelling skills of hearing impaired children in this study were significantly lower than normal controls on all reading measures (HI vs. NH) with one exception of the *Word Decoding* subtest on the TOWRE. Adjusted mean differences (NH minus HI) and t-scores on each measure were as follows: (1) untimed word reading: 14.386, $t(46) = 3.75$, $p = .001$; (2) untimed nonword reading: 10.003, $t(46) = 2.65$, $p = .029$; (3) passage comprehension: 12.058, $t(46) = 3.40$, $p = .003$; (4) spelling: 13.222, $t(46) = 3.72$, $p = .001$; (5) timed word reading: 7.873 $t(46) = 2.46$, $p = .048$; (6) timed nonword reading: 6.155, $t(46) = 1.90$, $p = .185$; (7) passage reading rate: 2.664, $t(46) = 3.14$, $p = .007$; and (8) passage reading accuracy: 2.883, $t(46) = 3.10$, $p = .007$. Descriptively, adjusted mean differences in timed word/nonword reading were smaller than untimed word-level reading, suggesting a contributive role of hearing-impaired readers' preserved lexical access skills to fast reading.

In addition, as expected, every mean score on the tests of reading were low average for the RD group and the HI group in our sample was significantly better than the RD controls on all measures. Remarkably, in timed measures, mean differences were more than 1.5 to 2 standard deviations. Adjusted mean differences (NH minus RD) and t-scores on each measure were as follows: (1) untimed word reading: 21.851, $t(47) = 5.71$, $p = .000$; (2) untimed nonword reading: 20.091, $t(47) = 5.34$, $p = .000$; (3) passage comprehension: 14.018, $t(47) = 3.96$, $p = .001$; (4) spelling: 15.013, $t(47) = 15.013$, $p = 4.23$; p = .000; (5) timed word reading timed: 24.020, $t(47) = 7.53$, $p = .000$; (6) timed nonword reading: 26.832, $t(47) = 8.28$, $p = .000$; (7) passage reading rate: 6.394, $t(47) =$

7.56, *p* = .000; and (8) passage reading accuracy: 5.782, t(47) = 6.3, *p* = .000. Table 4-13 is a summary of pairwise post-hoc comparisons. Lastly, RD group's reading and spelling scores were significantly lower than normal group's for all measures.

Question Category II: Correlations among Measures

Our second category of research questions involved the interrelationship between hearing impaired participants' literacy skills and other exploratory variables, including oral language, phonological processing, and auditory processing ability: The first step in this analysis was to explore the pattern of associations in correlation analyses. Correlational analyses are presented for the research questions below:

1. Question 1: What is the relationship between phonology and reading?
2. Question 2: What is the relationship between phonology and hearing loss?
3. Question 3: What is the relationship between phonology and oral language?
4. Question 4: What is the relationship between phonology and auditory processing?
5. Question 5: What is the relationship between reading, auditory processing?

Question 1: Phonology and reading

To assess the independent associations of each of the measures on phonological processing and reading skills, partial correlation coefficients were calculated with the effects of age, non-verbal intelligence (TONI-3), and hearing loss removed. Hearing loss, as measured by the better ear's pure-tone, was also removed from the correlations because the degree of hearing loss exhibited strong negative relations with phonological awareness when age and grade in months were partialed out (*Elision*: r = -.631, *p* = .007; *Blending*: r = -.728, *p* = .001; See Table 4-), short-term memory span (*Nonword repetition*: r = -.608, *p* = .010). Partial coefficients were computed for phonological processing and reading measures. The partial correlation matrices for the HI and NH separately are shown in Table 4-15 and Table 4-16. The results will be reported separately for the HI and NH groups.

Hearing-impaired group: As can be seen in Table 4-15, the *Elision* subtest was more highly correlated with reading measures than any other phonological processing variables. It was the only measure of phonological awareness which was significantly associated with *all* reading and spelling measures in both word and passage levels. Correlation coefficients between *Elision* and reading measures ranged from .562 to .751 as seen below: (1) untimed word reading (r = .582, $p < .01$); (2) untimed nonword reading (r = .751, $p < .001$); (3) timed word reading (r = .562, $p < .05$); (4) timed nonword reading (r = .611, $p < .05$); (5) spelling (r = .618, $p < .01$); (6) passage comprehension (r = .610, $p < .01$); (7) passage reading rate (r = .605, $p < .01$); and (8) passage reading accuracy (r = .711, $p < .001$). Even though the *Blending* is a measure of phonological awareness, it was not correlated with any word-level reading measures, spelling, and comprehension. It was only significantly associated with oral passage reading rate (r = .470, $p < .05$).

The pattern of correlations between rapid naming skills and reading measures was remarkable. Both RAN measures did not show any significant correlations with *untimed* tasks of reading at the word or passage level. Correlation coefficients among these variables were as follows: (1) untimed word reading (RAN-D: r = .307, $p = .124$; RAN-L: r = .259, $p = .166$); (2) untimed nonword reading (RAN-D: r = .411, $p = .057$; RAN-L: r = .301, $p = .129$); and (3) passage comprehension (RAN-D: r = .341, $p = .098$; RAN-L: r = .314, $p = .118$). Notably, however, significant correlations were found for rapid naming measures and *timed* reading tests at both word and passage levels: (1) Timed word reading (RAN-D: r = .459, $p = .037$; RAN-L: r = .559, $p = .012$); (2) timed nonword reading (RAN-D: r = .560, $p = .012$; RAN-L: r = .656, $p = .003$); (3) timed passage reading rate (RAN-D: r = .723, *p* = .001; RAN-L: r = .581, *p* = .009); and (4) timed passage reading accuracy . (RAN-D: r = .635, *p* = .004; RAN-L: r = .571, p = .003). Correlation coefficients ranged from .459 to .656 at word level and from .571 to .723 at the passage level. All correlations in the partial correlation matrix were higher than medium (about .3) or large (above .5) correlations (Cohen, 1988). The phonological memory tasks as measured by the *Nonword Repetition* task was correlated with untimed word reading (r = .594, p = .008). With other literacy measures, phonological STM tasks approached significant level (See Table 4-15).

Normally hearing controls: As can be seen in Table 4-16, after the effects of age and non-verbal intelligence had been controlled, phonological awareness variables were highly correlated with reading and spelling variables: (1) untimed word reading (elision: r = .711, *p* < .001; blending: r = .378, *p* < .05), (2) untimed nonword reading (elision: r = .692; p < .001; blending: r = .472, *p* < .05), (3) spelling (r = .825, *p* < .001), (4) passage comprehension (elision: r = .520, *p* <.05), (5) timed word reading (r = .474, *p* < .001), (6) passage reading rate (elision: r = .443, *p* < .05), and (7) passage reading accuracy (r = .671, *p* < .001). Highest correlations were observed between the *Elision* and spelling tests. Quite differently from the HI group, significant small to medium intercorrelations were found between rapid naming and *untimed* word reading tests for the NH subjects (word reading (RAN-D: r = .421, *p* = .016; RAN-L: r = .414, *p* = .018); (2) untimed nonword reading (RAN-D: r = .382, *p* = .027; RAN-L: r = .437, *p* = .013). Also, similar to the HI group, high correlation coefficients were found in the NH group between rapid naming tasks and timed reading tests for both word and passage level: (1) timed word reading (RAN-D: r = .559, *p* = .001; RAN-L: r = .542, *p* = .002); (2) timed nonword reading (RAN-D: r = .596, *p* = .001; RAN-L: r = .629, *p* = .000); (3) timed passage reading rate (RAN-D: ; r = .382, *p* = .027; RAN-L: r = .385, *p* = .026); and (4) timed passage reading accuracy . (RAN-D: r = .465, *p* = .008; RAN-L: r = .540, *p* = .002).

Another notable correlation pattern was found for phonological short-term memory measures. Different from the HI group, the two untimed word-level reading and spelling measures were highly correlated in the NH group. Partial coefficients are as follows: (1) *Memory for Digits*: (untimed word reading: r = .657, *p* = .000; untimed nonword reading: r = .603, *p* = .001; and spelling: r = .519, *p* = .003) and (2) Nonword repetition: (untimed word reading: r = .686, *p* = .000; untimed nonword reading: r = .650, *p* = .000; and spelling: r = .534, *p* = .002).

Question 2: Phonology and hearing loss

The partial correlation matrix adjusting for the variance accounted for by age and non-verbal IQ for the HI group (n=19) are shown in Table 4-17. Table 4-17 includes the six measures of phonological measures and variables related to hearing loss such as better ear's pure-tone, age at identification, age at initial hearing aid fitting, and length of hearing aid use. As expected, the better ear's PTA was correlated with phonological awareness and short-term memory span as seen in the following partial coefficients: (1) *Elision* (r = -.473, *p* = .024); (2) *Blending* (r = -.597, *p* = .004); (3) *Nonword repetition* (r = -.424, *p* = .040), underscoring the effect of decreased auditory input on meta-phonological skills.

On the other hand, the RAN tasks (letters and digits) were not correlated with the severity of hearing loss. This finding was also supported by the MANCOVA results, which revealed no effect of hearing loss on rapid naming skills.

Question 3: Phonology and oral language

It was also questioned whether lexical and grammatical knowledge would be related to phonological processing skills which measures children's ability to encode, store, and retrieve phonological information. The correlation and partial correlation matrices for the HI group are shown in Table 4-18. The results revealed that phonological short-term memory (nonword repetition, memory for digits) were strong correlates of both receptive and expressive vocabulary, and grammatical knowledge. Notably, the *Memory for digit* subtest was highly correlated with all language measures: (1) PPVT-III (r = .533, p = .014), (2) EVT (r = .592, p = .006), and (3) CASL (r = 558, p = .010). The *Nonword repetition* was also moderately correlated with the receptive and expressive vocabulary, but only approached the significance level: (1) PPVT-III (r = .406, p = .053) and (2) EVT (r = .359, p = .078).

In contrast, no significant association was found between the RAN tasks and any of oral language measures. Similarly, phonological awareness tasks did not show any correlations with vocabulary tests. However, a pattern of significant correlations was seen between phonological awareness and grammatical knowledge test, revealing coefficients higher than medium level: (1) *Elision* (r = .511, p = .018) and (2) *Blending* (r = .443, p = .038).

Question 4: Auditory processing, phonology, and reading measures

Table 4-19 shows correlations among the auditory and phonological measures and reading for the HI group, with partial correlations controlling for age, grade, duration of hearing aid use, and nonverbal intelligence.

Auditory processing skills measured by the three SCAN subtests (*Filtered Words, Auditory Figure-Ground, and Competing Words*) had no significant correlations with any of phonological awareness and rapid naming tasks. However, a high degree of significant associations were found between the *Competing Words* subtest and short-term memory span tasks (i.e., *Memory for Digits*: r = .653, p = .008; *Nonword Repetition*: r = .579, p = .024). The *Competing Words* subtest is a test of dichotic listening, where the subject hears two words simultaneously, one word presented to each ear. The subject is instructed to repeat the words presented in each ear. For a better performance, the two stimuli presented simultaneously should be efficiently stored in phonological buffer for later repetition. Thus, the high level of association between this type of dichotic listening test and short-term memory span was not surprising. Similarly, high correlations were found between the *Dichotic Digit* test and short-term memory span, an en expected results based on the previous explanation (i.e., *Memory for Digits*: r = .617, p = .014; *Nonword Repetition*: r = .548, p = .034).

None of the SCAN subtests showed significant correlations with any of reading measures, including word-level reading and passage reading and spelling. However, the *Dichotic Digit* task correlated with the two nonword reading tasks (untimed nonword: r = .546, p = .035 and timed nonword: r = .525, p = .044).

Question 5: Reading and oral language

Partial correlation coefficients were calculated between all of reading measures and oral language scores with the effects of age, grade, nonverbal intelligence, and the degree of hearing loss partialed out. Table 4-20 displays the correlations matrix. Passage comprehension was the only reading tests that correlated with the oral language measures: (1) PPVT-III (r = .474, p = .037), (2) EVT (r = .536, p = .020), and (3) grammatical knowledge (r = .442, p = .049). Interestingly, even though the GORT test measured reading fluency in passage level, no correlations were found between vocabulary and the passage reading fluency.

Question Category III: Exploratory Hierarchical Regressions

Although MANCOVA procedures can test for the statistical significance of group differences in one or more domains, these procedures do not necessarily provide a clear indication of how hard-of-hearing readers' depressed phonological skills are *predictive* of reading skills across wide range of domains.

In an effort to explore the relations between the reading measures and the exploratory variables, including phonological and auditory processing abilities, selected based on the previous partial correlation analyses, a series of multivariate analyses (i.e., hierarchically blocked regressions) was performed separately for each reading measure.

According to Whitley (1996), there are three different forms of multiple regression analysis: simultaneous (enter), stepwise, and hierarchical and each of them has a specific purpose. Hierarchical regression should be used for hypothesis testing while simultaneous and stepwise regressions should be used only for simple prediction.

In this study, specific hypotheses were tested regarding the significance of selected exploratory variables, so the use of hierarchical regression model was justified. Findings from multiple regression analyses allowed for examination of whether the children's performance in reading was significantly associated with the proposed set of exploratory variables, including phonological awareness, short-term memory span, rapid naming, and auditory processing ability

For regression analyses reported in this section, six phonology measures from the CTOPP test and one auditory processing test (*Dichotic Digit*) served as the exploratory variables. All of seven reading measures and a spelling measure were used as dependent variables. Each of these exploratory predictors was entered into the model individually in Step 2 after the effects of children's background characteristics were statistically eliminated. Specifically, grade, nonverbal IQ, and degree of hearing loss (better ear's PTA) were entered to control for the effects of these variables on reading performance controlled for. These three factors were entered at Steps 1 in all analyses. These hierarchical regression results are presented in Table 4-22 through Table 4-28. The research questions are as follows:

Regressions on word-level reading

Separate fixed-order hierarchical regression analyses with were carried out separately on four word-level reading achievement measures (i.e., untimed/timed, words/nonwords) to determine the variance contributed to the word-level reading accuracy by phonological awareness, rapid naming, short-term memory, and auditory processing skills (32 regressions = 4 reading measures * 8 predictors). As reported in the previous section, the zero-ordered correlations had shown significant correlations between reading and phonological processing tests. Especially, the *Dichotic Digit* test was included in the regression analyses since it was the only central auditory processing measures which was significantly correlated with phonological measures (i.e., elision, blending, nonword repetition, and memory for digits) and reading measures (i.e., timed and untimed nonword reading). The results are displayed in Table 4-21 through Table 4-24.

Regression on untimed word reading accuracy: The *Word Identification* subtest on the WRMT-R was the dependent variable. As shown in Table 4-21, when grade, better ear's PTA, and nonverbal IQ were entered in Steps 1, they explained 31.9% of the variance in the timed single-word reading scores. The results demonstrate that only the

Elision task significantly explained substantial amount of variance (30.3%) in the *Word Identification* test (p = .005).

Taken as a whole, the three control variables (grade, better ear's PTA, nonverbal IQ) and the *Blending* test accounted for 64.1% of variance for the *Word Identification*, showing the importance of phonological awareness in word recognition. The *Nonword Repetition* and *Dichotic Digits* subtests only approached significance with the *Word Identification* test(p = .054 and p = .093, respectively). Both the *RAN-Letters* and *RAN-Digit* tasks did not explain variance in this untimed word reading test (p = .131 and .081, respectively).

Regression on untimed nonword reading accuracy: The *Word Attack* subtest on the WRMT-R was the dependent variable. In Step 1, grade, better ear's PTA, and nonverbal IQ explained 11.0% of variance in the score. Similar to the *Word Identification*, when the *Elision* scores were entered in Step 2, it explained almost more than half of additional variance in the scores of the *Word Attack* subtest in a significant way (53.1 %, p < .0001). When the *Nonword Repetition* was entered instead of the *Elision*, it also explained 37% of additional variance. So, both the *Elision* and *Nonword Repetition* represented a substantial effect on the untimed single nonword reading scores (Table 4-22).

However, phonological short-term memory (*Memory for Digits*) only approached significance level and it explained about 19% of variance (p = .072). Unlike the *Blending*, when the RAN (Digits and Letters) scores were entered in Step 2 individually, none of them was significantly associated with the *Word Attack* scores. With the *Dichotic Digit* entered in Step 2, the overall regression model did not significantly explained the variance in the *Word Attack* scores (i.e., F[4,14] = 2,300, *p* = .110).

Regression on timed word reading accuracy: The *Word Efficiency* subtest on the TOWRE was the dependent variable. As Table 4-23 shows, when entered first in the regression function, grade, PTA, and nonverbal IQ accounted for 19.3% of the variance in timed nonword reading. In Step 2, following these controlled variables, each exploratory variable was entered separately into the regression equations. Similar to the results of regressions on the untimed reading condition, phonological awareness skill as measured by the *Elision* subtest continued to significantly account for unique variance in the dependent variable (28.7%, *p* = .015). It was noted that the *Memory for Digit*s (*p* = .178), *Nonword Repetition* (*p* = .115), and D*ichotic Digit* subtests (*p* = .306) did not explain the variance in a significant way.

It was of further interest to determine if the rapid naming tasks accounted for significant variance for *timed* reading activities. Recall that our correlation analyses indicated that rapid naming skills were strongly associated with *timed* reading tasks only and no significant partial correlations were observed for untimed reading measures: Correlation coefficients for timed measures were high, ranging from .459 to .656 at word level and from .571 to .723 at passage level. This strong correlation between rapid naming and timed reading was confirmed by the regression results. That is, in the second order of entry, the alphanumeric rapid naming measures accounted for significant variance in the *Word Efficiency* scores. Specifically, the RAN-Letter accounted for an additional 24.5% of the variance of scores in the timed word reading (*p* = .027) and the RAN-Digit test also explained almost 20% of the variance (19.4%, *p* = .049).

Regression on timed nonword reading accuracy: The *Word Decoding* subtest on the TOWRE was the dependent variable. When entered first in the regression function, non-verbal IQ, grade, and PTA accounted only for 9.7% of the variance in the Word Decoding. Similar to the previous results, phonological awareness measure (*Elision*) explained a highly significant 37% of unique variance as shown in Table 4-24.

No significance was seen for the contribution of phonological memory. Children's performance on the *Dichotic Digit* test only approached significance with the Word Decoding (p = .054). There was also a significant additional contribution from the alphanumeric naming measures at Step 2, explaining a highly significant 39.2% (RAN-Letter, p = .005) and 31.3% (RAN-Digit, p = .016) of unique variance, respectively. This confirmed the fact that there is a significant additional contribution of alphanumeric RAN to timed reading tasks.

Regression on passage reading rate and accuracy

Another set of analyses were carried out to test for the effects of our exploratory variables on reading skills in passage level. Recall that the RAN tasks did uniquely and significantly account for the variances of all timed, but not for untimed reading tests. So, we wanted to see if a similar trend would be found as well in passage level reading.

As Table 4-25 shows, each of our two RAN variables, when separately entered at the Step 2, accounted for substantial proportions of variance in both passage rate and accuracy scores below the significant level: The *RAN-Digit* accounted for 37.6% (p = .002) for rate scores and 31.7% for accuracy scores (p = .010), respectively. In a similar pattern, it was also observed that the *RAN-Letter* accounted for 19.7% (p = .044) for rate and 22.1% (p = .039) for accuracy.

Like our previous observation, the *Elision* consistently explained unique variances for both rate and accuracy scores below the significant level: 29.1% for rate (p = .011) and 42.8% for accuracy (p = .002), respectively. Children's performance on *the Memory for Digit* subtest also significantly explained 18.9% of variance in the passage rate scores (p = .049), but not for the accuracy score. The *Nonword Repetition* did not significant account for any of passage-level tests.

Finally, the *Dichotic Digit* test did not show significant association with the performance on the rate measure, but it uniquely and significantly accounted for 26.2% of variance in the rate scores (p = .017). This rate test was the only literacy measure for which the variance was significantly accounted for by the *Dichotic Digit* test.

It was noteworthy that when the *RAN-Digit* was entered in Step 2, the overall regression models explained significantly and uniquely 61.3% and 50.0% of variance, respectively, for passage reading rate and accuracy.

Regression on spelling

One final set of multiple regression analyses were carried out to test for the effects of our exploratory variables on spelling. The *Spelling* subtest on the WRAT was the dependent variable. In Step 2, chronological grade, better ear's PTA, and nonverbal IQ accounted for 18.3% of the variance. The results are reported in Table 4-27. Rapid naming measures did not significant predict children's spelling ability.

Again, significant contribution of phonological awareness was consistent: The *Blending* subtest explained statistically significant 33.8% of variance in spelling (p = .007). With the controlled variables entered in Step 1 taken together, the overall model accounted for more than half of variance in spelling scores (52.1%). Similarly, phonological short-term memory span as measured by the *Memory for Digit* explained almost 30% unique variance (p = .015).

When the *Dichotic Digit* subtest was entered in Step 2, which had significant standardized coefficient (β = .663, p = .016), the overall regression model itself did not significantly reduce the error term (F[4,14] = 3.071, p = .052).

Role of rapid naming in further regression analyses

In our previous regression analyses, rapid naming tests did not account for unique variance in untimed reading tasks in both word and passage level. Instead, it was shown that the RAN tasks are significantly associated only with timed reading tests, which demands high efficiency in *extraphonological* processing such as rapid lexical access and retrieval. Because this finding is relevant to the role of speed of processing (RAN) as a *non-phonological* factor in reading disabilities (Compton, DeFries, & Olson, 2001; Cornwall, 1992; Kirby, Parrila, & Pfeiffer, 2003; Savgrade et al., 2005; Strattman & Hodson, 2005; Wolf & Bowers, 1999; Wolf & O'Brien, 2001), it was necessary to ensure that the RAN would still accounted for unique variance of each timed reading task after the effects of phonology-based cognitive skills were also controlled for.

As a further test, a set of additional hierarchical regressions were performed by entering two phonological awareness (*Elision/Blending*) and two phonological short-term memory (*Memory for Digit/Nonword Repetition*) in the same block (Step 2) as a group. Each of the RAN tests (digit/letter) was entered separately in Step 3 for all timed reading measures. Similar to our previous regression, grade, non-verbal IQ, and better ear's PTA were entered in Step 1. The results of these regressions are displayed in Table 4-28.

In accordance to our hypotheses, the results of further analyses demonstrated that once IQ, grade, and better ear's PTA were considered first, a significant additional contribution from the alphanumeric naming measures was preserved: In the model where the *RAN-Digit* was entered in Step 3, it continued to account for unique variances in passage reading rate significantly (23.6%, p = .005), passage reading accuracy (16.0%, p = .022), and timed nonword reading (20.1%, p = .029), respectively. Similarly, the second set of analyses also confirmed that there was significant additional contribution of the *RAN-Letter* measure at Step 3, explaining 21.2% (p = .023) and 35.8% (p = .001) unique variances of timed word and nonword reading accuracy. The *RAN-Letter* also explained smaller but significant amount of variances in passage reading rate and accuracy (14.9% and 15%, respectively).

Summary:

1. The *Elision* from the CTOPP test, a measure of phonological awareness, was the only measure, which consistently and significantly explained variance in *all* of literacy measures ranging from word and nonword reading, spelling, to passage reading fluency. Unexpectedly, the *Blending* subtest was not significant for any of tests. The results also showed that alphanumeric rapid naming skills only accounted for unique variance in *timed* reading achievement in both word and passage level. In contrast, no significant contribution to timed reading was revealed.

2. When the effects of grade, non-verbal IQ, and better ear's PTA were eliminated, auditory processing skill as measure by the *Dichotic Digit* was not significant for any word-level reading and spelling tests. It explained statistically significant 26.2% of variance in passage reading rate (26.2%).

3. In addition, the significant contribution of phonological short-term memory skill was seen only for two literacy measures. The Memory for Digit subtest explained 28.7% unique variance in spelling scores and the Nonword Repetition accounted for 37.0% unique variance in untimed nonword reading (p = .015 and p = .007, respectively).

Table 4-1. Background information and basic auditory skills of individuals in the HI group.

Subj	Gender	Age[a]	Grade[b]	PTA[c]	SRT[c]	WRS[d]		HA-Fit[a]	Age_Id[a]	HA_Use[a]	Etiology	Hearing aid type
						R	L					
1	F	115	4.3	63	45	88	100	24	24	88	Genetic	Phonak Pico Forte
2	M	111	4.3	58	55	100	100	48	48	57	Unknown	Oticon 380P
3	F	114	4.4	38	40	100	100	30	30	84	Genetic	Phonak Pico Forte
4	M	100	2.5	70	65	46	67	20	20	75	Unknown	Oticon 380P
5	F	112	3.5	68	65	76	89	27	27	81	Genetic	Oticon Multi-Focus
6	F	106	2.5	38	35	93	100	42	42	66	Genetic	Phonak Sono Forte
7	M	86	1.5	31	30	100	100	24	24	62	Unknown	Unitron UM 60
8	F	125	3.5	27	20	100	100	36	36	75	Unknown	Oticon 39 PL
9	F	121	5.6	56	45	90	100	72	72	48	Genetic	Telex 366
10	M	91	2.7	65	35	100	88	7	7	80	Unknown	Phonak Pico Forte
11	M	99	1.9	38	35	96	88	48	48	25	Unknown	Oticon 380P
12	M	122	2.9	41	35	100	100	18	18	98	Genetic	Oticon 380P
13	M	84	1.0	43	35	88	96	29	29	33	Unknown	Phonak Sono Forte
14	M	152	6.9	41	40	100	100	36	36	115	Unknown	Unitron Icon
15	F	84	1.1	41	35	100	100	61	61	20	Genetic	Phonak Pico Forte
16	F	152	6.0	43	30	52	68	72	72	80	Unknown	Unitron Icon
17	M	106	3.0	28	10	56	72	*	*	*	Unknown	Unitron UM 60
18	M	111	3.2	45	45	72	80	24	24	51	Unknown	Oticon 38 P
19	M	116	3.2	58	50	52	76	24	24	82	Unknown	Rion HB 75AL
M (SD)	11 Boys 8 Girls	110.8 (19.3)	3.4 (1.61)	46.9 (13.5)	39.5 (13.5)	75.2 (29.7)	86.0 (21.9)	35.6 (17.8)	35.6 (17.8)	67.8 (25.1)		

Note. [a] :in months, [b]:in years.months, [c] :unaided, [d]: measured in the Most Comfortable Level, PTA: Pure-tone threshold, SRT: Speech recognition thresholds, WRS: Word recognition scores, HA_Fit: Age at initial hearing aids fitting, Age_Id: Age at identification, HA_Use: Duration of hearing aids use

Table 4-2. Descriptive statistics for the NH and HI groups on PTA, SRT, and WRS scores.

	NH[a,b]				HI[a,c]			
	Mean	SD	Min	Max	Mean	SD	Min	Max
PTA(L)[d]	5.1	4.7	-1	13.0	51.0	15.4	28	86
PTA(R)[d]	3.8	1.15	1	21.0	54.9	21.1	27	100
PTA (Better ear)[d]	3.31	3.9	-1	13.0	46.9	13.5	27	69
SRT(L)[e]	4.1	3.8	0	15.0	40.8	14.5	10	70
SRT(R)[e]	5.2	3.4	0	10.0	47.8	22.4	15	100
WRS(L)[f]	99.7	1.48	92	100	86.0	21.9	10	100
WRS(R)[f]	99.0	2.96	88	100	75.2	29.6	10	100

Note. [a]: in dB HL, [b]: Normally hearing children, [c]: Hearing-impaired children, [d]: unaided pure-tone threshold average, [e]: unaided speech recognition thresholds, [f]: word recognition scores in the most comfortable level (MCL)

121

Table 4-3. Mean pure-tone thresholds for all tested frequencies (NH and HI groups only).

Ear			250 Hz	500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz	6000 Hz	8000 Hz
Right	*HI	M	37.63	47.11	59.21	63.68	60.79	62.37	68.16	70.53
		SD	20.640	21.558	20.225	18.845	69.450	23.943	22.249	20.541
		Range	5 ~ 75	5 ~ 90	30 ~ 100	35 ~ 105	25 ~ 90	20 ~ 95	30 ~ 105	30 ~ 105
	NH	M	4.31	5.86	4.66	5.69	4.14	6.03	3.10	5.17
		SD	5.782	5.012	4.805	6.778	5.680	6.322	5.414	5.745
		Range	0 ~ 20	-5 ~ 15	0 ~ 20	0 ~ 35	-5 ~ 20	-5 ~ 25	-5 ~ 15	-5 ~ 25
Left	*HI	M	32.63	39.21	48.42	56.32	56.32	57.89	61.58	65.63
		SD	16.361	16.352	19.794	15.532	16.570	21.168	22.977	21.660
		Range	5 ~ 65	10 ~ 70	15 ~ 95	35 ~ 95	25 ~ 90	20 ~ 95	30 ~ 105	30 ~ 105
	NH	M	3.79	4.66	4.14	3.79	5.34	6.03	2.07	4.41
		SD	5.454	5.659	4.446	5.287	4.616	6.461	6.053	6.033
		Range	-5 ~ 15	-5 ~ 15	-5 ~ 15	-5 ~ 15	0 ~ 20	-5 ~ 25	-10 ~ 20	-5 ~ 20

Note. *: unaided thresholds, HI (n=19), NH (n=29)

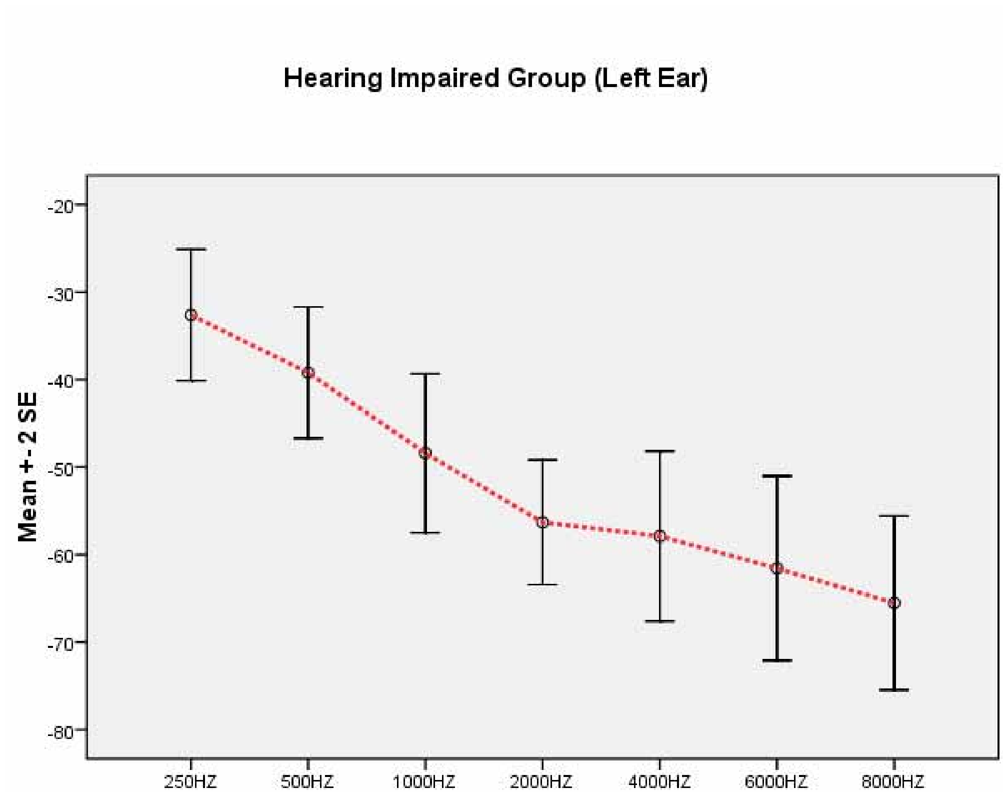

Figure 4-1. Mean PTA thresholds for the left ear (HI Group, N=19)

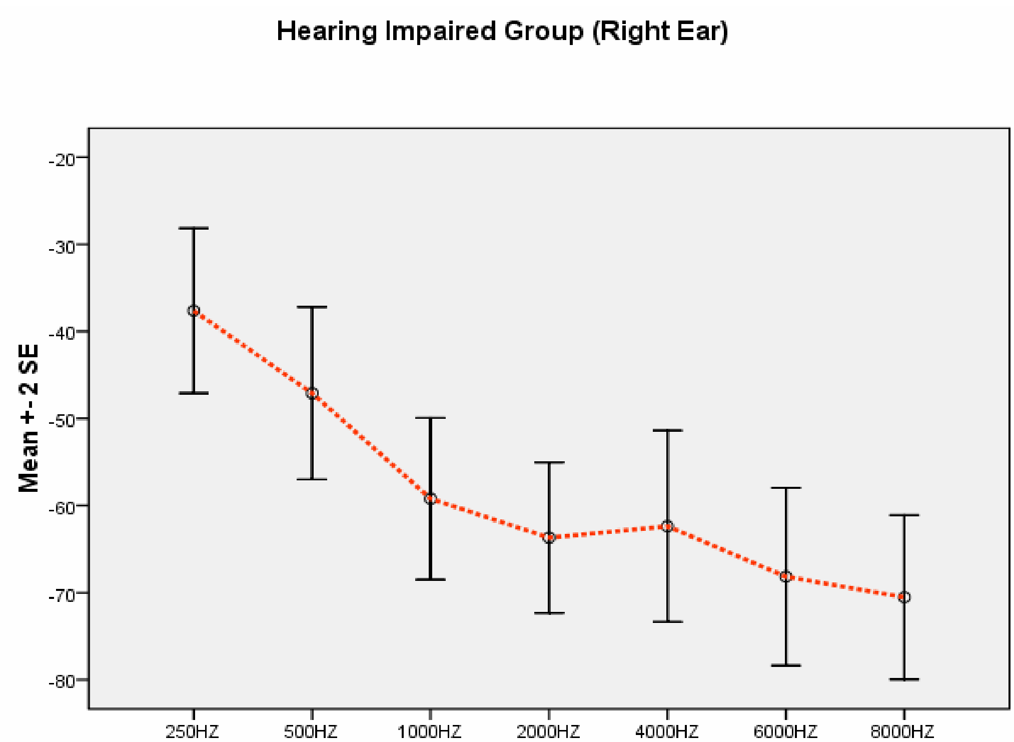

Figure 4-2. Mean PTA thresholds for the Right ear (HI Group, N=19)

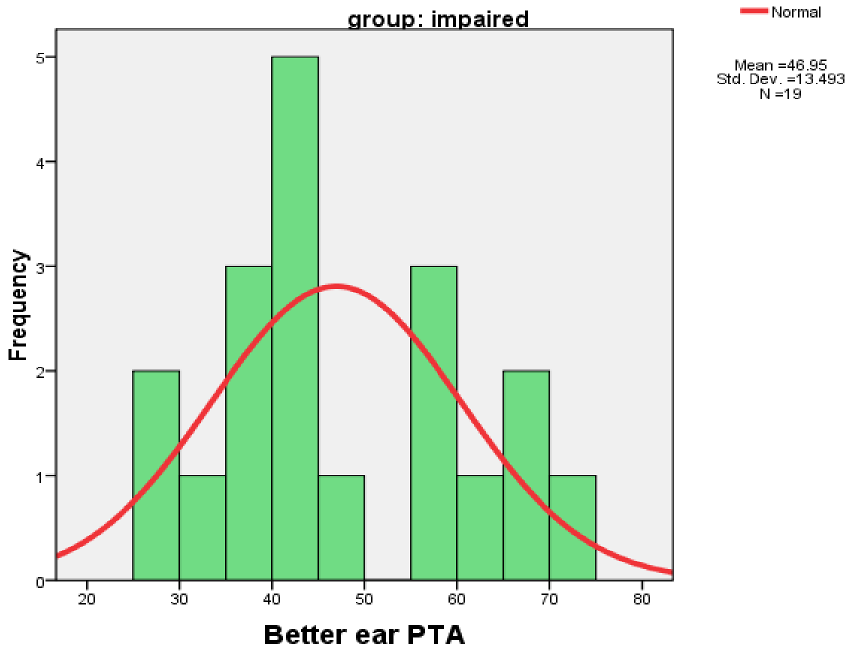

Figure 4-3. Histogram of 19 hearing impaired children by better ear pure-tone average.

Table 4-4. Descriptive statistics of auditory processing variables.

Group		SCAN (FW)	SCAN (AFG)	SCAN (CW)	DD
NH	Mean	12.10	9.41	10.14	8.54
	SD	1.970	2.383	2.812	8.533
	Min	6	5	4	67.50
	Max	15	15	14	98.75
HI	Mean	5.89	3.11	4.11	66.97
	SD	4.653	2.331	2.492	18.13
	Min	1	1	1	38.75
	Max	13	7	8	90

Note. SD: standard scores, FW: Filtered Words, AFG: Auditory Figure Ground, CW: Competing Words, DD: dichotic digit in %

Table 4-5. Descriptive statistics and estimated adjusted means of oral language measures (MANCOVA)

Dependent variables	Group	M	SD	Min	Max	Median	EAM	SE	95% CI	
									lower	Upper
PPVT-III	NH	112.00	12.45	81	132	113.0	110.45	2.496	105.42	115.47
	HI	91.42	15.31	62	115	93.0	93.80	3.133	87.48	100.10
EVT	NH	107.38	10.46	92	134	105.0	106.55	2.238	102.04	111.05
	HI	94.32	13.46	63	112	95.0	95.59	2.809	89.92	101.24
CASL	NH	117.86	12.68	89	149	118.0	116.51	2.122	112.24	120.78
	HI	95.68	10.40	75	115	96.0	97.74	2.663	92.38	103.12

Note. PPVT-III (receptive vocabulary), EVT (expressive vocabulary), CASL (grammatical knowledge), SE (standard error), NH: normally hearing group, HI: hearing-impaired group, M: mean, SD: standard deviation, Min: minimum, Max: maximum, EAM: estimated adjusted mean, SE: standard error

Table 4-6. ANOVA tables for univariate ANCOVAs for each oral language measure.

	MS	MSE	F(1,44)	p-value	partial η^2	Observed power
PPVT-III	2736.54	169.733	16.123	.000**	.268	.975
EVT	186.241	136.444	8.694	.005*	.165	.822
CASL	3477.002	122.627	28.354	.000**	.392	.999

Note. MS: mean square, MSE: mean η^2 = effect size. *: $p < .01$, **: $p < .001$

Table 4-7. Pairwise comparison results based on adjusted group means

Dependent Variable	A	B	Adjust means difference (A-B)	Standard errors	p-value	95% CI for Difference	
						Upper Bound	Lower Bound
PPVT	NH	HI	16.651	4.147	.000**	8.294	25.009
EVT	NH	HI	10.963	3.718	.005*	3.470	18.457
CASL	NH	HI	18.769	3.525	.000**	11.666	25.873

Note. NH = normally hearing group, HI = hearing impaired group. *: $p < .01$, **: $p < .001$
All pairwise comparisons are based on estimated marginal means and all scores are adjusted for multiple comparisons using Bonferroni's method. * The mean difference is significant at the .05 level.

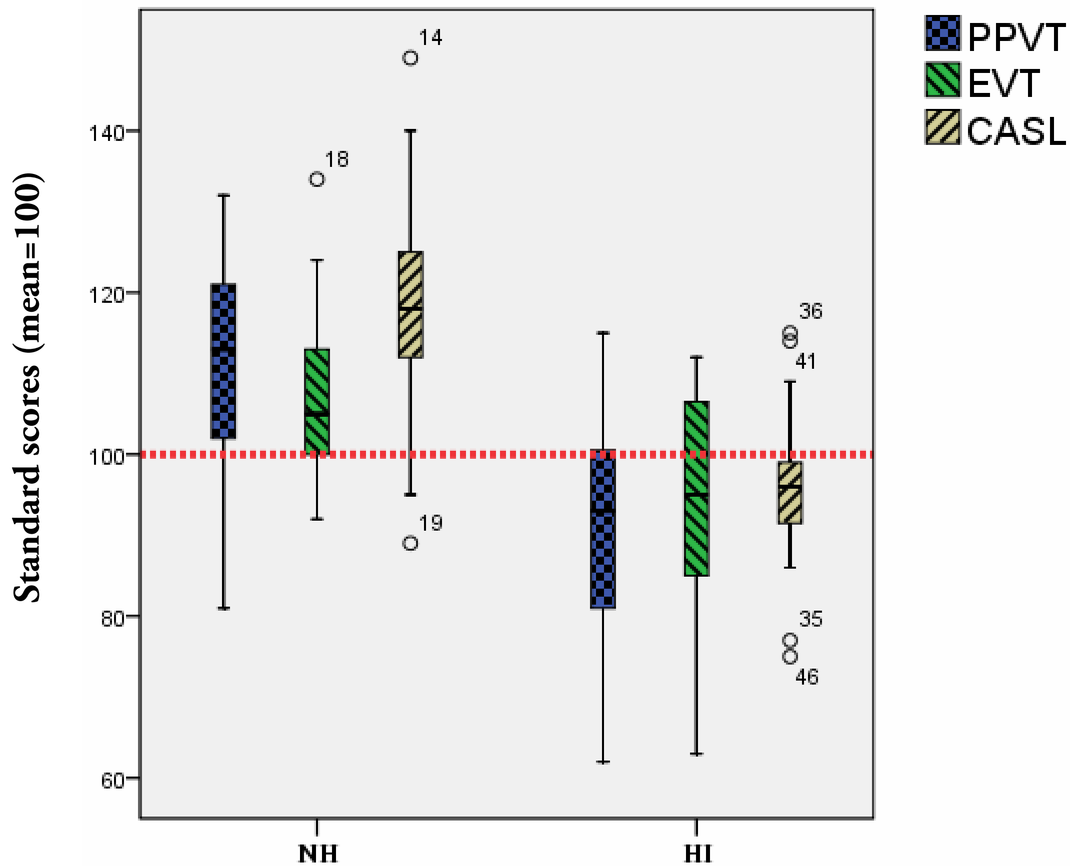

Figure 4-4. Clustered box plot of oral language measure for the NH and HI groups. Note: Dotted line indicates the mean score.

Table 4-8. Descriptive statistics and estimated adjusted groups means for phonological processing measures

	group	M	SD	Min	Max	Adjusted means	SE	95% CI Lower	95% CI Upper
Elision[#]	NH	12.10	2.410	7	16	12.080	.452	11.179	12.981
	HI	8.63	2.140	4	13	8.581	.571	7.443	9.719
	RD	7.43	2.528	3	13	7.488	.466	6.559	8.416
Blend[#]	NH	11.52	2.400	7	16	11.416	.409	10.601	12.232
	HI	7.79	1.584	4	11	7.567	.517	6.538	8.597
	RD	8.53	2.345	3	13	8.771	.422	7.931	9.611
RAN-Digit[##]	NH	11.17	2.406	7	18	11.064	.395	10.278	11.851
	HI	10.0	1.700	7	12	9.762	.498	8.769	10.755
	RD	7.77	2.112	4	13	8.022	.407	7.211	8.832
RAN-Letter[##]	NH	11.28	2.389	7	18	11.257	.429	10.403	12.111
	HI	10.05	2.094	6	14	10.012	.541	8.933	11.091
	RD	7.93	2.258	4	14	7.977	.442	7.097	8.857
Memory for Digits[#]	NH	11.07	2.685	6	17	11.078	.495	10.092	12.064
	HI	9.11	2.622	5	14	9.125	.625	7.881	10.370
	RD	9.10	2.551	4	15	9.079	.510	8.063	10.094
Nonword Repetition[#]	NH	12.41	2.292	8	17	12.433	.444	11.547	13.318
	HI	7.89	2.787	3	12	7.936	.561	6.818	9.055
	RD	8.90	2.107	5	14	8.855	.458	7.943	9.768

Note. NH: normally hearing group, HI: hearing-impaired group, M: mean, SD: standard deviation, Min: minimum, Max: maximum, SE: standard error, [#]: NH>HI=RD, [##]: NH=HI>RD.

Table 4-9. Summary of three univariate ANCOVAs on the phonological measures from the CTOPP.

	MS	MSE	F(2,74)	p-value	partial η^2	Observed power	Group comparisons
Elision	155.657	5.807	26.803	.000	.420	1.000	NH > HI = RD
Blending	96.433	4.755	20.281	.000	.354	1.000	NH > HI = RD
RAN Digits	60.917	4.425	13.767	.000	.271	.998	NH = HI > RD
RAN Letters	70.881	5.218	13.584	.000	.269	.997	NH = HI > RD
Memory for Digits	34.694	6.949	4.993	.009	.119	.798	NH > HI = RD
Nonword Repetition	144.587	5.609	25.780	.000	.411	1.000	NH > HI = RD

Note. MS: mean square, MSE: mean square for error, partial η^2 =effect size, $df_1 = 1$, $df_2 = 44$

Table 4-10. Summary of post hoc pairwise comparisons of phonological measures (CTOPP subtests).

Dependent Variables	A	B	Mean Difference (A-B)	SE	t	Sig	95% CI for Mean Difference[a] Upper Bound	Lower Bound
Elision	NH	HI	3.500	.716	4.888	.000**	1.747	5.252
	NH	RD	4.593	.664	6.917	.000**	2.965	6.220
	HI	RD	1.093	.766	1.427	.473	-.784	2.970
Blend	NH	HI	3.849	.647	5.949	.000**	2.263	5.435
	NH	RD	2.645	.601	4.400	.000**	1.172	4.118
	HI	RD	-1.204	.693	1.737	.260	-2.902	.4940
RAN-Digit	NH	HI	1.302	.625	2.083	.122	-.2280	2.832
	NH	RD	3.043	.580	5.247	.000**	1.622	4.464
	HI	RD	1.741	.669	2.568	.033*	.1020	3.379
RAN-Letter	NH	HI	1.245	.678	1.836	.211	-.416	2.907
	NH	RD	3.281	.630	5.208	.000**	1.738	4.823
	HI	RD	2.035	.726	2.803	.019*	.2560	3.814
Memory for Digits	NH	HI	1.953	.783	2.494	.044*	.0350	3.870
	NH	RD	1.999	.727	2.750	.022*	.2190	3.780
	HI	RD	.047	.838	0.056	1.00	-2.006	2.100
NWR	NH	HI	4.496	.703	6.395	.000**	2.774	6.219
	NH	RD	3.577	.653	5.478	.000**	1.978	5.177
	HI	RD	-.919	.753	1.220	.679	-2.763	.9260

Note. *: $p < .05$, **: $p < .001$. NH = normally hearing group, HI = hearing impaired group, RD = Dyslexic group,
All comparisons are based on estimated marginal means using Bonferroni's method for multiple comparisons.

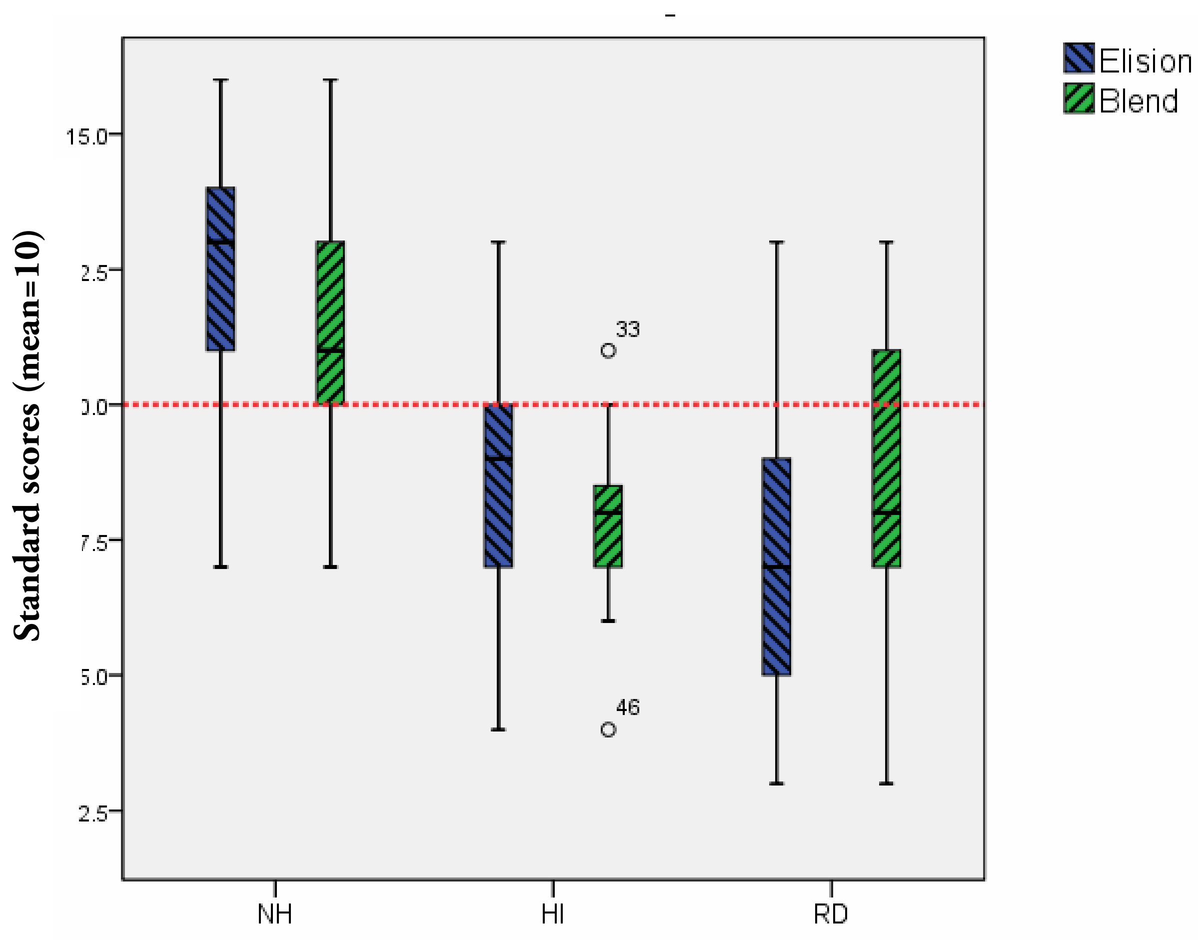

Figure 4-5. Clustered boxplot for phonological awareness measures for the NH, HI and RD groups. Note: Dotted line indicates the mean score.

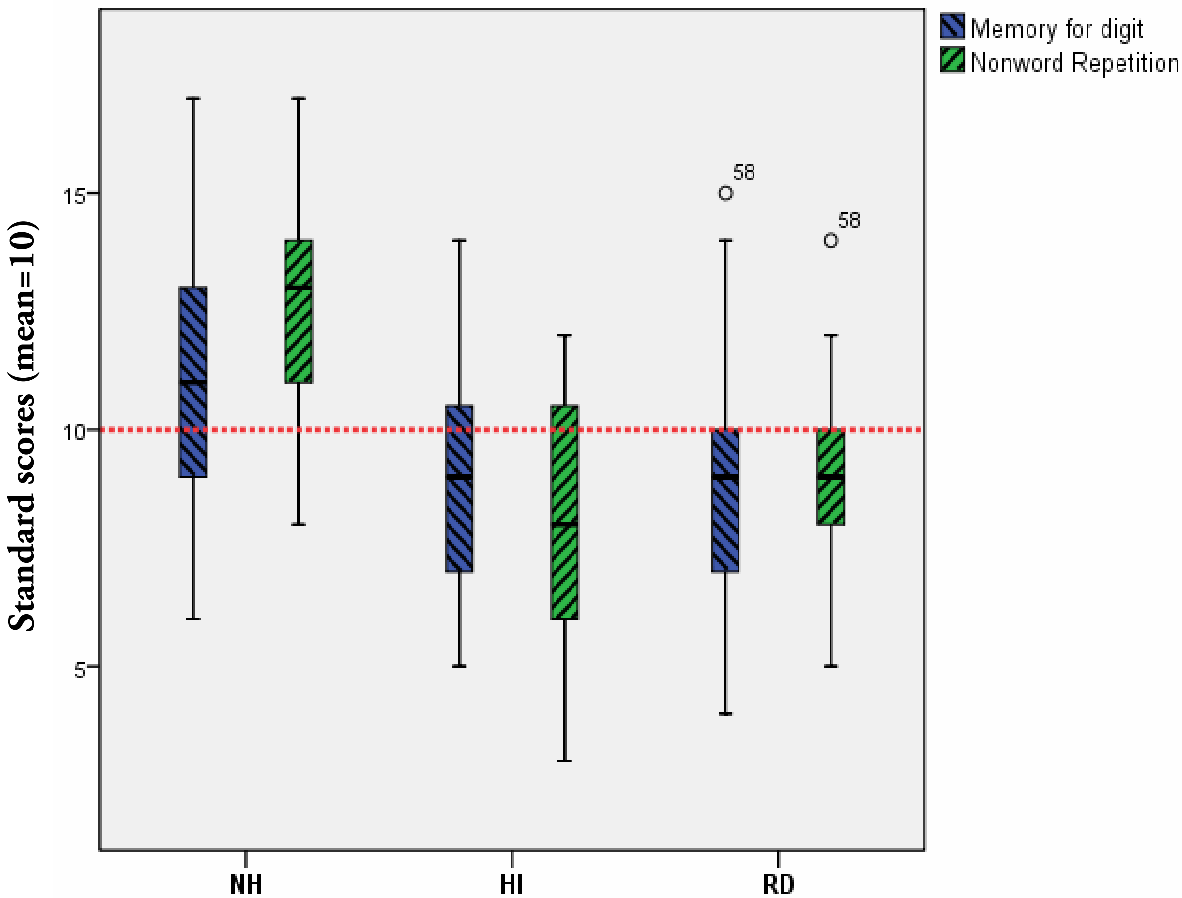

Figure 4-6. Clustered boxplot for phonological short-term memory for the NH, HI, and RD groups. Note: Dotted line indicates the mean score.

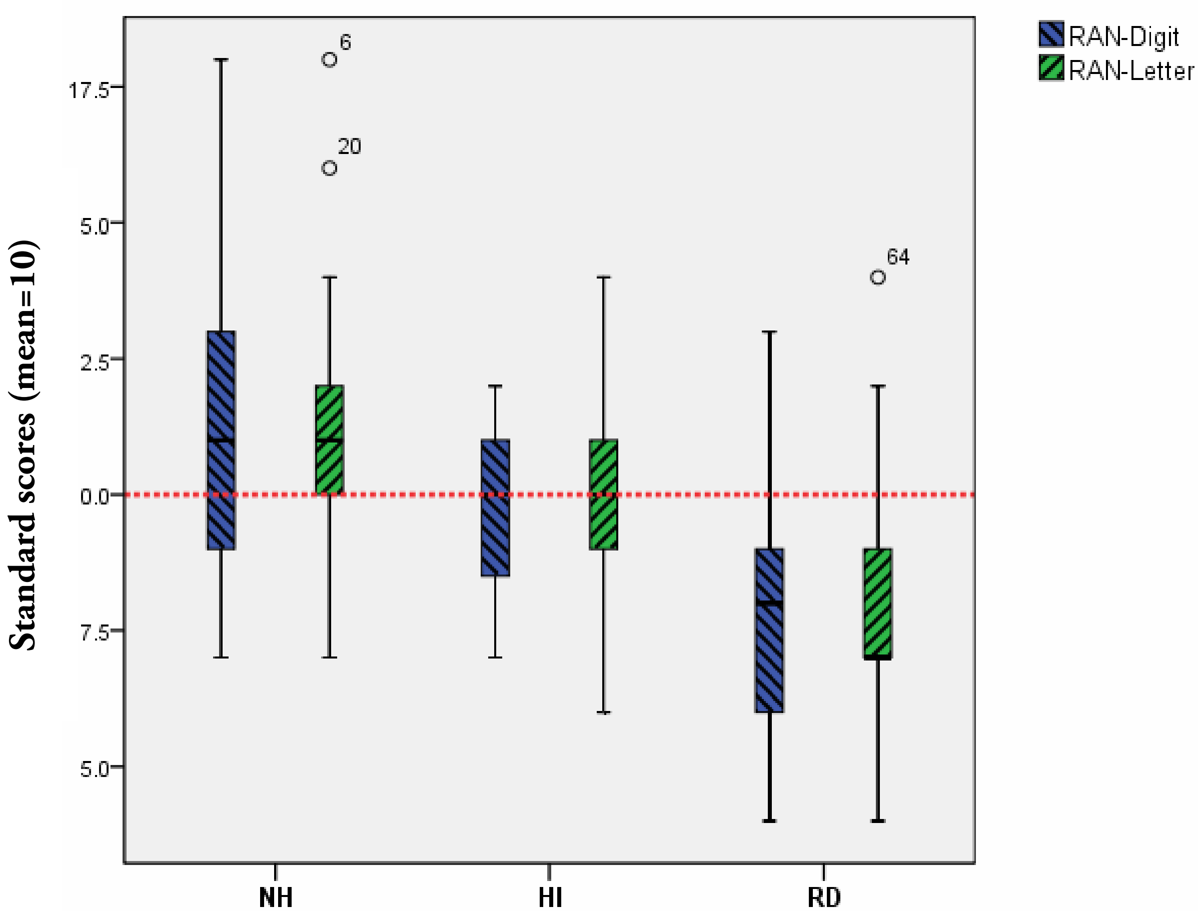

Figure 4-7. Clustered boxplot for rapid naming for the NH, HI, and RD groups. Note: Dotted line indicates the mean score.

Table 4-11. Descriptive statistics and estimated adjusted group means for literacy measures.

		M	SD	Adjusted means	SE	95 % CI	
						lower	upper
Timed reading (TOWRE)	*Word*						
	NH	115.24	8.947	119.5	2.398	114.728	124.283
	HI	108.11	9.451	105.1	2.984	99.174	111.066
	RD	83.10	13.469	83.3	2.364	78.558	87.980
	Nonword						
	NH	115.62	12.982	115.5	2.360	110.796	120.201
	HI	110.16	11.388	105.5	2.937	99.643	111.348
	RD	82.40	8.830	85.4	2.327	80.767	90.041
Untimed reading (WRMT)	*Word*						
	NH	119.34	13.036	110.7	2.220	106.235	115.082
	HI	106.37	15.475	98.6	2.763	93.096	104.106
	RD	82.63	13.405	84.6	2.189	80.221	88.945
	Nonword						
	NH	115.38	13.270	113.0	2.226	108.517	117.387
	HI	106.42	14.698	99.7	2.770	94.210	105.250
	RD	84.93	12.031	84.7	2.195	80.344	89.091
Spelling	NH	112.93	13.564	115.3	2.000	111.341	119.310
	HI	99.89	13.552	107.5	2.489	102.494	112.411
	RD	84.63	8.720	83.4	1.972	79.504	87.361
Passage reading	*Comprehension*						
	NH	110.62	9.951	115.7	2.030	111.654	119.745
	HI	98.89	12.391	109.5	2.527	104.509	114.580
	RD	84.43	13.318	82.7	2.002	78.723	86.702
	Reading rate						
	NH	14.00	2.104	13.9	.530	12.935	15.048
	HI	11.26	3.754	11.3	.660	10.013	12.643
	RD	4.97	2.822	4.9	.523	3.892	5.976
	Reading accuracy						
	NH	14.55	2.759	14.6	.572	13.407	15.688
	HI	11.63	3.804	11.7	.712	10.245	13.084
	RD	5.90	2.820	5.9	.564	4.758	7.008

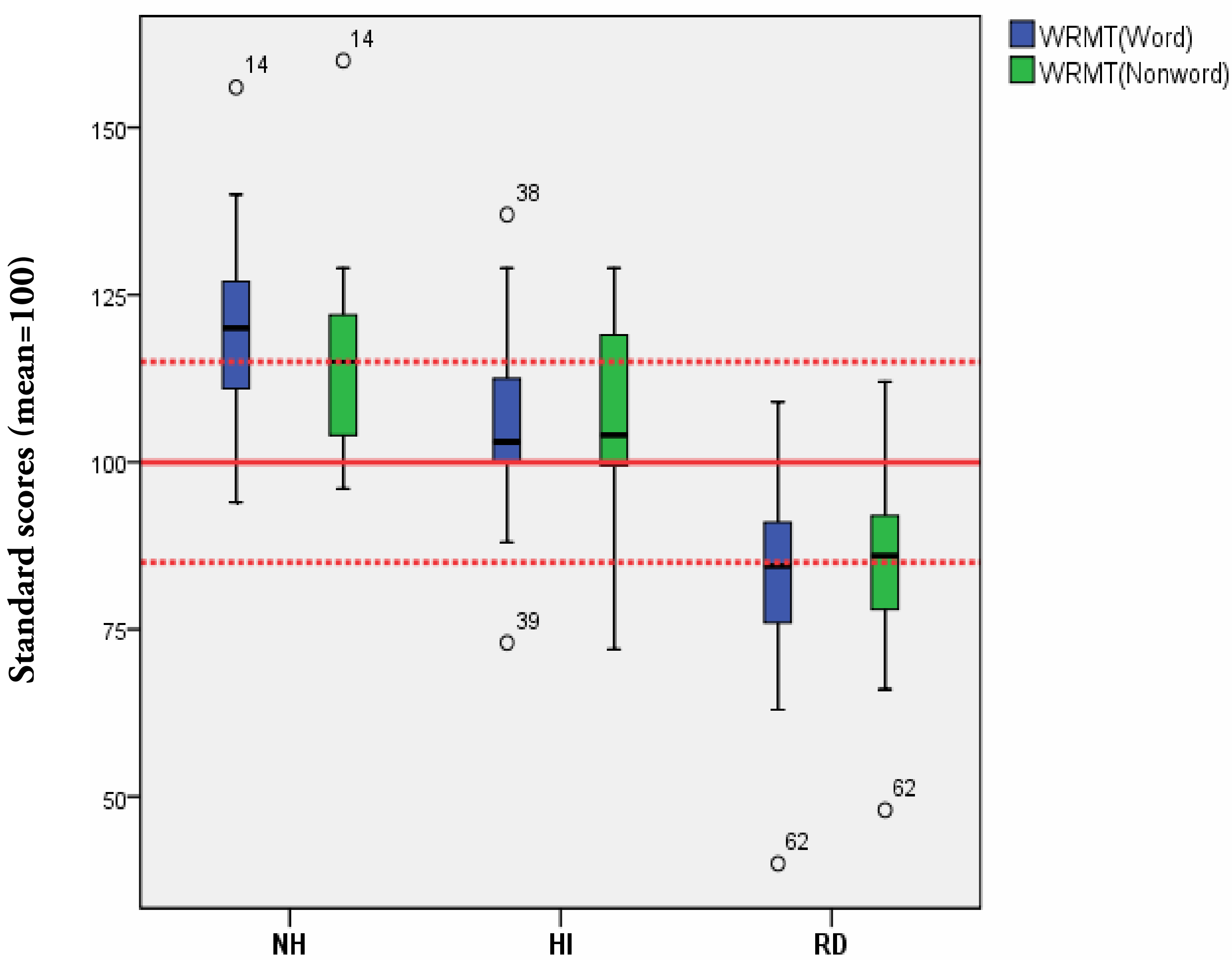

Figure 4-8. Clustered boxplot for untimed word-level reading (*Word Identification* and *Word Attack* subtests on the WRMT-R). Note: Dotted lines indicate ± 1 SD.

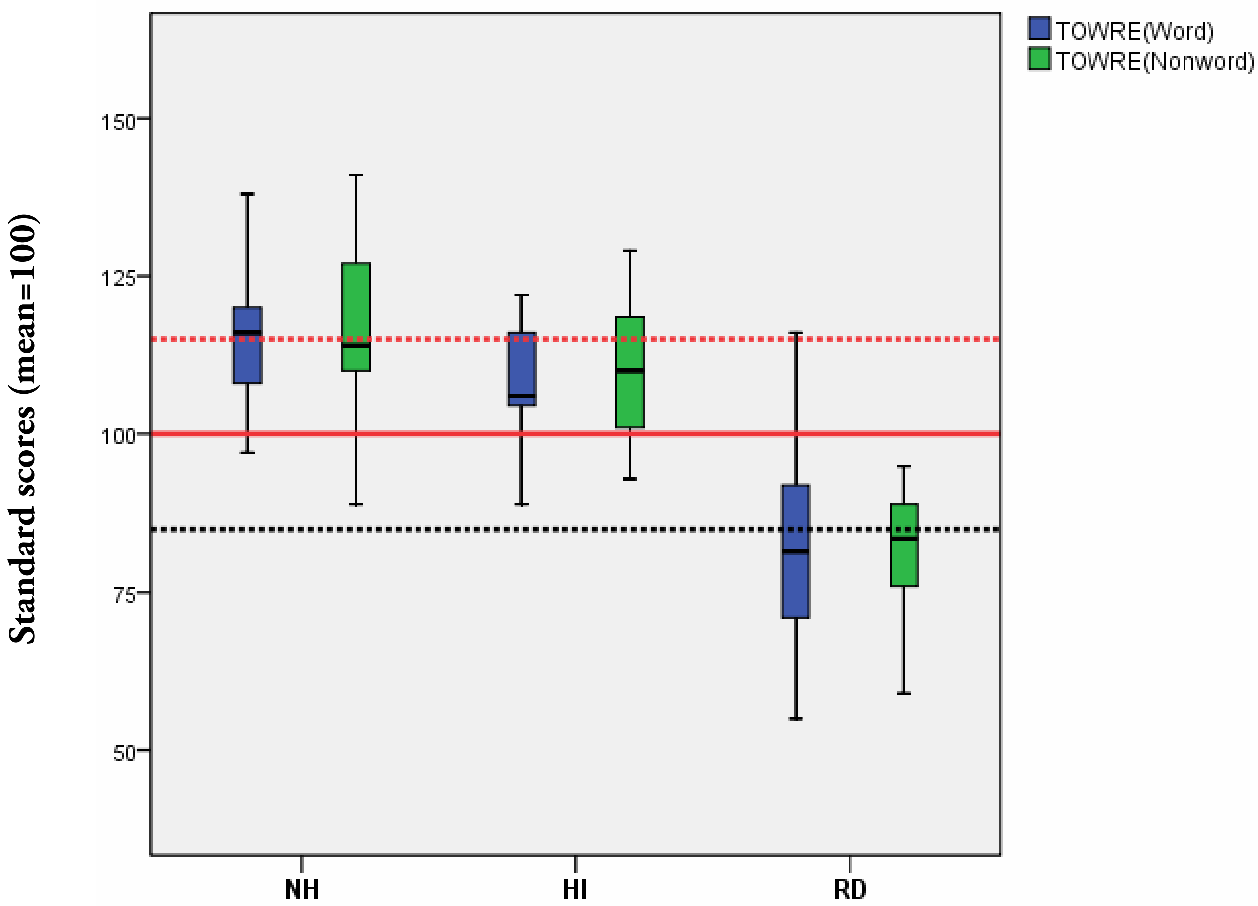

Figure 4-9. Clustered boxplot for untimed word-level reading (*Word Efficiency* and *Word Decoding* subtests on the WRMT-R). Note: Dotted lines indicate ± 1 SD.

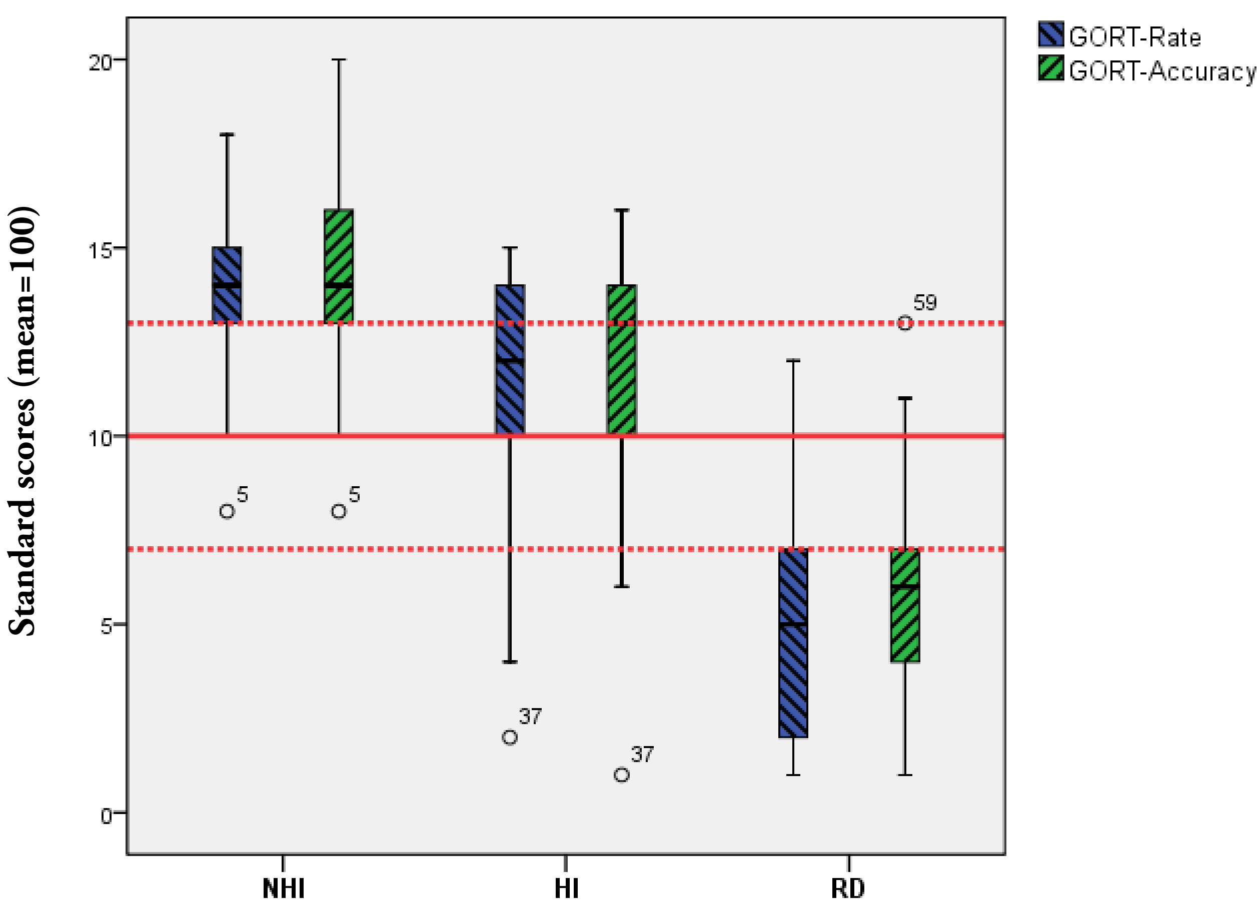

Figure 4-10. Clustered boxplot for connected-text reading fluency (GORT-4 Rate and Accuracy) (Note: Dotted lines indicate ± 1 SD.

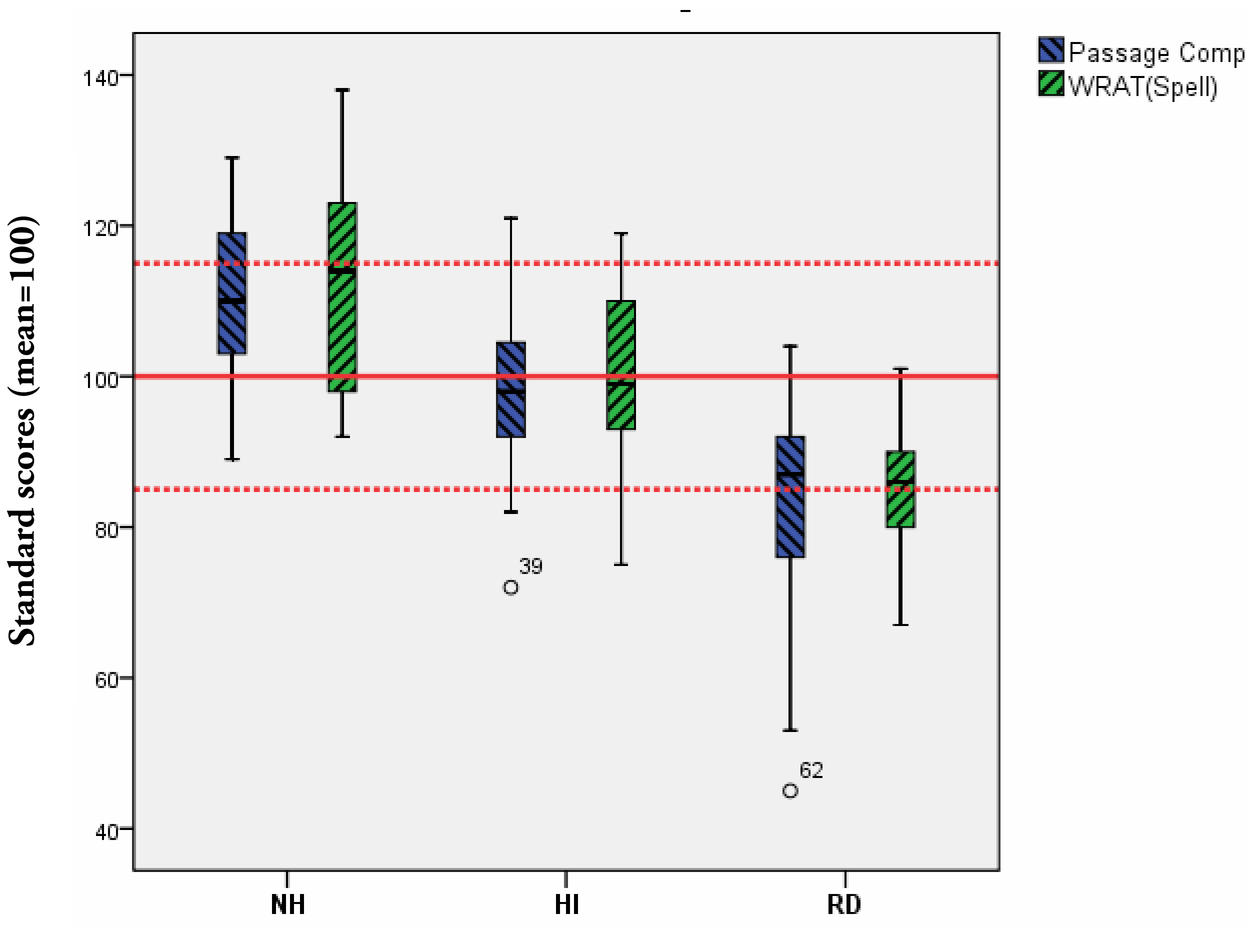

Figure 4-11. Clustered boxplot for passage comprehension (WRMT-R) and spelling (WRAT) (Note: Dotted lines indicate ± 1 SD).

Table 4-12. Summary of univariate ANCOVAs on the reading and spelling measures.

Dependent Variable			MSB	MSE	F(2,74)	*p*	partial η^2	Observed Power	Group comparison
Untimed	Word	WRMT-R	9767.786	166.657	58.610	.000	.613	1.000	NH > HI > RD
	Nonword		6850.592	161.457	42.430	.000	.534	1.000	NH > HI > RD
Timed	Word	TOWRE	7955.022	115.904	68.634	.000	.650	1.000	NH > HI > RD
	Nonword		8774.433	119.518	73.415	.000	.665	1.000	NH = HI > RD
Spelling		WRAT	5874.333	143.631	40.899	.000	.525	1.000	NH > HI > RD
Passage reading	Comp*	WRMT-R	5012.224	142.865	35.084	.000	.487	1.000	NH > HI > RD
	Rate	GORT	629.020	8.154	77.143	.000	.676	1.000	NH > HI > RD
	Accuracy	GORT	567.806	9.499	59.777	.000	.618	1.000	NH > HI > RD

Note. The F tests the effect of group in each ANCOVA. Covariate was grade in months. *: passage comprehension.

MSB: mean squares for between group, MSE: mean square error

Table 4-13. Summary of post hoc pairwise comparisons of eight reading and spelling measures.

Dependent Variables	A	B	Mean Difference (A-B)	SE	t	Sig[a]	95% CI for Mean Difference[a]	
							Upper Bound	Lower Bound
WRMT[a] (untimed word)	NH	HI	14.386	3.833	3.75	.001**	4.997	23.774
	NH	RD	36.237	3.365	10.77	.000***	27.994	44.479
	HI	RD	21.851	3.825	5.71	.000***	12.481	31.221
WRMT[a] (untimed nonword)	NH	HI	10.003	3.772	2.65	.029*	.762	19.243
	NH	RD	30.094	3.312	9.09	.000***	21.981	38.207
	HI	RD	20.091	3.765	5.34	.000***	10.869	29.314
WRMT (compre-hension)	NH	HI	12.058	3.548	3.40	.003***	3.366	20.750
	NH	RD	26.076	3.115	8.37	.000**	18.444	33.707
	HI	RD	14.018	3.541	3.96	.001*	5.343	22.693
WRAT (spelling)	NH	HI	13.222	3.558	3.72	.001*	4.507	21.938
	NH	RD	28.235	3.124	9.04	.000**	20.583	35.887
	HI	RD	15.013	3.551	4.23	.000**	6.314	23.711
TOWRE[b] (timed word)	NH	HI	7.873	3.196	2.46	.048*	.044	15.703
	NH	RD	31.893	2.806	11.37	.000***	25.019	38.767
	HI	RD	24.020	3.190	7.53	.000***	16.206	31.834
TOWRE[b] (timed nonword)	NH	HI	6.155	3.246	1.90	.185	-1.795	14.106
	NH	RD	32.987	2.849	11.58	.000***	26.007	39.967
	HI	RD	26.832	3.239	8.28	.000***	18.897	34.767
GORT (reading rate)	NH	HI	2.664	.848	3.14	.007**	.587	4.740
	NH	RD	9.058	.744	12.17	.000***	7.235	10.881
	HI	RD	6.394	.846	7.56	.000***	4.322	8.467
GORT (reading accuracy)	NH	HI	2.883	.915	3.1	.007***	.641	5.124
	NH	RD	8.664	.803	10.9	.000***	6.697	10.632
	HI	RD	5.782	.913	6.3	.000***	3.545	8.019

Note. [a]: timed test, [b]: untimed test, *: $p < .05$, ** $p < .01$, *** $p < .001$, Covariate: grade(in months and years)

Table 4-14. Correlations between the degree of hearing loss and phonological measures, partialing out for age and grade.

			elision	blending	RAN-Digit	RAN-Letter	Memory for Digit	Nonword repetition
PTA (better ear)	HI	r	-.644	-.721	-.367	-.396	-.287	-.597
		sig.	.007**	.002**	.162	.129	.281	.015*
	NH	r	-.203	.049	-.174	-.108	.322	.031
		sig.	.320	.814	.394	.598	.109	.880

Note. **p* < .05, ***p* < .01

Table 4-15. Partial correlation matrix between phonology and reading (HI group).

		untimed		timed			Passage		
		word	nonword	word	nonword	spell	compre hension	rate	accuracy
elision	r	.582	.751	.562	.611	.618	.610	.605	.711
	sig	.009	.000	.012	.006	.005	.006	.007	.001
blend	r	.189	.304	.193	.159	.379	.289	.470	.378
	sig	.241	.126	.237	.278	.074	.139	.033	.074
RAN-Digits	r	.307	.411	.459	.560	.418	.341	.723	.635
	sig	.124	.057	.037	.012	.054	.098	.001	.004
RAN-Letter	r	.259	.301	.559	.656	.479	.314	.581	.571
	sig	.166	.129	.012	.003	.030	.118	.009	.010
Memory for Digits	r	.160	.394	.287	.285	.558	.284	.525	.393
	sig	.277	.066	.141	.143	.012	.143	.018	.066
Nonword Repetition	r	.362	.594	.323	.324	.291	.324	.375	.322
	sig	.084	.008	.111	.110	.137	.111	.076	.112

Table 4-16. Partial correlation matrix between phonology and reading (NH group).

		untimed		timed			Passage		
		word	nonword	word	nonword	spell	Compre-hension	rate	accuracy
elision	r	.711	.692	.142	.474	.825	.520	.443	.671
	sig	.000	.000	.244	.007	.000	.003	.012	.000
blend	r	.378	.472	-.023	.326	.511	.185	.116	.392
	sig	.028	.007	.456	.052	.004	.183	.286	.024
RAN-Digits	r	.421	.382	.559	.596	.311	-.018	.382	.465
	sig	.016	.027	.001	.001	.061	.465	.027	.008
RAN-Letter	r	.414	.437	.542	.629	.399	.006	.385	.540
	sig	.018	.013	.002	.000	.022	.489	.026	.002
Memory for Digits	r	.657	.603	-.106	.305	.519	.502	.185	.377
	sig	.000	.001	.302	.065	.003	.005	.182	.029
Nonword Repetition	r	.686	.650	.137	.366	.534	.484	.433	.558
	sig	.000	.000	.253	.033	.002	.006	.014	.002

Table 4-17. Correlation matrix between better ear's PTA and phonology, partialing out age (in months).

Control Variables			Elision	Blend	RAN-Digit	RAN-Letter	Memory for Digits	Nonword Repetition
age_month	Better ear PTA	r	-.473	-.597	.120	.085	.116	-.424
		p	.024	.004	.318	.368	.323	.040
	Better ear SRT	r	-.565	-.528	-.012	.032	.166	-.438
		p	.007	.012	.481	.449	.255	.034
	Elision	r	1.000	.608	.320	.215	.326	.579
		p	.	.004	.097	.196	.094	.006
	Blend	r	.608	1.000	.225	.160	.415	.461
		p	.004	.	.185	.263	.043	.027
	RAN-Digit	r	.320	.225	1.000	.868	.197	.149
		p	.097	.185	.	.000	.216	.278
	RAN-Letter	r	.215	.160	.868	1.000	.126	-.004
		p	.196	.263	.000	.	.309	.494
	Memory for Digits	r	.326	.415	.197	.126	1.000	.502
		p	.094	.043	.216	.309	.	.017
	Nonword Repetition	r	.579	.461	.149	-.004	.502	1.000
		p	.006	.027	.278	.494	.017	.

Table 4-18. First-order correlation matrix between oral language and phonology measures.

		Elision	Blend	RAN-Digit	RAN-Letter	Memory for Digit	Nonword Repetition
PPVT	r	.324	.362	-.063	-.130	.533	.406
	p	.102	.077	.405	.309	.014	.053
EVT	r	.252	.224	.112	-.044	.592	.359
	p	.164	.194	.335	.434	.006	.078
CASL	r	.511	.443	.210	.162	.558	.494
	p	.018	.038	.209	.267	.010	.022

Table 4-19. Correlation matrices among auditory processing measures, and phonology and reading scores, partialing out for age, grade, duration of hearing aid use, and nonverbal intelligence.

	Phonological measures						Reading measures							
	PA		RAN		STM		Untimed		timed			Passage reading		
	elision	Blend	Digit	Letter	MD	NWR	Word	NW	Word	NW	Spell	Comp	Rate	Accu
SCAN1	.354	.410	-.022	-.012	.143	.409	-.135	-.028	.294	-.100	-.191	-.110	-.270	-.225
(FW)	.196	.129	.939	.965	.610	.130	.633	.921	.287	.722	.496	.696	.330	.420
SCAN2	.087	.432	-.131	-.333	.430	.563	-.193	-.155	.075	-.361	-.323	-.118	-.158	-.404
(AFG)	.757	.108	.641	.225	.110	.029	.491	.580	.790	.187	.240	.676	.575	.135
SCAN3	.222	.451	-.105	-.250	.653	.579	-.215	-.120	-.059	-.152	-.192	-.272	-.264	-.514
(CW)	.426	.091	.711	.368	.008	.024	.442	.671	.835	.589	.493	.327	.341	.050
DD_perc	.714	.659	.391	.069	.617	.548	.306	.546	.234	.525	.479	.322	.439	.261
	.003	.008	.149	.808	.014	.034	.267	.035	.400	.044	.071	.242	.102	.348

Note. MD: Memory for Digit, NWR: Nonword Repetition, Comp: Comprehension, FW: Filtered Words, AFG: Auditory Figure-Ground, CW: Competing Words, DD_perc: Dichotic Digits in percentile, Accu: Accuracy

Table 4-20. Correlation matrix between oral language and reading measures.

	PPVT	EVT	CASL
Word Identification	.286	.283	.203
(WRMT-R)	.151	.153	.234
Word Attack	.247	.361	.291
(WRMT-R)	.187	.093	.147
Passage Comprehension	.474	.536	.442
(WRMT-R)	.037	.020	.049
Spell (WRAT-3)	.187	.319	.238
	.252	.123	.197
Word Efficiency	.368	.127	.363
(TOWRE)	.088	.326	.092
Word Decoding	-.025	.128	.129
(TOWRE)	.465	.325	.324
GORT-4 Rate	.271	.442	.194
	.164	.050	.245
GORT-4 Accuracy	.092	.189	.129
	.372	.250	.323

Note. Age, grade, duration of hearing aid use, and nonverbal intelligence were partialed out.

Table 4-21. Hierarchical regressions of variables *separately* predicting untimed word reading (the *Word Identification* subtest on the WRMT-R).

	B	SE B	β	t	sig	R^2	ΔR^2	ΔF
Step1								
Age								
Better ear's PTA						.319		
Nonverbal IQ								
Step 2								
Elision	4.673	1.395	.646	3.351	.005	.622	.303	11.227
Blending	3.260	2.517	.334	1.295	.216	.392	.073	.216
RAN-Digits	4.061	2.156	.446	1.883	.081	.457	.138	3.547
RAN-Letter	3.055	1.903	.413	1.606	.131	.425	.106	2.578
Memory for Digits	1.662	1.263	.282	1.316	.209	.394	.075	1.732
Nonword Repetition	2.459	1.169	.443	2.103	.054	.482	.164	4.423
Dichotic Digits	.380	.211	.445	1.803	.093	.447	.128	3.249

Note. B: estimated beta, SE B: standard error of estimated beta, β: estimated standardized beta, R^2: multiple correlation, ΔR^2: amount of increased multiple correlation coefficient.

Table 4-22. Hierarchical regressions of variables *separately* predicting untimed nonword reading (the *Word Attack* subtest on the WRMT-R).

	B	SE B	β	t	sig	R^2	ΔR^2	ΔF
Step1								
Age								
Better ear's PTA						.110		
Nonverbal IQ								
Step 2								
Elision	5.873	1.291	.855	4.550	.000	.641	.531	20.698
Blending	4.008	2.686	.432	1.492	.158	.233	.122	2.227
RAN-Digits	4.495	2.329	.520	1.930	.074	.297	.187	3.726
RAN-Letter	2.636	2.134	.396	1.235	.237	.198	.087	1.525
Memory for Digits	2.505	1.290	.447	1.943	.072	.299	.189	3.774
Nonword Repetition	3.513	1.113	.666	3.156	.007	.480	.370	9.957
Dichotic Digits	.539	.209	.665	2.576	.022	.397	.286	6.637

Note. B: estimated beta, SE B: standard error of estimated beta, β: estimated standardized beta, R^2: multiple correlation, ΔR^2: amount of increased multiple correlation coefficient.

Table 4-23. Hierarchical regressions of variables *separately* predicting timed word reading (the *Word Efficiency* on the TOWRE).

	B	SE B	β	t	sig	R^2	ΔR^2	ΔF
Step1								
Age								
Better ear's PTA						.193		
Nonverbal IQ								
Step 2								
Elision	2.780	.999	.629	2.784	.015	.481	.287	7.748
Blending	1.794	1.705	.301	1.053	.310	.252	.059	1.108
RAN-Digits	2.953	1.397	.531	2.113	.050	.388	.195	4.465
RAN-Letter	2.840	1.148	.629	2.473	.027	.438	.245	6.117
Memory for Digits	1.180	.832	.327	1.418	.178	.294	.101	2.010
Nonword Repetition	1.366	.814	.403	1.678	.115	.328	.135	2.817
Dichotic Digits	.159	.150	.305	1.064	.306	.253	.060	1.131

Note. B: estimated beta, SE B: standard error of estimated beta, β: estimated standardized beta, R^2: multiple correlation, ΔR^2: amount of increased multiple correlation coefficient.

Table 4-24. Hierarchical regressions of variables *separately* predicting timed nonword reading (the *Word Decoding* on the TOWRE).

	B	SE B	β	t	sig	R^2	ΔR^2	ΔF
Step1								
Age								
Better ear's PTA						.097		
Nonverbal IQ								
Step 2								
Elision	3.809	1.217	.716	3.130	.007	.469	.372	9.795
Blending	1.990	2.194	.277	.907	.147	.147	.050	.823
RAN-Digits	4.510	1.653	.673	2.728	.016	.411	.313	7.445
RAN-Letter	4.328	1.319	.796	3.280	.005	.489	.392	10.761
Memory for Digits	1.484	1.063	.342	1.397	.184	.207	.110	1.951
Nonword Repetition	1.723	1.039	.422	1.658	.120	.245	.148	2.748
Dichotic Digits	.364	.173	.579	2.105	.054	.414	.217	4.431

Note. B: estimated beta, SE B: standard error of estimated beta, β: estimated standardized beta, R^2: multiple correlation, ΔR^2: amount of increased multiple correlation coefficient.

Table 4-25. Hierarchical regressions of variables *separately* predicting timed passage reading rate on the GORT-4.

	B	SE B	β	t	sig	R^2	ΔR^2	ΔF
<u>Step1</u>								
Age								
Better ear's PTA						.238		
Nonverbal IQ								
<u>Step 2</u>								
Elision	1.110	.378	.633	2.938	.011	.528	.291	8.631
Blending	1.198	.604	.505	1.982	.607	.405	.167	3.929
RAN-Digits	1.628	.441	.737	3.690	.002	.613	.376	13.614
RAN-Letter	1.011	.458	.564	2.210	.044	.435	.197	4.884
Memory for Digits	.640	.298	.447	2.149	.050	.427	.189	4.616
Nonword Repetition	.506	.317	.375	1.596	.133	.355	.117	2.547
Dichotic Digits	.132	.049	.636	2.705	.017	.499	.262	7.317

Note. B: estimated beta, SE B: standard error of estimated beta, β: estimated standardized beta, R^2: multiple correlation, ΔR^2: amount of increased multiple correlation coefficient.

Table 4-26. Hierarchical regressions of variables *separately* predicting timed passage reading accuracy on the GORT-4.

	B	SE B	β	t	sig	R^2	ΔR^2	ΔF
Step1								
Age								
Better ear's PTA						.183		
Nonverbal IQ								
Step 2								
Elision	1.366	.348	.768	3.929	.002	.611	.428	15.435
Blending	1.047	.660	.436	1.586	.135	.307	.124	2.514
RAN-Digits	1.514	.509	.676	2.977	.010	.500	.317	8.860
RAN-Letter	1.085	.476	.596	2.279	.039	.404	.221	5.195
Memory for Digits	.520	.332	.359	1.565	.140	.305	.122	2.449
Nonword Repetition	.482	.337	.353	1.427	.175	.287	.104	2.038
Dichotic Digits	.180	.056	.515	1.931	.074	.355	.172	3.727

Note. B: estimated beta, SE B: standard error of estimated beta, β: estimated standardized beta, R^2: multiple correlation, ΔR^2: amount of increased multiple correlation coefficient.

Table 4-27. Hierarchical regressions of variables *separately* predicting scores on the *Spelling* on the WRAT.

	B	SE B	β	t	sig	R^2	ΔR^2	ΔF
Step1								
Age								
Better ear's PTA						.183		
Nonverbal IQ								
Step 2								
Elision	4.322	1.375	.683	3.143	.007	.521	.338	9.877
Blending	4.091	2.310	.478	1.771	.098	.332	.150	3.137
RAN-Digits	3.816	2.079	.479	1.836	.088	.341	.159	3.369
RAN-Letter	3.377	1.770	.522	1.908	.077	.351	.169	3.642
Memory for Digits	2.849	1.034	.551	2.755	.015	.470	.287	7.592
Nonword Repetition	1.790	1.195	.368	1.498	.156	.296	.113	2.245
Dichotic Digits	.495	.181	.663	2.735	.016	.467	.285	7.480

Note. B: estimated beta, SE B: standard error of estimated beta, β: estimated standardized beta, R^2: multiple correlation, ΔR^2: amount of increased multiple correlation coefficient.

Table 4-28. Summary of hierarchical regressions on timed reading measures, controlled for phonological awareness and short-term memory scores (showing the results from Step 3 only).

Criterion variables	Entered exploratory variable (RAN-Digit) in Step 3						
	B	SE B	β	t	Sig.	R^2	ΔR^2
Reading rate (GORT-4)	1.522	.425	.689	3.583	.005	.816	.236
Reading accuracy (GORT-4)	1.270	.471	568	2.695	.022	.779	.160
Words (TOWRE)	2.449	1.592	.440	1.538	.155	.592	.096
Non-words (TOWRE)	4.259	1.666	.636	2.556	.029	.692	.201

Criterion variables	Entered exploratory variable (RAN-Digit) in Step 3						
	B	SE B	β	t	Sig.	R^2	ΔR^2
Reading rate (GORT-4)	.927	.396	.517	2.340	.041	.728	.149
Reading accuracy (GORT-4)	.945	.370	.520	2.553	.029	.770	.150
Words (TOWRE)	2.786	1.035	.617	2.691	.023	.708	.212
Non-words (TOWRE)	4.368	.895	.803	4.882	.001	.850	.358

Note. B: estimated beta, SE B: standard error of estimated beta, β: estimated standardized beta, R^2: multiple correlation, ΔR^2: amount of increased multiple correlation coefficients.

CHAPTER 5
DISCUSSION

Introduction

This present study sought to explore four major questions concerning the specific link between mild to moderate SNHL and reading and spelling abilities.

(1) Are there significant effects of SNHL on hard-of-hearing children's skills of spoken language, phonological processing, and reading/spelling?

(2) What are the patterns of correlations among reading, phonological ability, and spoken language? Which phonological variables are associated with which types of reading tasks in the HI group?

(3) Are phonological processing skills important in reading achievement of hearing impaired readers? Specifically, do they predict unique variance in reading and spelling?

Oral Language Skills Findings

The first purpose of the present study was to replicate the results of previous studies on the spoken language ability of the HI children compared to children with normal hearing. There are only a few scientific studies of the language skills of children with mild to moderate SNHL (Davis, Shepard, Stelmachowicz, & Gorga, 1981; Gilbertson & Kamhi, 1995; Davis, Elfenbein, Schum, & Bentler, 1986; Blair, Peterson, & Viehweg, 1985; Blamey, Sarant, Paatsch, Barry, Bow, Wales, 2001; Gilbertson and Kamhi, 1995; Hansson et al., 2004; Stelmachowicz et al., 2004). Most previous studies, conducted on children with a range of linguistic skills, revealed that a significant proportion of children with mild to moderate SNHL have depressed vocabulary and morphosyntactic performance.

Group Comparison

The investigator's goal was to determine whether mild to moderate SNHL has significant effects on hard-of-hearing children's vocabulary and grammatical knowledge and, if so, to what degree, and in what areas when controlling for non-verbal IQ and grade.

As indicated in Delage and Tuller (2007), SNHL is associated with not only lowered hearing thresholds, but also distortion of speech signals and degraded language input, factors that are assumed to affect age-appropriate development of linguistic knowledge. Considering the fact that normal speech recognition development is contingent upon successful auditory input during a constrained critical period in the first few years of life (e.g. McConkey Robbins, Burton Koch, Osberger, Zimmerman-Phillips & Kishon-Rabin, 2004; Sharma, Dorman & Spahr, 2002), one would expect that many children with mild to moderate HL are at risk for delayed language development.

The average age for initial hearing aids fitting of the HI subjects included in this study was close to 4 years (mean: 44.4 months). Researchers have indicated that although language input can be noticeably improved through hearing aids, mild to moderate level of SNHL in children is detected and remediated at relatively older ages than profound hearing loss, with the average age for remediation between 4 and 5 (Hansson, Forsberg, Löfqvist, Mäki-Torkko, & Sahlén, 2004; Stelmachowicz, Pittman, Hoover, & Lewis, 2004; Tuller & Jakubowicz, 2004). Thus, due to perceptual distortion of phonological input during the critical language acquisition period, if not aided early, hard-of-hearing children are likely to experience inaccurate speech perception and develop unclear phonological representations of words, and delayed of phonological sensitivity (awareness). Since phonological awareness is required for efficient phonemic segmentation, which is necessary for distinct phonological representations of newly learned words, hearing loss may ultimately cause language impairments (Chiat, 2001).

Consistent with previous studies, the findings described in this study also indicate that the group of aided, school-aged children with mild to moderate SNHL have significantly lower spoken language skill in *all* tests areas than would be expected for children with normal hearing. Adjusted means for the HI groups were more than 1 SD below the mean of the NH children for both receptive vocabulary and grammatical knowledge tests: 16.651 for the PPVT-III and 18.769 for the CASL (See Table 4-5). The largest group difference was noted for morphosyntactic knowledge task, as evidenced by a strongest effect size of .392. Although the HI group's performance on the PPVT-III, EVT, and CASL tests was not impaired below the mean score of 100 (See Figure 4-4), further inspections of raw scores in each test showed that 31% of the HI children had standard scores of 1 SD below the mean and only 26% of them had raw scores above the mean.

Findings of oral language skills in this study are different from those reported by Briscoe et al. (2001), who suggested that the vocabulary and receptive grammar of HI children were not significantly lower than their control group matched on age. One possible reason for this discrepant result is associated with the statistical treatment of the data. In Briscoe et al. (2001), multiple univariate ANOVAs were used to investigate the group effect instead of multivariate analyses which can control the effects of confounding covarying factors (i.e., age, grade, or IQ). Secondly, Briscoe and colleagues' (2001) sample was comprised primarily of children with mild hearing loss; only 3 children had moderate HL. Further, Briscoe et al. reported that their HI subjects can be divided into two subgroups based on the severity of phonological impairments: unimpaired and impaired groups. The latter subgroup showed significantly poorer vocabulary skills than the group with unimpaired phonological skills. Close scrutiny of their data showed that the impaired group's scores on vocabulary were at or below 1 SD below the normative mean scores: 86.6 (receptive) and 84.6 (expressive), respectively. Interestingly, these two subgroups did differ significantly in the severity of hearing loss, that is, the impaired group's hearing loss was more severe across all frequencies. Based on the graphic display of the hearing thresholds (Briscoe et al., 2002:337), the unimpaired group's PTA based on 0.5, 1, and 2 KHz was around 25 dB HL. This strongly suggests that the unimpaired group's oral language skills were not affected by this mild level of hearing loss. Based on these observations, it can be inferred that the phonologically unimpaired group's normal level of language skills masked the negative effect of hearing loss on spoken language ability causing overall mean scores of the HI group to be exaggerated. That is, significant differences might have been captured if the sample of the HI group was more representative of the population with mild to moderate SNHL. Lastly, existing significant difference could have been observed when confounding variables such as age, grade, or non-verbal IQ were statistically controlled.

Interrelationships between Phonological Processing and Language Skills

The investigator also tried to determine whether linguistic knowledge was related to HI subjects' phonological processing skills that include the ability to encode, store, and retrieve phonological information.

Phonological short-term memory and vocabulary

Previous research has consistently indicated a close association between children's phonological short-term memory (STM) and their vocabulary knowledge (Baddeley, Gathercole, and Papagno, 1998; Gathercole & Baddeley, 1990; Gathercole, Hitch, Service, & Martin, 1997; Jarrold, Baddeley, Hewes, Leeke, & Phillips, 2004). Baddeley et al. (1998) argued that the central purpose of verbal STM to facilitate the efficiency of the long-term learning of vocabulary. For example, learning an unfamiliar word requires ordering the constituent phonemes of the word along with its accurate phonological representation for storage in memory. They suggested that phonological material is first represented in phonological STM, which makes it available for long-term learning. As reviewed in chapter 2, the authors described the phonological loop as a language learning device and argued that the ability to retain small amounts of phonological information in STM evolved as a human characteristic that has a selection advantage for language acquisition.

Gupta (2003) provided a similar explanation when he suggested that during learning of unfamiliar phonological sequences for new word acquisition, incoming phonemes are stored in a specific short-term memory system, called ‘sequence memory’. This stored information permits the replay or verbal rehearsal of the new phonological sequences and increases the probability that phonological representation in the long-term memory will be stable.

Findings from the current study support this word learning hypothesis. In fact, the subjects’ STM tested by a digit span and a nonword repetition test, was strongly correlated with vocabulary (See Table 4-18). Especially, the *Memory for digits* was significantly associated with *all* vocabulary and morphosyntactic with partial coefficients ranging from .533 to .592. The *Nonword repetition* was highly correlated with morphosyntax measure (partial coefficient = .494, $p = .022$) and partial coefficients for receptive and expressive vocabulary measures approached the significant level (r = .406, $p = .053$ with the PPVT-III and r = .359, $p = .078$ with the EVT, respectively). In Baddeley and colleagues’(1998) study of memory in 6-year old children, first-order correlation coefficients between two measures of verbal STM (auditory digit span and nonword repetition) and vocabulary knowledge were .44 and .56. Similarly, in Gathercole and colleagues’ (1997) study, digit span scores correlated significantly with all tested vocabulary measures, with significant correlations ranging from .38 to .44 ($p < .01$).

Grammatical knowledge and phonological processing

In a study of short-term memory in children with specific language impairment (SLI), Gathercole and Baddeley (1990) developed a theoretical framework linking deficits in phonological STM (i.e., nonword repetition) to impaired language acquisition. The authors pointed out that poor performance on nonword repetition is a marker of specific language impairment. However, as pointed out by Leonard (1998), vocabulary is typically less impaired than syntax in children with SLI (Leonard, 1998). This raises the question of whether phonological STM is implicated in acquisition of syntactic knowledge as well as vocabulary.

Considerably less work has addressed the role of phonological STM in the acquisition of syntax, even though there is increasing support for the notion that the same psychological mechanisms underpin vocabulary and syntax acquisition (Marchman & Bates, 1994). In their 1998 study, Baddeley et al. indicated that in typically developing children, nonword repetition, a measure of phonological loop capacity, was related not only to vocabulary learning but also to acquisition of syntax. In this respect, the HI group's performance on the *Grammatic Knowledge* subtest in this study is of particular interest since it was strongly associated *all* of the phonological awareness and phonological memory tests (range of partial coefficients: .443 ~ .558).

How would we explain this strong association between phonological STM, phonological awareness, and morphosyntactic knowledge in the HI group? Gathercole (2006) offers three hypotheses to explain the link between weak phonological STM and poor morphosyntax. The first hypothesis relates to a *storage capacity*, proposing that incoming speech stream needs to be stored in a temporary buffer while the morphosyntactic analysis is carried out. To process the grammatical morpheme, each phoneme should be perceived well and the inflection marker must be separated from the content part. Next, its grammatical function must be realized based on the utterance situation. All of this must be completed before the next item in an utterance enters the system. So, perceived material may be lost owing to restrictions in working memory or because previous material is still being processed. That is, an inflected verb will be fully processed some times and at other times it will not. Therefore, if stored phonological material is rapidly decayed, subsequent operations will become inefficient.

The second hypothesis is related to the contribution of *phonological awareness* to morphosyntactic awareness. It proposes that poor morphosyntactic skills will follow if a child persists in segmenting or identifying incoming speech at the supra-phonemic level such as syllable. For instance, past tense markers in monosyllabic words such as "walked," "hopped," and "laughed" may not be recognized if the child is only processing incoming words at syllable or onset-rime borders, not being able to separately recognize the word-final grammatical morphemes. Thus, underdeveloped phonological awareness can cause the skills for extracting a morphosyntactic rule, such as past tense formation to be delayed. That is, children's phonological sensitivity (awareness) will help to successfully divide a word into content and bound morphemes (phonemic segmentation), enhancing their ability to perceive and manipulate morphological units, too. The high association found in this study between phonological awareness and knowledge of grammatical morphemes ($r = .511$ for the *Elision* and $r = .443$ for the *Blending*) well supports this theoretical standpoint.

The third and final hypothesis addresses the possible challenges faced by some children to perceive English grammatical morphemes that have *low-perceptual salience* (Rom & Leonard, 1990), which might result in weaker or low-quality representation of grammatical markers such as '-ed' (past tense) and '-s' (plural or third person singular marker). Recent data from children with cochlear implants suggests that the pattern of language development is strongly influenced by the perceptual prominence of relevant morphological markers (Svirsky, Stallings, Lento, Ying, and Leonard, 2000). As indicated above, lower-quality phonological representations resulting from inaccurate speech perception may cause slowed morphosyntactic computation. Although the speech of children with mild to moderate hearing loss is intelligible, research indicated that aided speech perception would be still problematic. For instance, Elfenbein et al's (1994) study reported that misarticulation of fricatives and affricates was common, particularly for children with 3-frequency pure-tone average thresholds greater than 45 dB HL.

Thus, as hypothesized in Nobury et al. (2001), even mild hearing impairment might result in morphemes of low perceptual salience being missed and therefore delaying grammatical development.

Phonological Processing Findings

We know that an intact phonological system provides an important foundation for learning to read in normally hearing children (Nathan, Stackhouse, Goulandris, & Snowling, 2004; Rayner, Foorman, Perfetti, Pesetsky, & Seidenberg, 2001). This present research was aimed at investigating what happens to the hard-of-hearing children's phonological system when auditory stimulus signals are distorted. Specifically, this study was designed to investigate which part of the phonological system is affected and which part is preserved (i.e., the whole phonological system, or sub-processes such as some aspects of the metaphonological skills, phonological memory, or lexical access/retrieval skills?)

Previous studies have reported that, overall, phonological processing skills of children with mild to moderate SNHL are significantly lower than those children without hearing loss. Surprisingly, however, little information is known regarding (1) the degree to which these skills are impaired and (2) the range of phonological skills affected.

Furthermore, no previous studies have compared HI children's phonological skills with those of dyslexic children at the varying range of phonological processing skills. Since dyslexic children are known to have persistent deficits in phonological processing with no auditory perceptual limitations related to cochlear damage, comparing these two groups should help to elucidate the nature and degree of deficit in HI children's phonological processing skills.

The fundamental hypothesis underlying this study was that hearing loss would affect HI children's auditory perceptual accuracy, leading to phonological processing abilities. In general, phonemic manipulations become very difficult if the relevant segments are not distinctly specified in the representation of the words (e.g. Elbro, 1996, 1998; Elbro, Borstrøm & Petersen, 1998; Foy & Mann, 2001; Fowler, 1991; Griffith & Snowling, 2002; Swan & Goswami, 1997a; Wesseling & Reitsma, 2001). Group data in this study revealed statistically significant differences between the HI and NH groups on phonological awareness and phonological STM skills. HI children had lower scores on tasks of: *Elision* ($p < .0001$), *Blending* ($p < .001$), *Memory for digits* ($p < .05$), and *Nonword repetition* ($p < .0001$). Adjusted mean differences (NH minus HL) were more than 1 SD for the *Elision* (3.50), *Blending* (3.849), and *Nonword repetition* (4.496) measures. Associated with this depression, the HI group's skills on phonological awareness and STM were not better than those of the RD group.

The results of this present investigation are only partially in line with previous studies. Most of research indicated that mild to moderate hearing SNHL would adversely affect phonological processing ability. For instance, in Briscoe et al. (2001), children with SNHL were significantly lower than normal age controls on phonological awareness (as measured by onset and rhyme matching), phonological discrimination, and nonword repetition. Interestingly, they found that hearing-impaired children's digit recall was not lower than that of normal controls. In this study, however, the HI group's phonological STM skill was significantly lower than the NH group on both tasks. But, the *Nonword repetition* task showed bigger group mean difference than the *Memory for Digit* task. One way of explaining this result is that the of degree of familiarity of the phonological representation for digit names (e.g., 'one', 'two', …) should place fewer demands on long-term memory than the nonword repetition task (Bruck, 1992; Bruck & Treiman, 1990). Since immediate nonword repetition is highly dependent on verbal memory function, it should be more sensitive than digit span in detecting any existing memory deficit.

In contrast, this present study found *no* significant differences between the HI and NH groups on the alphanumeric RAN tasks. At the same time, the HI group showed significantly *better* rapid naming skills than the RD children. This remarkable finding suggests that hearing-impaired students' lexical access and retrieval skills are preserved in spite of their impaired phonological awareness and short-term memory skills.

This finding was supported further by correlations which revealed that degree of hearing loss was only associated with phonological awareness and short-term memory skills, not with the RAN measures. Specifically, when chronological age (in months) was controlled, better ear's PTA and SRT showed moderate to high negative correlations with the *Elision*, *Blending*, and *Nonword repetition*. This tight association suggests that hearing and speech perception would impact the HI children's phonologically-based skills.

Gibbs (2004) also reported similar negative correlation levels between hearing thresholds and phonological awareness for rhyme awareness and initial phoneme awareness. As noted above, no significant relation was noted between the RAN tasks and the scores of better ear's PTA or SRT. This lack of significant association indicates that peripheral hearing loss does not affect the efficiency of fast lexical access and retrieval or speed of processing.

Hearing Loss and Phonological Representation

It is now well established that early reading problems are associated with difficulties in phonological domain of language (Mann, 1998; Stanovich, 1993; Wagner & Torgesen, 1987) and most researchers view weak phonological awareness skills as contributing *directly* to dyslexics' deficiency in word recognition skill (Blachman, 1989; Bowey, Cain, & Ryan, 1992). However, despite the strong relationship between phonological skills and reading, the nature of the phonological deficits that underlie poor reading remains to be elucidated.

Elbro and Jensen (2005) proposed that dyslexic readers' problems with phonemic awareness are due to can be explained by their poorly specified phonological representations. In line with Elbro and Jensen (2005)'s proposal, other researchers have suggested that the relationship between impaired phonological awareness and reading difficulty be considered from the perspective of the quality (or 'distinctness' as in Elbro, 1998) of phonological representations of words in the mental lexicon. This hypothesis, referred to as the 'phonological representation hypothesis,' states that a lack of distinctness or segmental specificity in phonological representations cause phonological processing difficulties (e.g. Elbro, 1996; Fowler, 1991; Hansen and Bowey, 1994; Metsala, 1997; Snowling *et al*., 1986; Swan and Goswami, 1997).

Fowler (1991) has proposed that words in each individual's mental lexicon vary according to the precision of the phonological specification of the underlying representations. So, words with less detailed representations are those that lack full segmental organization into a sequence of discrete phonemic elements. As a consequence, segmental manipulation of the phonetic form of the word may be hampered as a ''crystallized'' phonetic code is not available. Snowling and Hulme (1989), Hulme and Snowling (1992), and McDougall, Hulme, Monk, and Ellis (1994) have also suggested that an *awareness* of the phonological segments of words may not be as critical to success on phonological awareness tasks as the *accuracy* of the underlying phonological representations of the words. In accordance with Fowler, they argue that if the integrity of a person's phonological representations is compromised, it follows that the person should have difficulty performing segmental operations on those representations. Similarly, Manis et al. (1997) noted that if children cannot perceive clear distinctions between phonemes, it will be hard for them to develop representations that can be easily accessed to further processing.

Several lines of evidence also have suggested that poor phonological awareness relates to poor speech perception. For example, consonant perception in newborns is associated with language competence at 3 to 5 years, is predictive of reading achievement at 8 years (Scarborough, 1990). Children and adults with reading difficulties have difficulties perceiving speech in noise (Brady, Poggie, & Rapala, 1989; Brady, Shankweiler, & Mann, 1983), and children who are poor readers require a longer segment of a gated word in order to perceive it correctly (Metsala, 1997).

In sum, problems with accessing phonological representations, in turn, lead to difficulty in segmenting and manipulating phonemes (phonological awareness). Thus, knowing that children with congenital SNHL may experience degraded auditory input that interferes with their speech perception (Abraham, 1993) and even small speech perception problems may be very important for the ability to form fully specified phonological representation (Manis et al., 1997), it is expected that hypothesized that hard-of-children with prelinguistic auditory disadvantage should thus have lexical representations that are less distinct or accurate, leading to difficulties in phonological awareness. The HI group's weak phonological awareness skills found in this study support this theoretical position.

Phonological Representation and Short-term Memory Skill

The results of this study replicated previous studies showing that hearing loss can also lead to inefficient storage capacity. However, while the measures on nonword repetition and digit span are good markers of depressed phonological STM, it is not clear why hearing loss should affect the capacity of verbal memory.

Research has documented that phonological STM is also constrained by the *quality* of stored material. Service, Maury, and Luotoniemi (2007) explored the idea that good verbal STM depends on the quality of representations of phonological sequences that are encoded into the phonological store. Generally speaking, this idea is justified because the efficiency of phonological segments in temporary storage should be maximized if the material to be stored is as distinct or clear as possible. As Nairne (1990) and Neath & Nairne (1995) suggested, phonological representations of good quality are less prone to being overwritten and should not quickly decayed. Of course, such better-quality traces will serve as a good resource for more efficient and accurate phonological awareness.

The present findings of reduced STM in children with SNHL appear to support the theories that predict a relationship between the quality of phonological representations and STM. That is, individuals with hearing loss whose auditory-phonetic inputs are not clearly represented in STM have smaller spans. As they can hold less material of good quality in working memory, they would also not be as good at manipulating stored phonemes and passing information from the *phonological store* to the *articulatory control process* as would children with normal hearing do. Articulatory control process is an active process component in Baddeley's memory model that can keep the contents of the phonological store active and counteract time-based decay of phonological traces by a kind of inner speech (Baddeley, 2003).

Intact Rapid Naming

In the present study, the rapid naming skills of HI children with mild to moderate SNHL were preserved in spite of their impaired phonological awareness and phonological memory abilities. While rapid naming predicts reading skills, the nature of the RAN as a measure phonological skill is still unclear. Wagner and Torgesen (1987) argued that rapid naming is a phonologically-based skill. Wagner, Torgesen, and Rashotte (1999) proposed that young readers first retrieve sounds associated with letters or letter pairs, then retrieve the pronunciations of word segments, and finally retrieve the whole word.

From this perspective, rapid naming should predict reading skill because this task measures the *efficiency* of retrieving phonological codes associated with phonemes, word parts, or entire words (Shankweiler & Crain, 1986; Share, 1995; Torgesen & Burgess, 1998). To them, RAN tasks are an index of the speed with which phonological information can be accessed from memory and, thus, are best described as tapping into an aspect of *phonological* processing.

However, other researchers have argued that rapid naming is not exclusive a phonological skill and that it requires several other skills, including executive functioning (Denckla & Cutting, 1999), the ability to detect and represent orthographic redundancy (Bowers & Wolf, 1993; Wolf & Bowers, 1999), global processing efficiency (Kail, Hall, & Caskey, 1999), and attention skill (Neuhaus, Foorman, Francis, & Carlson, 2001).

In a similar context, Wolf and Bowers (1999) have proposed that processes related to serial naming speed represent a second core-deficit in children with RD. This alternative model, known as the double-deficit hypothesis, presumes that phonological processing and rapid automatized naming (RAN) deficits are *separable* sources of reading dysfunction. As discussed in chapter 2, three separate subtypes of RD individuals (i.e. phonological-only, rate-only, and double deficit) can be predicted based on the varying effects of deficits in phonological processing and RAN. Among these, the phonological-deficit-only subtype is characterized as having significant deficits in phonological processing (PA and STM) with otherwise intact naming speed processes.

This present study revealed that the HI group's performance on the rapid naming tasks was well preserved and hearing loss differentially affected their phonologically-based skills only (PA and STM). Hence, their profile is, at least to some degree, characteristic of the single (phonological-only) deficit group described by Wolf and Bower (1999). The RD group who showed depression in both rapid naming and phonologically based skills (PA and STM) is characteristic of double-deficit group.

Literacy Findings

Based on the findings discussed in the previous section, it was hypothesized that if poorer hearing in the HI children influenced their phonological processing performance, then their performance on a range of reading and spelling tasks will also be affected. This position is consistent with the well-recognized phonological core deficit hypothesis. It was also hypothesized that the correlations between phonological processing ability and reading performances would be significant.

Group Comparisons

Although the HI children's performances on literacy measures were within normal range on all tasks using standardized test scores as the criterion, statistically significant quantitative differences between the NH and HI groups were found. That is, the reading and spelling skills of the hearing-impaired children studied lagged behind those of their age-matched normal-hearing peers and were significantly better than those of their RD peers.

Specifically, the HI group's reading and spelling skills were significantly lower than normally developing group on *all* word-level and passage-level measures with the exception of the nonword reading subtest (Decoding Efficiency on the TOWRE). When compared to the NI controls, both the HI and NH subjects had significantly better scores that their RD peers on *all* tested measures. The RD group overall showed marked deficits in both phonological awareness and rapid naming (i.e., double-deficits) while the HI group showed deficits in phonological awareness (i.e., phonological deficit only). That is, the data clearly showed that two core deficits (i.e., phonological deficit and rapid naming deficit) were *selectively* depressed in the HI and RD groups' literacy skills. These results lend support to the double-deficit hypothesis, which proposes that reading disability can be caused either by phonological processing deficits, by RAN deficits, or (in the most severe cases) by a combination of both deficits (Wolf and Bower, 1999).

However, these findings were moderately different from the previous studies (Briscoe et al., 2001, Gibbs, 2004, Halliday & Bishop, 2006). Halliday & Bishop (2006) used two timed word reading tests from the TOWRE and they reported no significant difference between the HI and NH groups on both tests. Briscoe et al. (2001) used three reading tests, including two untimed word and nonword reading tests and one passage comprehension test and reported that their HI children's reading was not different from the age-matched controls and was slightly better than that of an SLI group in spite of their depress phonological processing skills. Based on this observation, the authors concluded that hard-of-hearing children's reading development would not necessarily require the support from phonological processes.

If deficient PA skills in HI kids do not impact their reading, this finding would pose a serious challenge to the universality of phonological core deficit theory. To date, many experimental studies with special populations have provided findings that support the case for the universal necessary role of phonological processing capacity in reading acquisition. For example, a series of studies with deaf readers provides strong evidence for the necessity of phonological coding in memory for skilled reading. Hanson, Goodell, & Perfetti (1991) documented that congenitally deaf individuals who had become fluent readers had somehow acquired a phonological coding strategy despite never having heard speech. Fowler, Doherty, & Boynton (1995) also documented the contribution of phonological memory to reading acquisition in young adults with Down syndrome. These subjects, performance in phonological memory accounted for a substantial portion of the within-group variability in reading achievement.

Furthermore, neuroimaging studies support a universal phonologically-based neurocognitive differences in all dyslexics. Researchers posited that if dyslexia is caused by phonological deficit, this deficit should be observed in neurobiological measures of the brain of dyslexics across cultures and language. Recently, Paulesu, Demonet, Fazio, McCrory, Chanoine, Brunswick, Cappa, Cossu, Habib, Frith, and Frith (2008) analyzed three dyslexic groups who spoke either Italian, French, or English on tasks of single word reading and phonological short-term memory. Positron emission tomography (PET) scans during reading showed the same reduced activity in a region of the left hemisphere in all dyslexics groups, with the maximum peak in the middle temporal gyrus and additional peaks in the inferior and superior temporal gyri and middle occipital gyrus. They concluded that dyslexia is a result of a universal phonological processing deficit that is evident across different orthographies.

In a similar vein, this study showed that the HI group's partly impaired phonological processing skill has a strong association with literacy, confirming its contributive and necessary role in developing skilled reading. Thus, as suggested by previous studies, the central role of phonological processing skills should not be diminished in the population of children with mild to moderate SNHL. In the following section, the results from the correlational analyses and hierarchical regression are discussed.

Correlation and Regression Findings

No previous studies focused on the relationship between reading and phonological processing ability in children with mild to moderate SNHL, when the effect of hearing loss was statistically partialed out. Four key findings emerged from the correlational and regression data. First, as similar before, the correlations between the HI children's phonological awareness (*Elision*) and *all* reading and spelling measures was remarkably consistent once covariations with age, nonverbal IQ, and degree of hearing loss were controlled (partial coefficients' ranged from .582 to .751). These correlations occurred regardless of the test conditions (i.e., timed, untimed) and level of tasks (i.e., word/passage) (Bowers, 1993; Bradley & Bryant, 1985; Cornwall, 1992; Cronin & Carver, 1998; Muter, Hulme, Snowling,& Taylor, 1997).

This strong relationship between phonological processing skill and reading skill was supported with hierarchical regression analyses. Regression analyses on scores of untimed tasks indicated that the *Elision* subtest accounted for around 33% of the variance of word reading and 50% of variance of nonword reading measure. More than 60% of variance was reduced for each skill by including the *Elision* subtest and background control variables (age, nonverbal, and better ear's PTA). Similarly, on timed word-level reading tasks, an average of 33% of the variance were associated with the *Elision* subtest. The *Elision* test also significantly accounted for the variance in both passage reading rate (53%) and accuracy (43%).

Interestingly, consistent with the findings reported in the CTOPP manual (Wagner et al., 1999), the *Blending* subtest did not correlated with any literacy measures. Findings from this study support that although *Elision* and *Blending* tests are phonological awareness measures, they tap into different cognitive abilities. Blending may be less challenging than elision because it requires only one operation, the synthesis of separate sounds into a word while holding these sounds in STM. On the other hand, the task of elision requires segmenting sound in words, omitting the target sound ‘g’, and creating a new word while holding all sounds in STM. Hence, elision appears to be a more rigorous test of phonological awareness. In their study of children with dyslexia, Katzir, Kim, Wolf, O’Brien, Kennedy, Lovett, & Morris (2006) found that the dyslexic group’s blending ability was correlated with only one reading test (*Word Attack* subtest on the WRMT-R) out of five phonological awareness and reading measures. In contrast, elision was significantly correlated with all five measures. These cumulative findings imply that not all phonological tasks are created equal and that greater precision in our conceptualization of phonological tasks is required.

Secondly, the relationships between rapid naming skill and reading were examined. Data of the HI group in this study underscored the independent characteristic of the RAN task. That is, it was remarkable that the RAN measures did not show any significant correlations with *untimed* tasks of reading at both the word or passage level, but large correlations were found with *timed* reading tests at both word and passage levels. These data were supported in the regression analyses.

These cumulative results support previous findings suggesting that the rapid letter naming task assesses different underlying constructs than those assessed by phonological measures (Misra, Katzir, Wolf, & Poldrack, 2004; Wolf & Bowers, 1999; Wolf et al., 2002). Thus, in a task that primarily places no demands on speeded reading, phonologically-based skills are important. For a task requiring fast lexical access (timed measures), the rapid naming skills play more of a role. In other words, RAN primarily affects performance on reading tasks that require *speeded/fluent* response, and phonological awareness and short-term memory primarily affect performance on reading tasks that emphasize phonological processing skill.

In a study of 476 children with reading disorder, Compton, DeFries, & Olson (2001) similarly reported that the double-deficit group most resembled the rate-deficit group on measures that require fluent/speeded word reading skill and reading comprehension, whereas the double-deficit group tended to perform similarly to the phonological-deficit group on measures emphasizing phonological processing skills. Katzir et al. (2006) also reported that phonological awareness (elision and blending) contributed more variance to phonologically-based reading measure and RAN contributed more to high frequency word reading and word-reading efficiency, that are more related to speed of processing. In support of this observation, no significant correlations were found between the two alphanumeric rapid naming tasks and *all* other phonologically-based measures in the HI group (PA and STM) (See Table 4-17).

For further analyses, the investigator tried to evaluate explicitly the additive nature of the RAN task's prediction of timed reading measures. A final set of regression analyses was conducted, where phonological awareness and short-term memory variables were entered in Step 2 and each of the two RAN measures (letter and digit) was separately entered in Step 3 showed that RAN contributed independent variance to timed reading measures *even after* controlling for children's background variables, phonological awareness, and phonological short-term memory variables. This additive prediction by the RAN seems to confirm the findings from Wolf and Bowers (1999), who viewed rapid naming as an *extraphonological* construct and view rapid naming deficits as an additive source of reading difficulty over phonological awareness.

As yet, it is not clear which cognitive processes underlie RAN and account for its relationship with reading. Even though Wolf and Bower's theoretical framework can neatly explain the heterogeneity of clinical data, complex interrelationships between RAN, phonological awareness, and reading itself make causal inferences very difficult.

In their large-sized study which assessed 1,010 children's reading performance, Powell, Stainthorp, Stuart, Garwood, & Quinlan (2007) also reported that RAN deficits occurred in the absence of phonological awareness deficits. In their structural equation modeling, solutions where RAN was subsumed within a phonological processing factor did not provide a good fit to the data, suggesting that processes outside phonology may drive RAN performance and its association with reading. Convincingly, children with single RAN deficits performed more slowly in speed of processing than did closely matched controls with normal RAN skill.

Kail, Hall, & Caskey (1999) also proposed that speed of processing underlies the RAN skills. The reason for the lack of clarity about the causal nature of the link between RAN and reading is that most of previous studies have been correlational. Using this approach, they could not rule out the possibility that, rather than being causal in nature, the relationship between RAN and reading may be driven by a third unknown factor. This view was proposed by Kail and colleagues (Kail, 1991; Kail & Hall, 1994; Kail et al., 1999), who argued that, rather than being constricted to the reading system or even to linguistic processes, RAN performance reflects more generalized processing speed. According to this approach, early childhood is characterized by a general and gradual increase in global processing speed. Thus, the relationship between RAN and reading should be understood by the fact that both are influenced by the same underlying factor, namely, processing speed. The present study's results from the correlation and regression analyses which revealed important role of rapid naming in timed reading seem to fit into this approach.

Thirdly, relationships between reading and oral language skills were investigated. As expected, only grammatical knowledge and vocabulary skills were correlated with passage comprehension, suggesting that linguistic capacity dealing with vocabulary or grammatical knowledge does not significantly contribute to word-level reading tasks. This is likely to be the case because it appears that word-level reading does not necessarily require syntactic or semantic computation. That is, at the word level, poor phonological difficulties are likely to hinder children's word recognition ability, but at the sentence level, children may have more difficulties integrating the information and extract meaning due to grammatical and syntactical difficulties and/or their restricted semantic knowledge (Hartas, 2005; Perfetti, 1985; Perfetti, 1992).

Lastly, the predictive role of auditory processing skills for reading ability was investigated. Most of auditory processing tasks scores failed to show significant correlations with reading and spelling measure and did not predict reading in the HI group. Specifically, no SCAN subtests were correlated with reading measures. Only the Dichotic Digit test showed significant correlations with two nonword reading tests. Based on the lack of association, it appears that auditory tests of this nature provide little predictive value for assessing reading skills, at least in children who have normal levels of intellectual abilities.

Summary

Contemporary research has revealed a great deal about the factors that interfere with the process of learning to read (Snow, Burns, Griffin, 1998). Perhaps the greatest contribution over the past two decades is accumulating evidence of a phonological processing deficit as the core problem leading to poor reading (Stanovich & Siegel, 1994). Marschark (1997) explained hard-of-hearing children's reading difficulty as resulting from their impaired phonological channel. Such findings support the theory about the role of impaired auditory perception in reading disability and provided the impetus for the comparison between two populations with impaired phonological processing skills and depressed reading ability: (1) dyslexics with a good peripheral hearing system, but whose phonological processing is impaired, and (2) a non-dyslexic hearing-impaired population, whose peripheral hearing system is impaired. This dilemma was the basis of this present research.

This study was designed with the premise that that literacy development requires the same acquisition of phonological processing skills, whether a child's hearing is impaired or normal. First, the principle aim of the study was to examine the effect of mild to moderate SNHL on children's performances on a range of spoken language, phonological processing skills, and literacy (reading and spelling). Performances of two controls groups of children (NH and RD), matched for age, grade, and non-verbal intelligence were used to investigate the HI group's weaknesses and strengths in phonological processing ability and its relationship to reading skills.

Consistent with previous findings, the HI group's receptive and expressive vocabulary and morphosyntactic skills were significantly delayed when compared to those of the NH group. Similarly, the HI group's performance on the phonological processing tasks was significantly lower than their normal controls. However, their phonological processing skills were *selectively* depressed such that only phonologically-based tasks (i.e., phonological awareness and phonological short-term memory) were seen significantly lower than the normal controls and the RAN skills, a measure of general speed of processing or efficiency of lexical access, was seen intact.

In line with Katzir and colleagues' (2006) explanation, this finding suggests that auditory perceptual distortion due to SNHL only affects phonologically-based processing abilities and not *extraphonological* processing abilities (RAN).

Secondly, turning to performance on the literacy tasks, this study sustains the view that reading is the 'most difficult academic challenge for the hearing impaired' (Marschark & Harris, 1996). It was found that the HI group's literacy skills were significantly lower than their normally hearing controls in most of reading and spelling measures. Therefore, it was clearly noted that phonological processing deficit related to early perceptual inaccuracy is very likely to affect later literacy and related tasks of children with mild to moderate SNHL. This critical role of phonological processing component was also confirmed by the correlational and regression analyses which showed that phonological processing skills are important correlates and predictors of hearing-impaired children's reading and spelling as well. This finding contradicts previous studies which argued that reading skills of hearing-impaired would not necessarily require the support from phonological processing ability. As noted previously, RAN measures were not associated with any of untimed reading tasks, but had significant correlations only with timed reading tasks. This *extraphonological* property of the RAN was clearly demonstrated in the regression analyses, where RAN measures additively contributed independent variance to timed reading measures after phonologically-based variables were controlled for.

One final issue for comment is the impact of degree of hearing loss on language, phonological processing and literacy. Many previous studies of reading in children with mild to moderate SNHL have not reported a significant effect of hearing loss on reading (Blair et al., 1985; Davis et al., 1995; Elfenbein et al., 1986; Gilbertson et al., 1995). In a similar vein, degree of hearing loss did not show any significant correlations with reading and spelling measures after age and non-verbal IQ were controlled for. One possible explanation for this insignificance is that, with the advent of better hearing aid technology, the impact of degree of hearing loss perceptual might have become latent in predicting reading achievement, only affecting phonological processing component. It is possible that the latent relationship between hearing loss and reading could be mediated by other confounding factors such as age at identification and/or initial hearing aid fitting, clinical efficacy of hearing aids, educational environment, and so on.

Clinical Implications

First, consistent with prior research, the current study revealed that hearing-impaired children's depressed phonological processing abilities are significantly related to reading and spelling skills. The clinical implications are evident. Language, phonological processing skills, and reading ability should be thoroughly examined even in children with mild to moderate HL.

Secondly, in clinical settings, a common view is that some children with mild or moderate impaired hearing loss who are trained orally do show systematic phonological deficits similar to those of normal hearing children with phonological disorders (Abraham, 1993). It is generally accepted that deaf and hard-of-hearing children learn to read following the same sequence of skill development that hearing children do (Chall, 1996; Hanson, 1989; King & Quigley, 1985; Paul, 1998, 2001). Therefore, it can be assumed that hard-of-hearing individuals, like hearing individuals, will also benefit from the development of phonological processing skills as part of their beginning reading instruction. Nielsen and Luetke-Stahlman (2002) maintained that if hearing-impaired children are to read the sound-based printed words and phrases of English, they must develop and improve phonological sensitivity (awareness). Thus, previous results which suggested that phonological ability is not necessarily required in children with mild to moderate HL might lead many educators to assume that HI children's weak phonological awareness would not be a barrier to successful reading development and ignore the importance of phonological awareness training.

There is research evidence to suggest that the ability to use phonological information while reading is a distinguishing variable when comparing accomplished deaf and hard-of-hearing readers to average deaf and hard-of-hearing readers (Conrad, 1964; Engle, Cantor, & Turner, 1989; Hanson, 1982; Hanson & Fowler, 1987; Hanson & Lichtenstein, 1990; Hanson, Goodell, & Perfetti, 1991; Leybaert, 1993; Musselman, 2000; Perfetti & Sandak, 2000). These findings imply that effective programs and strategies for teaching hearing-impaired children these skills may be the key to obtaining higher levels of reading achievement for this population. Unfortunately, survey studies of instructional methods being used by teachers of hard-of-hearing children reported that the overwhelming majority of teachers do not incorporate direct teaching of phonological awareness in their reading instruction (Coley & Bockmiller, 1980; Hasenstab & McKenzie, 1981; LaSasso, 1978, 1987; LaSasso & Mobley, 1997). Thus, currently, it is not surprising that hearing impaired students are at risk for acquiring sufficient decoding skills due to their limited access to and instruction focused on the phonological aspects of the English language (e.g., phonemic awareness and phonics). In this vein, the findings of this research would have implications on the direction of intervention planning and the strategies of teaching reading to members of the studied populations. Furthermore, speech pathologists who work with hard-of-children need to be aware of clinical methods of explicit phonological instructions beyond traditional intervention techniques used for children with articulation or phonological disorder.

Limitations

While this study was the first of its kind to provide a comprehensive profile of the phonological and literacy profiles HI children's with mild to moderate SN hearing loss, a few limitations in the study's methodology must be acknowledged.

First, the relatively small sample size of the HI group (N=19) makes it difficult to draw conclusions regarding the effect of degree of hearing loss beyond this study. In most psychometric studies of hearing impaired children, it is well assumed that there will be a problem associated with participation. Children with mild hearing impairments are less likely to participate in extensive testing than children with more extensive hearing losses because their problems are not perceived as being as serious and parents of these children may not feel the immediate need to see results of their children's performance in the areas of language and literacy. Secondly, the administration of more than ten psychometric tests combined with hearing tests might have been too demanding for some of the children, reducing the validity of tests. Lastly, in a recent comprehension review of reading research for students who are deaf or hard of hearing, Schirmer and McGough (2005) indicated that intervention research evaluating the effectiveness of phonological instruction for students is extremely limited. Unfortunately, no clinical studies exist regarding the efficacy of direct phonological instruction for children with moderate levels of HL. This limited number of studies certainly warrants attention. As a cross-sectional study, this research could not address the developmental trajectory of reading skills in children with mild to moderate SNHL. Future longitudinal studies are needed to unravel the long-term effects of hearing loss on academic achievement.

APPENDIX A
INFORMED CONSENT LETTER FOR PARENTS AND GUARDIANS

Informed Consent Letter for Parents or Guardians

Jungjun Park
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Jan, 2007

Dear Parent/Guardian,

I am a doctoral student of Communication Sciences and Disorders at the University of Florida, conducting research under the supervision of Dr. Linda Lombardino. We are interested in examining the effect of hearing loss on oral language, phonological processing, and reading skills of 7- to 12-year-old children. In spite of increasing number of children with hearing loss, little is known about their reading performance. Especially, very few research efforts have been directed to literacy development of children with less-than-profound hearing loss, so studies strictly focusing on the reading ability in this population are needed.

The main purpose of this study is to assess the oral language, phonology, and reading skills of children with or without sensorineural hearing loss and compare them. For the study, we need; 1) 30 children with ***normal hearing/reading ability***, 2) 30 children with ***mild or moderate sensorineural hearing loss*****.** Children with conductive hearing loss would **NOT** be able to participate in the study and only children whose primary communication mode is spoken language are qualified. Students will be mostly engaged in linguistic activities that have them listen to the sounds, read and write words and sentences, or give appropriate answers to the questions of the researcher. Assessment is expected to take 90 to 100 minutes and will be done using a set of standardized oral language and reading tests. Only when we could not finish the assessment, your child will be asked to work with us once more on the other day. Either a trained student or me will be present during all sessions to help your child to do the tests.

There is no expected risk of physical, psychological, or economic harm to your child. This assessment project will directly benefit your child's literacy skills regardless of their hearing level. That is, through the whole assessment procedures, your child's profile of oral language and reading development will be investigated. Based on this, you and the classroom teachers are also expected to benefit from this study by being informed of the child's current level of oral language and literacy performance, which can be used to decide the steps needed to improve reading and oral language instruction. A copy of the results of the assessment will be available upon your request.

With your permission, we will audio record your child's responses during assessment and obtain your child's hearing loss level from school files if your child has a hearing loss. Tapes will be used only to validate our assessment results and the contents will not be transcribed. It will be available only to the assistant student, my supervisor, and me.

I also have attached a questionnaire asking for some information regarding the developmental characteristics of your child and family background. Including the information from this questionnaire, all the data will be numerically coded and will not be marked with your child's name. All individual records including the audiotapes will be destroyed once the study has ended. Your child's identity will strictly be kept confidential to the extent provided by law. No real names, initials, or other identifying information will be used during spoken or written presentation of study results. Participation or non-participation in this study will not affect your child's grades or placement in programs at all.

As mentioned, children with normal hearing ability are also needed for this study. If your child would participate in the study as a subject with normal hearing regardless of his/her reading proficiency, his/her hearing will be screened at the University of Florida Speech Hearing Clinic (UFSHC) by a graduate clinician of Doctoral of Audiology program of the University of Florida. Hearing will be screened based on puretone audiometry and tympanometry and **there is no cost for this evaluation.** For this audiologic assessment, I will make an appointment with you beforehand. You and your child have the right to withdraw consent for your child's participation at any time without consequence. No compensation will be offered. If you have any questions about this research protocol, please contact me, **Jungjun Park at (352) 392-2113, ext 293 or (352) 328-7671(pajjgsc@gmail.com)** or **Dr. Lombardino at (352) 392-2113, ext 285.** Questions or concerns about your child's rights as a research participant may be directed to the UFIRB Office, University of Florida, Box 112250 Gainesville, FL., 32611, (352) 392-0433. If you should decide to grant permission, please complete the attached questionnaire form and return it with this consent letter to the classroom teacher. You can also keep a copy of this informed consent letter for your information. Thank you for the consideration.

Sincerely,
Park, Jungjun

Please sign below and return this letter to the classroom teacher

....

I have read the procedure described above and I have received a copy of this form. I understand that my decision is entirely voluntary and agree to allow my child ___________________, to participate in the study to investigate oral and written language skills.

I also authorize the principal investigator, Jungjun Park, to secure and use information in the questionnaire form for his research.

Signatures:

Parent/Guardian: ___________________________ Date:__________

Principal Investigator: _________________________ Date:__________

Supervisor/Investigator: ________________________ Date:__________

Child Assent Script

The following is a script that will be used prior to each session to ensure that the student knows of his/her involvement and that he/she may choose not to participate if he/she does not want to.

Investigator: **We are going to do some activities with sounds and words. During these activities you will be looking at listening to, or reading different sounds and words. If you don't want to do this, that is okay. Do you want to do the activities with me?**

If the student indicates **yes**, the investigator will begin the assessment session.

If the student indicates **no**, the investigator will say:
That's okay. Maybe I will come back later to see if you want to do these activities.

When the investigator returns, the same script will be used.

Date: ________________________________

Signature: ________________________________

APPENDIX B
QUESTIONNAIRE FORM

IDENTIFYING INFORMATION

1. **Child's Legal Name: ______________________________**
2. **Date of Birth: _________________ Age: _______ years and ______ months**
3. **Address:**

   ____

   Street City/State Zip Code
4. **Mailing Address (if different):**

   ____
5. **Person Completing This Form: ____________________ ______________**

   Name Relationship
6. **Phone (Home):(_______) ________- ___________**

   (Work): (_______) ________- ___________

   (Cell): (_______) ________- ___________
7. **E-mail address (if available) _______________@_______________________________**

EDUCATIONAL HISTORY & GENERAL HEALTH

1. EDUCATION

Name of Current School: ____

Grade: ___________

Teacher's Name: __________________________

Describe the child's progress in school: _____________________________________

____

Does your child have any problems in reading books or classroom materials? If yes, please describe in your own words your child's difficulty. Give examples, if possible.

____

____

2. SPEECH/LANGUAGE/READING

Does your child have any speech and/or language problems? □ Yes □ No

If yes, please describe in more detail.

____

____

Does your child have any reading problem? □ Yes □ No

Please describe in your own words your child's difficulty. Give examples, if possible.

____

____

Because of this, has your child received speech-language therapy or any remedial reading program at clinic or school? □Yes □ No

If yes, please indicate the following:

- □ **When/where:____**
- □ **Dates:____**

- □ **Length and frequency of sessions: ____**
- □ **Primary focus of therapy: ____**

How do you feel about your child's reading competence?

□ Excellent □ Good □ Fair □ Slightly Poor □Very Poor

3. <u>GENERAL HEALTH</u>

Do you feel your child has normal vision? **□ Yes □ No**

If not, has the child's vision been examined? **□ Yes □ No**

Describe any illness, accidents, injuries, operations, and/or hospitalizations and include the age of the child:

____

____

____

FAMILY BACKGROUND

1. Mother's Name: ___________________ Age: _______

2. Father's Name: ____________________ Age: _______

3. Guardian's Name: _________________ Age: _______

4. Education level of the primary income earner in the home (Please mark in the box.)

- **□ Completed elementary school**
- **□ Completed junior high school**
- **□ Received general education degree**
- **□ Completed high school**
- **□ Completed 1 or more years of technical/vocational school**
- **□ Completed technical/vocational school**
- **□ Completed 1 or more years of university/college**
- **□ Bachelor's degree**
- **□ Completed 1 or more years of graduate school**
- **□ Master's degree**
- **□ Course work completed for Ph.D., but no dissertation; law degree without bar; medical degree without internship completed**
- **□ Ph.D.; law degree with bar; medical degree with internship completed**

4. Annual Income: $ __________________

(This information is especially very important for successful comparison of the children's performance and will be kept completely confidential in any circumstances.)

AUDIOLOGIC HISTORY (For Hearing impaired Child)

- ☺ **Please check your child's *hearing status* and use an appropriate section for this audiologic history information.**
- ☺ **If your child has *a hearing loss*, please answer only to the following questions.**
- ☺ **For children with *normal hearing*, different questions are provided at page 6 of this questionnaire form.**

▪ **Hearing loss**

1. *When* and *how* did you first notice your child's hearing problem?

____

____

2. When did you *first* consult an Ear, Nose, and Throat physician or an audiologist since your initial notice?

____

3. If you remember, please indicate the clinic name.

____

4. What was the *initial treatment* after the physician or the audiologist identified your child's hearing loss?

____

____

5. Do you know the result(s) of initial audiologic diagnosis? This information may be available from a copy of initial audiologic evaluation. If you know any one of the followings, please indicate based on exact information. If not sure, just leave it blank.

- □ **Cause(s) of hearing loss (e.g., congenital, genetic, developmental)**

  ____

- □ **Degree of hearing loss (in dB units; if known) :**

  Right ear ________(dB HL)   Left ear ________(dB HL)

- □ **Type of hearing loss (if known) :**

  □ sensorineural   □ conductive   □ mixed

6. Does your child *currently* wear hearing aid(s)?

- □ **If yes, please describe:**
  - ◆ **Make _____________________ Model ________________________**
  - ◆ **Both ears_______ Right ear only _______ Left ear only _______**
- □ **Does the child wear it all time ?** □ **Yes** □ **No**
- □ **If not, when does your child not wear it? _____________________________**

7. When did your child *first* start to wear hearing aid(s)? _____________________

Based on this information, for how many years has your child been wearing a hearing aid? __________ years and ___________months

8. Is there a *history of hearing loss* in the family? □ **Yes** □ **No** □ **Not sure**

If yes, which family member(s) have a hearing loss? ________________________

What caused their hearing loss? ____

____

▪ **<u>Speech and Language</u>**

1. Do you have any trouble understanding your child's speech? □ **Yes** □ **No**

2. If yes, briefly provide the difficulties.

____

____

3. Does your child use both oral and sign language at home? □ **Yes** □ **No**

4. Which one of the followings is your child's major communication mode at home?

□ **oral language** □ **Sign language**

5. Does any parent of your child use sign language fluently? □ **Yes** □ **No**

6. Which language mode does your child's school use mostly?

□ **oral language** □ **Sign language**

AUDIOLOGIC HISTORY (normal hearing)

A. History of Ear Infections

1. **My child has suffered from ear infections.** **□ Yes □ No**
2. **My child had more than 3 ear infections between birth and 12 months of age.** **□ Yes □ No**
3. **My child has had at least one ear infection which lasted more than 3 months.** **□ Yes □ No**
4. **What was the treatment for the ear infections at that time?**

   ____

B. Hearing

1. **My child has never failed hearing screening(s) in school.** **□ Yes □ No**
2. **My child has at least once failed a hearing screening in school.** **□ Yes □ No**

   Date of screening (if available): ____________________
3. **Has your child ever been referred to professionals for hearing evaluation?** **□ Yes □ No**
4. **If yes, what was the result?**

   ____

   ____

APPENDIX C
SCORING SHEETS

Date: _____/ _____/ 2007   Subject #____

Language and Literacy

Name		DOB & age(year/month)	___/___/19___ (___years /___months)
Gender		School	
Grade		Testing Location	
Tester		Others	

Hearing level	_____Normal ______ mild _____ moderate ______ severe ______ RD		
PTA	Left: Right:	Tympanometry	

Oral language					
area	**Raw**	**Standard**	**%-ile**	**Age-equi(month)**	**Grade-equi**
PPVT-III				- ( )	
EVT				- ( )	
CASL				- ( )	

Phonology								
area	**raw**	**Stand**	**%-ile**	**Age equi**	**Grade equi**	**Sum standard**	**Composite standard**	**Comp %-ile**
Elision				- ( )	.			
Blending				- ( )	.			
Rapid Digit Naming				- ( )	.			
Rapid Letter Naming				- ( )	.			
Memory for Digit				- ( )	.			
Nonword Repetition				- ( )	.			
Rapid Object Naming				- ( )	.			

Digit Ordering – WM	Raw:
Digit Backward – WM	Raw:

Literacy

area	raw	Age-Norm		AE	GE	Grade-Norm	
		stan	%			stan	%
Word ID (WRMT)				- ( )			
Word attck(WRMT)				- ( )			
Pass Comp(WRMT)				- ( )			
Spelling (WRAT)							

	raw	Age-Norm					Grade-Norm					AE	GE
		stan	%	Sum	R-profic		stan	%	Sum	R-profici			
					stan	%				stan	%		
Word effi(TOWRE)													
word deco(TOWRE)													

	raw	stand	%	Age-equi	Grade-equi
Passage Reading *Rate*(GORT-4)					
Passage Reading *Accuracy*(GORT-4)					
GORT fluency					
TONI				- ( )	

Audiologic Tests

Name		DOB & age(year/month)	___/___/19___ (___years /___months)
Gender		Testing Date	

Puretone Audiometry (Unaided)

	250 Hz	500 Hz	1 K	2K	PTA	3K	4K	6K	8K	SRT	WRS(%)
Right											
Left											

*SRT: Threshold level for speech (word) recognition (dB HL)
*WRS: Word recognition score based the MCL (most comfortable hearing level) - % score

Type of Hearing loss:

Normal : □ Only Right Ear □ Only Left Ear □ Both Ear Normal

If not: Left Ear : ______________________________ Sensorineural hearing loss
Right Ear : ______________________________ Sensorineural hearing loss

Tympanometry (Middle ear status):

□ Normal

If not, Right Ear: ______________________ Left Ear: __________________________

SCAN-C/A TEST (Unaided; Using 50 dB HL for normal group and the MCL for HI group)

Subtests	Raw Score		Sum(L/R)	Standard	%-ile
	Right	Left			
Filtered Words	/20	/20	/40		
Figure-ground	/40	/40	/80		
Competing Words (Dichotic words)	/30	/30	/60		
Sum of Standard scores					
Mean of 3 Standard scores					

Dichotic Digits (Two Digits only) :

(Unaided using 50 dB above the PTA for the normal group and the MCL for HI group)

Subtests	Raw Score		
	Left	Right	Sum (L/R)
Double Digits	/40	/40	/80
%			

LIST OF REFERENCES

Abraham, S. (1993). Differential Treatment of Phonological Disability in Children With Impaired Hearing Who Were Trained Orally. *American Journal of Speech-Language Pathology, 2,* 23-30.

Abu-Rabia, S. (2002). Phonemic awareness and middle-ear disease among Bedouin Arabs in Israel. *Reading Psychology*, *23*, 289-296(8)

Adams, M. (1990). *Beginning to read: Thinking and learning about print*. Cambridge, MA: MIT Press.

Allen, T. E. (1986). Patterns of academic achievement among hearing impaired students: 1974 and 1983. In A. N. Schildroth & M. A. Karchmer (Eds.), *Deaf Children in America (pp. 161-206)*. San Diego, CA: College Hill Press.

Allen, T. E. (1994). What are the deaf and hard-of-hearing students leaving high school and entering postsecondary education? Unblished manuscript. Washington, DC: Gaullaudet University.

Allen, T. E., & Schoem, S. R. (1997). Educating deaf and hard-of-hearing youth: What works best? Paper presented at the Combined Otolaryngological Spring Meetings of the American Academy of Otolaryngology. Scottsdale, AZ.

Anthony, J. L. & Francis, D. (2005). Development of phonological awareness. *Current Directions in Psychological Science, 14,* 255-259.

Archer, A. L., Gleason, M. M., & Vachon, V. L. (2003). Decoding and fluency: Foundation skills for struggling older readers. *Learning Disability Quarterly*, 26*,* 89-101.

Baddeley, A. D. & Hitch, G. J., (1974). Working memory. In Bower, G.H. (ed.), *Recent Advances in Learning and Motivation* (Volume 8), New York: Academic Press.

Baddeley, A. D. (1986). *Working Memory*. London: Oxford University Press.

Baddeley, A. D., Gathercole, S. E., & Papagno, C. (1998). The phonological loop as a language learning device. *Psychological Review, 105,* 158-173.

Baddeley, A.D. (2003) Double dissociation: Not magic but still useful. *Cortex, 39,* 129-131.

Beitchman, J. H. & Young, A. R. (1997). Learning disorders with a special emphasis on reading disorders: A review of the past 10 years. Journal of the American *Academy of Child and Adolescent Psychiatry, 36,* 1020 – 1032.

Bess, F. H., Dodd-Murphy, J., & Parker, R. A. (1998). Children with minimal sensorineural hearing loss: Prevalence, educational performance, and functional status. *Ear and Hearing, 19,* 339-354.

Biddle, K. R. (1996). Timing deficits in impaired readers: An investigation of visual naming speed and verbal fluency. Unpublished doctoral dissertation, Tufts University, Boston, MA.

Blachman**,** B. (1989). Phonological awareness and word recognition: Assessment and intervention. In A. Kamhi & H. Catts (Eds.), *Reading disabilities: A developmental language perspective (pp.* 133-158). Boston, MA: College-Hill Press.

Blachman, B. A. (1991). Early intervention for children's reading problems: Clinical applications of the research in phonological awareness. *Topics in Language Disorders, 12,* 51-65.

Blair, J., Peterson, M., & Viehweg, S. (1985). The effects of mild hearing loss on academic performance of young school-age children. *Volta Review, 87,* 87–93.

Blair, J., Peterson, M., Viehweg, S. (1985). The effects of mild sensorineural hearing loss on academic performance of young school-age children. *Volta Review, 87,* 87–93.

Blamey, P. J., Sarant, J., Paatsch, L. E., Barry, J. G., Bow, C. P., Wales, R. J. (2001). Relationships among speech perception, production, language, hearing loss and age in children with impaired hearing. *Journal of Speech, Language and Hearing Research, 44,* 264–285.

Bowers, P. G. & Wolf, M. (1993). Theoretical links among naming speed, precise timing mechanism, and orthographic skill in dyslexia. *Reading and Writing: An Interdisciplinary Journal, 5,* 69-85.

Bowers, P. G. (1989). Naming speed and phonological awareness: Independent contributors to reading disabilities. In S. McCormick & J. Zutell (Eds.), *Cognitive and social perspectives for literacy research and instruction: 38th Yearbook of the National Reading Conference* (pp. 165-173). Chicago: National Reading Conference.

Bowers, P. G. (1993). Text reading and rereading: Determinants of fluency beyond word recognition. *Journal of Reading Behavior, 25,* 133-53.

Bowers, P. G. (1995). Re-examining selected reading research from the viewpoint of the "double-deficit hypothesis." Paper presented at the Annual Meeting of the Society for Research in Child Development, Indianapolis, IN.

Bowers, P. G., & Swanson, L. B. (1991). Naming speed deficits in reading disability: Multiple measures of a singular process. *Journal of Experimental Child Psychology, 51,* 195-219.

Bowers, P. G., Golden, J. O., Kennedy, A., & Young, A. (1994). Limits upon orthographic knowledge due to processes indexed by naming speed. In V. W. Berninger (Ed.), *The varieties of orthographic knowledge: Theoretical and developmental issues* (pp. 173–218). Dordrecht: Kluwer Academic Publishers.

Bowers, P. G., Steffy, R., & Tate, E. (1988). Comparison of the effects of IQ control methods on memory and naming speed predictors of reading disabilities. *Reading Research Querterly, 23,* 304-309.

Bowey, J. A., Cain, M. T., & Ryan, S. M. (1992). A reading-level design study of phonological skills underlying fourth-grade children's word reading difficulties. *Child Development, 63,* 999-1011.

Bradley, L. & Bryant, P.E. (1983). Categorizing sounds and learning to read: A Causal connection. *Nature, 30,* 419-421.

Bradley, L., and Bryant, P.E. (1985). *Rhyme and Reason in Reading and Spelling.* Ann Arbor: University of Michigan Press.

Brady, S. (1991). The role of working memory in reading disability. *In Phonological Processes in Literacy: A Tribute to Isabelle Y. Liberman*, Brady, S., Shankweiler, D. (Eds.), Hillsdale, NJ: Lawrence Erlbaum Associates.

Brady, S. (1997). Ability to encode phonological representations: An underlying difficulty of poor readers. In *Foundations of Reading Acquisition and Dyslexia: Implications for Early Intervention,* Blachman, B., et al. (Eds), Mahwah, NJ: Lawrence Erlbaum Associates.

Brady, S., Poggie, E., and Rapala, M. M. (1989). Speech repetition abilities in children who differ in reading skill. *Language and Speech, 32,* 109-22.

Brady, S., Shankweiler, D., and Mann, V. A. (1983). Speech perception and memory coding in relation to reading ability. *Journal of Experimental Child Psychology, 35,* 345-367.

Brandes, P. J., & Ehinger, D. M. (1981). The effects of early middle ear pathology on auditory perception and academic achievement. *Journal of Speech and Hearing Disorder, 46,* 301-307.

Briscoe, J., Bishop, D. V. M., & Norbury, C. F. (2001). Phonological processing, language, and literacy: A comparison of children with mild-to-moderate sensorineural hearing loss and those with specific language impairment. *Journal of Child Psychology and Psychiatry, 42,* 329-340.

Briscoe, J., Gathercole, S. E., & Marlow, N. (2001). Everyday memory and cognitive ability in children born prematurely. *Journal of Child Psychology and Psychiatry, 42,* 749-754.

Brown, P. M. & Brewer, L. C. (1996). Cognitive processes of deaf and hearing skilled and less skilled reader. *Journal of Deaf Studies and Deaf Education, 1,* 263-270.

Brown,L, Sherbenou, R. J., Johnsen, S. K. (1997). *Test of nonverbal intelligence-3* (TONI-3). Pearson Education, Inc.

Bruck, M. (1992). Persistence of dyslexics' phonological awareness deficits. *Developmental Psychology, 28,* 874-886.

Bruck, M., & Treiman, R. (1990). Phonological awareness and spelling in normal children and dyslexics: The case of initial consonant clusters. *Journal of Experimental Child Psychology, 50,* 156–178.

Bryant, P. E. (1990). Phonological development and reading. In P. D. Pumfrey, & C. D. Elliot (Eds.), *Children's difficulties in reading, spelling and writing Challenges and responses* (pp. 63-82). London The Falmer Press.

Bryant, P. E., Bradley, L., MacLean, M., & Crossland, J. (1989). Nursery rhymes, phonological skills and reading. *Journal of Child Language, 16,* 407-428.

Byrne, B., & Fielding-Barnsley, R. (1989). Phonemic awareness and letter knowledge in the child's acquisition of the alphabetic principle. *Journal of Educational Psychology, 81,* 313-321.

Byrne, B., & Fielding-Barnsley, R. (1990). Acquiring the alphabetic principle: A case for teaching recognition of phoneme identity. *Journal of Educational Psychology, 82*, 805-812.

Campbell, R., & Wright, H. (1989). Immediate memory n the orally trained deaf: Effects of 'lipreadability' in the recall of written syllables. *British Journal of Psychology, 80,* 299-312.

Carrow-Woolfolk, E. (1999). *Comprehensive Assessment of Spoken Language*. Circle Pines, MN: American Guidance Service.

Chall, J. (1996). *Learning to Read: The Great Debate* (1967). New York: McGraw Hill.

Chall, J. S. (1996). *Stages of reading development.* Fort Worth, TX: Harcourt Brace.

Chiat, S. (2001). Mapping theories of developmental language impairment: Premises, predictions and evidence. *Language and Cognitive Processes 16*, 113-42.

Coley, J., & Bockmiller, P. (1980). Teaching reading to the deaf: An examination of teacher preparedness and practices. *American Annals of the Deaf, 125,* 909–915.

Compton, D. L., DeFries, J. C, & Olson, R. K. (2001). Are RAN- and phonological awareness-deficits additive in children with reading disabilities? *Dyslexia, 7,* 125-149.

Conrad, R. (1977). The reading ability of deaf school-leavers. *British Journal of Educational Psychology, 47, 138*-48.

Cornwall, A. (1992). The relationship of phonological awareness, rapid naming, and verbal memory to severe reading and spelling disability. *Journal of Learning Disabilities, 25*, 532-8.

Cornwall, A. (1992). The relationship of phonological aware-ness, rapid naming, and verbal memory to severe reading and spelling disability. *Journal of Learning Disabilities, 8,* 532-538.

Cronin, V. and Carver, P., 1998. Phonological sensitivity, rapid naming, and beginning reading. *Applied Psycholinguistics 19*, 447–461.

Davis, J. M., Effenbein, J., Schum, R., & Bentler, R. A. (1986). Effects of mild and moderate hearing impairments on language, educational, and psychosocial behaviours of children, *Journal of Speech and Hearing Disorder, 51,* 53–62.

Davis, J. M., Shepard, N. T., Stelmachowicz, P. G., & Gorga, M. P. (1981). Characteristics of hearing-impaired children in the public schools. Part II. Psychoeducational data. *Journal of Speech and Hearing Disorders, 46,* 130-137.

Delage, H., & Tuller, L. (2007). Language development and mild-to-moderate hearing loss: does language normalize with age? *Journal of Speech, Language, and Hearing Research, 50,* 1300-1313.

Denckla, M. B. & Cutting, L. E. (1999). History and significance of rapid automatized naming. *Annals of Dyslexia, 49,* 29–42.

Denckla, M., & Rudel, R. (1974). Rapid "automatized" naming of picture objects, colors, letters, and numbers by normal children. *Cortex, 10*, 186-202.

Denckla, M., & Rudel, R. (1976). Rapid "automatized" naming (R.A.N.): Dyslexia differentiated from other learning disabilities. *Neuropsychologia, 14*, 471-479.

Dodd, B., & Hermelin, B. (1977). Phonological coding by the prelinguistically deaf. *Perception and Psychophysics, 21,* 413-417.

Duara, R., Kushch, A., Gross-Gleen, K. Barker, W. W., Jallad, B., Pascal, S., Loewenstein, D. A., Sheldon, J., Rabin, M. Levin, B., Lubs, H. (1991). Neuroanatomic differences between dyslexic and normal readers on magnetic resonance imaging scans. *Archives of Neurology, 48,* 410-416.

Dunn, L. M., & Dunn, L. M. (1997). *Peabody Picture Vocabulary Test-Third Edition: Manual.* Circle Pines, MN: American Guidance Services.

Dunn, L. M., & Dunn, L. M. (1997). *Peabody Picture Vocabulary Test–III.* Circle Pines, MN: American Guidance Service.

Ehri, L. C. & Wilce, L. S. (1987). Does learning to spell help beginners learn to read words? *Reading Research Quarterly, 12,* 47-65.

Ehri, L. C. (1989). The development of spelling knowledge and its role in reading acquisition and reading disability. *Journal of Learning Disabilities, 22,* 349-364.

Ehri, L., Nunes, S., Willows, D., Schuster, B., Yaghoub-Zadeh, Z., & Shanahan, T. (2001). Phonemic awareness instruction helps children learn to read: Evidence from the National Reading Panel's meta-analysis. *Reading Research Quarterly, 36,* 250–287.

Eimas, P. (1974). Auditory and linguistic processing of cues for place of articulation by infants. *Perception & Psychophysics, 16*, 513-521.

Elbro, C. (1996). Early linguistic ability and reading development: A review and a hypothesis about underlying differences in distinctness of phonological representations of lexical items. *Reading and Writing: An Interdisciplinary Journal, 8,* 453-85.

Elbro, C. (1998). When reading is "readn" or somthn. Distinctness of phonological representations of lexical items in normal and disabled readers. *Scandinavian Journal of Psychology. 39*, 149-53.

Elbro, C., & Jensen, M. N. (2005). Quality of phonological representations, verbal learning, and phoneme awareness in dyslexic and normal readers. Scandinavian *Journal of Psychology, 46,* 375-384.

Elbro, C., Borstrøm, I., & Petersen, D. K. (1998). Predicting dyslexia from kindergarten: The importance of distinctness of phonological representations of lexical items. *Reading Reseaerch Quarterly, 33*, 36-57.

Elbro, C., Nielsen, I., & Petersen, D. K. (1998). Predicting dyslexia from kindergarten: the importance of distinctness of phonological representations of lexical items. *Annals of Dyslexia, 44,* 205-226.

Elfenbein, J. L., Hardin-Jones, M. A., Davis, J. M. (1994). Oral Communication Skills of Children Who Are Hard of Hearing. *Journal of Speech and Hearing Research, 37,* 216 - 226.

Engle, R. W., Cantor, J., & Turner, M. L. (1989). Modality effects: Do they fall on deaf ears? *Quarterly Journal of Experimental Psychology, 41A,* 273-292.

Felton, R. H. & Wood, F. (1992). Cognitive deficits in reading deficits in reading disability and attention deficit disorder. *Journal of Learning Disabilities, 22,* 3-13.

Felton, R. H., Wood, F., Brown, I. S., & Campbell, S. K. (1987). Separate verbal memory and naming deficits in attention deficit disorder and reading disability. *Brain and Language, 31,* 171-184.

Fletcher, J. M., Shaywitz, S. E., Shankweiler, D. P., Katz, L., Liberman, I. Y., Stuebing, K. K., Francis, D. J., Fowler, A., & Shaywitz, B. A. (1994). Cognitive profiles of reading disability: Comparisons of discrepancy and low achievement definitions. *Journal of Educational Psychology, 85,* 1-18.

Foorman, B. R., Francis, D. J., Beeler, T., Winikates, D., & Fletcher, J. M. (1997). Early interventions for children with reading problems: Study designs and preliminary findings. *Learning Disabilities: A Multi-Disciplinary Journal*, *8*, 63–71

Fowler, A. E. (1991). How early phonological development might set the stage for phoneme awareness. In *Phonological Processes in Literacy: A Tribute to Isabelle Y.* Liberman, Brady, S., Shankweiler, D. (Eds.), Hillsdale, NJ: Lawrence Erlbaum Associates.

Fowler, A. E., Doherty, B. J., & Boynton, L. (1995). The basis of reading skill in young adults with Down syndrome. In L. Nadel & D. Rosenthal (Eds.), *Down syndrome living and learning in the community* (pp. 182–196). New York: Wiley.

Foy, J. G. and Mann, V. (2001) Does strength of phonological representations predict phonological awareness? *Applied Psycholinguistics, 22,* 301-325.

Foy, J. G., & Mann, V. (2001). Does strength of phonological representations predict phonological awareness? *Applied Psycholinguistics, 22,* 301-325.

Friel-Patti, S., & Finitzo, T. (1990). Language learning in a prospective study of otitis media with effusion in the first two years of life. *Journal of Speech Hearing Research, 33,* 188-94.

Gathercole, S. E. (2006). Nonword repetition and word learning: The nature of the relationship [Keynote]. *Applied Psycholinguistics, 27*, 513–543.

Gathercole, S. E., & Baddeley, A. D. (1990). Phonological memory deficits in language disordered children: Is there a causal connection? *Journal of Memory and Language, 29,* 336-360.

Gathercole, S. E., Hitch, G. J., Service, E. & Martin, A. J. (1997). Phonological short-term memory and new word learning in children. *Developmental Psychology 33*, 966-979.

Gibbs, S. (2004). The skills in reading shown by young children with permanent and moderate hearing impairment. *Educational Research, 46,* 17-27.

Gilbertson, M., & Kamhi, A.G. (1995). Novel word learning in children with hearing impairment. *Journal of Speech and Hearing Research, 38,* 630-642.

Gillon, G. T. (2004). *Phonological Awareness: from research to practice*. New York: Guilford Press.

Goldin-Meadow, S., & Mayberry, R. I. (2001). How do profoundly deaf children learn to read? *Learning Disabilities Research & Practice, 16,* 222-229.

Goswami, U. (2000). Phonological and Lexical Processes. In Barr, R., Kamil, M., Mosenthal, P., and Pearson, D. (2000) *Handbook of Reading Research, 3,* 251-268.

Goswami, U. (2000). Phonological representations, reading development and dyslexia: Towards a cross-linguistic theoretical framework. *Dyslexia, 6, 124*-132.

Goswami, U. (2001). Developmental dyslexia. In N. J. Smelser & P. B. Baltes (Eds.), *International encyclopedia of the social & behavioral sciences*. (pp. 3918-3921). Amsterdam: Elsevier Sciences.

Goswami, U. (2003). Why theories about developmental dyslexia require developmental designs. *Trends in Cognitive Sciences, 7,* 534-54.

Goswami, U., & Bryant, P (1990). *Phonological skills and learning to read.* Hove, East Sussex: Lawrence Erlbaum Associates Ltd.

Gottardo, A., Stanovich, K. & Siegel, L. (1996). The relationships between phonological sensitivity, syntactic processing and verbal working memory in the reading performance of third-grade children. *Journal of Experimental Child Psychology, 63,* 563-582.

Griffiths, Y. M., & Snowling, M. J. (2002). Predictors of exception word and nonword reading in dyslexic children: the severity hypothesis. *Journal of Educational Psychology, 94,* 34-43.

Grigorenko, E. L. (2001). Developmental dyslexia: An update on genes, brains, and environments. *Journal of Child Psychology and Psychiatry, 42*, 91-125.

Grushkin, D. A. (1998). Why shouldn't Sam read? Toward a new paradigm for literacy and the deaf. *Journal of Deaf Studies and Deaf Education. 3,* 179-204.

Gupta, P. (2003). Examining the relationship between word learning, nonword repetition, and immediate serial recall in adults. *Quarterly Journal of Experimental Psychology, 56,* 1213-1236.

Halliday, L. F. & Bishop, D. V. (2006) Auditory frequency discrimination in children with dyslexia, *Journal of Research in Reading, 29,* 213–228.

Halliday, L. F., & Bishop, D. V. (2005). Frequency discrimination and literacy skills in children with mild to moderate sensorineural hearing loss. *Journal of Speech, Language, and Hearing Research, 48,* 1187-1203.

Hansen, J., & Bowey, J. (1994). Phonological analysis skills, verbal working memory, and reading ability in second-grade children. *Child Development, 65*, 938-50.

Hanson, V. L. (1982). Short-term recall by deaf signers of American Sign Language: Implications for order recall. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 8*, 572–583.

Hanson, V. L. (1989). Phonology and reading: Evidence from profoundly deaf readers. In D. Shankweiler & I. Lieberman (Eds*.), Phonology and reading disability: Solving the reading puzzle (pp. 69-89).* Ann Arbor, MI: University of Michigan Press.

Hanson, V. L., & Fowler, C. A. (1987). Phonological coding in word reading: Evidence from hearing and deaf readers. *Memory and Cognition, 15,* 199-207.

Hanson, V. L., & Lichtenstein, E. (1990). Short-term memory coding by deaf signers: The primary language coding hypothesis reconsidered. *Cognitive Psychology, 22,* 211-224.

Hanson, V. L., & McGarr, N. S. (1989). Rhyme generation by deaf adults. *Journal of Speech and Hearing Research, 32,* 2-11.

Hanson, V. L., Goodell, E. W., & Perfetti, C. A. (1991). Tongue twister effects in the silent reading of hearing and deaf college students. *Journal of Memory and Language, 30*, 319–330.

Hansson, K., Forsberg, J., Lofqvist, A., Maki-Torkko, E., & Sahlen, B. (2004). Working memory and novel word learning in children with hearing impairment and children with specific language impairment. *International Journal of Language and Communication Disorders, 39, 401*–422.

Harris, M., & Beech, J. R. (1998). Implicit phonological awareness and early reading development in prelingually deaf children*. Journal of Deaf Studies and Deaf Education, 3,* 205-216.

Hartas, D. (2005). *Language and Communication Difficulties,* London: Continuum.

Hasenstab, M. S., & McKenzie, C. D. (1981). A survey of reading programs used with hearing-impaired students. *The Volta Review, 83,* 383–388.

Hayiou-Thomas, M. E., Bishop, D. V. M. & Plunkett, K. (2004). Simulating SLI: General cognitive processing stressors can produce a specific linguistic profile. *Journal of Speech, Language, and Hearing Research 47,* 1347–62.

Hemmer, V.H. & Ratner, N.B. (1994). Communicative development in twins with discordant histories of recurrent otitis media. *Journal of Communication Disorders, 27,* 91-106.

Hickok, G., & Poeppel, D. (2000). Towards a functional neuroanatomy of speech perception. *Trends in Cognitive Sciences, 4,* 131–138.

Hoffmeister, R. J. (2000). A piece of the puzzle: ASL and reading comprehension in deaf children. In C. Chamberlain, J. P. Morford, & R. I. Mayberry (Eds.), *Language Acquisition by Eye* (pp. 165-89). Mahwah, NJ: Earlbaum.

Hoien, T., Lundberg, L., Stanovich, K. E., & Bjaalid, L. K. (1995). Components of phonological awareness. *Reading & Writing: An Interdisciplinary journal, 7,* 171-188.

Holt, J. (1994). Classroom attributes and achievement test scores for deaf and hard of hearing students. *American Annals of the Deaf, 139,* 430-437.

Hulme, C., & Snowling, M. (1992). Phonological deficits in dyslexia: a reappraisal of the verbal deficit hypothesis. In N. Singh & I. Beale (Eds.), *Current perspectives in learning disabilities*, (pp. 270-331). New York: Springer-Verlag.

Hurford, D. P., Darrow, L. J., Edwards, T. L., Howerton, C. J., Mote, C. R., Schauf, J. D., & Coffey, P. (1993). An examination of phonemic processing abilities in children during their first-grade year. *Journal of Learning Disabilities, 26,* 167-177.

Hynd, G. W., Semrud-Clikemand, M., Lorys, A. R., Novey, E. S., & Eliopulos, D. (1990). Brain morphology in developmental dyslexia and attention deficity-hyperactivity disorder (ADHD): Morphometric analysis of MRI. *Archives of Neurology, 47,* 919-926.

Jarrold, C., Baddeley, A. D., & Phillips, C. E. (2002). Verbal short-term memory in Down syndrome: A problem of memory, audition, or speech? *Journal of Speech,Language, and Hearing Research, 45*, 531–544.

Jenkins, R., & Bowen, L. (1994). Facilitating development of preliterate children's phonological abilities. *Topics in Language Disorders, 14,* 26-39.

Justas, S., & Wilkinson, G. S. (1984). *Wide Range Achievement Test—Revised.* Wilmington, DE: Justas Associates.

Kail, R. (1991). Developmental change in speed of processing during childhood and adolescence. *Psychological Bulletin, 109*, 490–501.

Kail, R., & Hall, L. K. (1994). Procesisng speed, naming speed, and reading. *Developmental Psychology, 30,* 949–954.

Kail, R., Hall, L. K., & Caskey, B. J. (1999). Processing speed, exposure to print, and naming speed. *Applied Psycholinguistics, 20,* 303–314.

Katz, R. (1986). Phonological deficiencies in children with reading disability: Evidence from an object-naming task. *Cognition, 22,* 225-257.

Katzir, T., Wolf, M., O'Brien, Kennedy, B., Lovett, M., & Morris, R. (2006). Reading Fluency: The Whole is more than the Parts. *Annals of Dyslexia. 56,* 51-82.

Keith, R. W. (1986). *SCAN: A Screening Test for Auditory Processing Disorders*. San Antonio, TX: The Psychological Corporation, Harcourt, Brace, Jovanovich, Inc.

Keith, R. W., Rudy, J., Donahue, P. A., & Katbamna, B. (1989). Comparison of SCAN results with other auditory and language measures in a clinical population. *Ear and Hearing, 10,* 382–386.

King, C.M., & Quigley, S.P. (1985). *Reading and deafness.* San Diego, CA: College-Hill Press.

Kramer, J. H., Knee, K., & Delis, D. C. (2000). Verbal memory impairments in dyslexia. *Archieves of Clinical Neuropsychology. 15,* 83-93.

Kushch, A., Gross-Glenn, K., Jallad, B., Lubs, H., Rabin, M., Feldman, E., & Duara, R. (1993). Temporal lobe surface area measurements on MRI in normal and dyslexic readers. *Neuropsychologia, 31,* 811-821.

Landerl, K., Wimmer, H., & Frith, U. (1997). The impact of orthographic consistency on dyslexia: a German-English comparison. *Cognition, 63,* 315-334.

Larsen, J. P., Hoien, T., Lundberg, I., & Odegaard, H. (1990). MRI evaluation of the size and symmetry of the planum temporale in adolescents with developmental dyslexia. *Brain Lanugage, 39,* 289-301.

LaSasso, C. (1978). A national survey of materials and procedures used to teach reading to hearing-impaired children. *American Annals of the Deaf, 123*, 22–30.

LaSasso, C. (1987). Survey of reading instruction for hearing impaired students in the United States. *The Volta Review, 89*, 85–98.

LaSasso, C., & Mobley, R. T. (1997). National Survey of reading instruction for deaf or hard-of-hearing students in the U.S. *The Volta Review, 99,* 31–59.

Laybaert, J., & Charlier, B. (1996). Visual speech in the head: The effect of Cued-Speech on rhyming, remembering, and spelling. *Journal of Deaf Studies and Deaf Education, 1,* 234-248.

Leonard, C. M., Eckert, M. A., Lombardino, L. J., Oakland, T., Kranzler, J., Mkohr, C. M., King, W. M., & Kreeman, A. (2001). Anatomical risk factors for phonological dyslexia. *Cerebral Cortex, 11,* 148-157.

Leonard, C. M., Puranik, C., Kuldau, J. M., & Lombardino, L. J. (1998). Normal variation in the frequency and location of human auditory cortex landmarks: Heschl's gyrus: Where is it? *Cerebral Cortex, 8*, 397-406.

Leonard, C. M., Voeller, K. K., Lombardino, L. J., Morris, M. K., Hynd, G. W., Alexander, A. W., Andersen, H. G. Garofalakis, M., Honeyman, J. C., Mao, J., Agee, F. & Staab, E. V. (1993). Anomalous cerebral structure in *dyslexia* revealed with magnetic resonance imaging. *Archives of Neurology, 50,* 461-469.

Leonard, L. (1989). Language learnability and specific language impairment in children. *Applied Psycholinguistics, 10,* 179–202.

Leonard, L. (1995). Functional categories in the grammars of children with specific language impairment. *Journal of Speech and Hearing Research, 38,* 1270–1283.

Leonard, L. (1998). *Specific Language Impairment.* MIT Press, Cambridge, MA.

Levelt, W. J. M. (1989). *Speaking: from intention to articulation.* Cambridge, Massachusetts: The MIT Press.

Leybaert, J. (1993). Reading in the deaf: The roles of phonological codes. In M. Marschark & M. D. Clark (Eds.), *Psychological perspectives on deafness* (pp. 269-309). Hillsdale, NJ: Lawrence Erlbaum Associates.

Leybaert, J. (1998). Phonological representations in deaf children: the importance of early linguistic experience. *Scandinavian Journal of Psychology, 39,* 169-173.

Leybaert, J., & Alegria, J. (1990). Cued speech and the acquisition of reading by deaf children. *The Cued Speech Journal, 4,* 24-38.

Liberman, I. Y., Shankweiler, D., & Liberman, A. M. (1989). The alphabetic principle and learning to read. In D. Shankweiler & I. Y. Lieberman (Eds.), *Phonology and reading disability: Solving the reading puzzle* (pp. 1-33). Ann Arbor: University of Michigan Press.

Lichtenstein, E. H. (1998). The relationships between reading processes and English skills of deaf college Students. *Journal of Deaf Studies and Deaf Education, 3,* 80-134.

Lieberman, I. Y., & Shankweiler, D. (1985). Phonology and problems of learning to read the write. *Remedial and Special Education, 6*, 8-17.

Lindsay, P. H., Shapiro, A., Musselman, C., & Wilson, A. (1988). Predicting language development in deaf children using subscales of the Leiter International Performance Scale. *Canadian Journal of Psychology, 42,* 144-162.

Lovett, M. W., Steinbach, K. A., & Frijters, J. C. (2000). Remediating the core deficits of developmental reading disability: a double-deficit perspective. *Journal of Learning Disabilities, 33,* 334-358.

Lyon, G. R. (1998). Why reading is not a natural process. *Educational Leadership, 55,* 4-19.

Lyon, G. R., Shaywitz, S. E. & Shaywitz, B. A. (2003). A definition of dyslexia. Ann *Dyslexia, 53,* pp. 1-14.

Lyxell, B., Anderson, U., Borg, E., & Ohlsson, I. S. (2003). Working-memory capacity and phonological processing in deafened adults and individuals with a severe hearing impairment. *International Journal of Audiology, 42,* Suppl 1:S86-89.

Lyxell, B., Rönnberg, J. & Samuelsson, S. (1994). Internal speech functioning and speechreading in deafened and normal hearing adults. *Scandinavian Audiology, 23,* 179-185.

Majerus, S., Amand, P., Boniver, V, Demanez, J. P., Demanez, L., & Linden, M. V. (2005). A quantitative and qualitative assessment of verbal short-term memory and phonological processing in 8-year-olds with a history of repetitive otitis media. *Journal of Communication Disorders, 9,* 1-26.

Manis, F. R., Doi, L. M., & Bhadha, B. (2000). Naming speed, phonological awareness, and orthographic knowledge in second graders. *Journal of Learning Disabilities, 33,* 325–333.

Manis, F. R., McBride-Chang, C., Seidenberg, M. S., Keating, P., Doi, L. M., Munson, B., & Petersen, A. (1997). Are speech perception deficits associated with developmental dyslexia? *Journal of Experimental Child Psychology, 66,* 211-235.

Mann, V. A. (1993). Phoneme awareness and future reading ability. *Journal of Learning Disabilities, 26,* 259-269.

Mann, V. A. (1998) Language problems: A key to early reading problems. In B. Wong (Ed.) *Learning about Learning disabilities, 2nd Ed*. (pp. 163-202). Chicago.

Marchman, V. A. & Bates, E. (1994). Continuity in lexical and morphological development: A test of the critical mass hypothesis. *Journal of Child Language, 21,* 339-366.

Marschark, M. & Harris, M. (1996). Success and failure in learning to read: the special case of deaf children. In C. Cornoldi & J. Oakhill (Eds.), *Reading comprehension difficulties: Processes and intervention* (pp 279 - 300). Hillsdale, NJ: Lawrence Erlbaum Associates Inc.

Marschark, M. (1997). *Raising and educating a deaf child*. New York: Oxford University Press.

Marschark, M. (2003). Cognitive functioning in deaf adults and children. In M. Marschark & P. E. Spencer (Eds.), *Oxford handbook of deaf studies, language, and education* (pp. 464–477). New York: Oxford University Press.

Marschark, M., & Everhart, V. S. (1999). Problem solving by deaf and hearing children: Twenty questions. *Deafness and Education International*, *1*, 63–79.

Marschark, M., & Lukomski, J. (2001). Understanding language and learning in deaf children. In M. D. Clark, M. Marschark, & M. Karchmer (Eds.), *Cognition, context, and deafness* (pp. 71–86). Washington, DC: Gallaudet University Press.

McConkey Robbins, A., Burton Koch, D., Osberger, M.J., Zimmerman-Phillips, S., Kishon-Rabin, L. (2004). Effect of age at cochlear implantation on auditory skill development in infants and toddlers. *Archives of Otolaryngology, Head, and Neck Surgery, 130*, 570-574.

McDougall, S., Hulme, C., Ellis, A., & Monk, A. (1994). Learning to read: The role of short-term memory and phonological skills. *Journal of Experimental Child Psychology*, *58***,** 112–133.

Merzenich, M. M., Jenkins, W. M., Johnson, P., Schreiner, C., Miller, S., & Tallal, P. (1996). Temporal processing deficits of language-learning impaired children ameliorated by training. *Science, 271,* 77-80.

Metsala, J. L. (1997). Spoken word recognition in reading in reading disabled children. *Journal of Educational Psychology, 89,* 159-169.

Metsala, J. L. (1999). Young children's phonological awareness and nonword repetition as a function of vocabulary development*.* *Journal of Educational Psychology, 91,* 3-19.

Metsala, J. L., & Walley, A. C. (1998). Spoken vocabulary growth and the segmental restructuring of lexical representations: precursors to phonemic awareness and early reading ability. In J. L. Metsala & L. C. Ehri (Eds.), *Word Recognition in Beginning Literacy,* 89-120. Hillsdale, NJ: Erlbaum.

Misra M., Katzir, T., Wolf, M., & Poldrack, R. A. (2004). Neural systems of rapid automatized naming in skilled readers: Unraveling the RAN-reading relationship. *Scientific Studies of Reading, 8,* 241-256.

Misra, M., Katzir, T., Wolf, M. & Poldrack, R.A. (2004). Neural systems for rapid automatized naming (RAN) in skilled readers: Unraveling the RAN-reading relationship. *Scientific Studies in Reading. 8,* 241-256.

Mody, M. (2003). Rapid auditory processing deficits in dyslexia: A commentary on two differing views. *Journal of Phonetics, 31,* 529-539.

Mody, M., Studdert-Kennedy, M., & Brady, S. (1997). Speech perception deficits in poor readers: Auditory processing or phonological coding? *Journal of Experimental Child Psychology, 64, 199*-231.

Mody, R., Schwartz, G., Gravel, J.S., & Ruben, R. J. (1999). Speech perception and verbal memory in children with and without histories of otitis media. *Journal of Speech, Language, and Hearing Research, 42,* 1069-1079.

Moeller, M. P. (2000). Early intervention and language development in children who are deaf and hard of hearing. *Pediatrics,* 106, 43-51.

Moeller, M. P., & Luetke-Stahlman, B. (1990). Parents' use of signing exact English: A descriptive analysis. *Journal of Speech and Hearing Disorders, 55,* 327-38.

Moncrieff, D. W. (2002). Auditory Processing Disorders and Dyslexic Children. http://www.audiologyonline.com/articles/pf_article_detail.asp?article_id=369.

Moore, B. C .J. (1995). *Perceptual Consequences of Cochlear Damage,* Oxford University Press, Oxford.

Morals, J., Alegria, J., & Content, A. (1987). The relationships between segmental analysis and alphabetic literacy: An interactive view. *Cahiers de Psychologie Cognitive, 7,* 415-38.

Morford, J. P., & Mayberry, R. I. (2000). A reexamination of "early exposure" and its implication for language acquisition by eye. In C. Chamberlain, J. P. Morford, & R. I. Mayberry (Eds.), *Language Acquisition by Eye* (pp. 165-89). Mahwah, NJ: Earlbaum.

Morris, R. D., Stuebing, K. K, Fletcher, J. M., Shaywitz, S. E., Lyon, G. R., Shankweiler, D. P. (1998). Subtypes of reading disability: Variability around a Phonological Core. *Journal of Educational Psychology, 90,* 347–373.

Musiek, F. E., & Chermak, G. D. (1994). Three commonly asked questions about central auditory processing disorders: Assessment. *American Journal of Audiology, 3*, 23–27.

Musiek, F. E., & Reeves, A. G. (1990). Asymmetries of the auditory areas of the cerebrum. *Journal of the American Academy of Audiology, 1,* 240-245.

Musselman, C. (2000). How do children who can't hear learn to read an alphabetic script? A review of the literature on reading and deafness. *Journal of Deaf Studies and Deaf Education*, *5*, 9–31.

Muter, V., Hulme, C., Snowling, M., & Taylor, S. (1997), Segmentation, not rhyming, predicts early progress in learning to read. *Journal of Experimental Child Psychology, 65,* 370–396.

Nairne, J. S. (1990). A feature model of immediate memory. *Memory & Cognition, 18*, 251–269.

Nathan, L., Stackhouse, J., Goulandris, N., & Snowling, M. (2004). The development of early literacy skills among children with speech difficulties: A test of the "critical age hypothesis." *Journal of Speech, Language, and Hearing Research, 47*, 377-391.

Neath, I., & Nairne, J. S. (1995). Word-Length effects in immediate memory: Overwriting trace decay theory. *Psychonomic Bulletin & Review, 2,* 429-441.

Nemeth, S. (1992). The role of phonology and context in word recognition in hearing impaired readers. Unpublished master's thesis. Montreal, Quebec, Canada: McGill University.

Neuhaus, G. F., Foorman, B. R., Francis, D. J., & Carlson, C. (2001). Measures of information processing in Rapid Automatized Naming (RAN) and their relation to reading *Journal of Experimental Child Psychology, 78*, 359-373.

Nicholson, R. I., & Fawcett, A. J. (1990). A New Framework for Dyslexia Research? *Cognition, 35,* 159-182.

Nielsen, D. C., & Luetke-Stahlman, B. (2002). Phonological Awareness: One key to the reading proficiency of deaf children. *American Annals of the Deaf, 147*, 11-19.

Nittrouer, S. (1996). Discriminability and perceptual weighting of some acoustic cues to speech perception by 3-year-olds. *Journal Speech and Hearing Research, 39*, 278-297.

Nittrouer, S. (1996). The relation between speech perception and phonemic awareness: Evidence from low-SES children and children with chronic OM. *Journal of Speech and Hearing Research. 39,* 1059-1070.

Nittrouer, S., & Burton, L. T. (2005). The role of early language experience in the development of speech perception and phonological processing abilities: Evidence from 5-year-olds with histories of otitis media with effusion and low socioeconomic status. *Journal of Communication Disorders,* 38, 29-63.

Norbury, C. F., Bishop, D. V. M., & Briscoe, J. (2001). Production of English finite verb morphology: A comparison of SLI and mild-moderate hearing impairment. *Journal of Speech, Language, and Hearing Research, 44,* 165–178.

Nozza, R. J., Bluestone, C. D., Kardatzke, D., Bachman, R. (1994). Identification of middle ear effusion by aural acoustic admittance and otoscopy. *Ear and Hearing, 15*, 310-23.

O'Connor, R. E., Jenkins, J. R., Leicester, N., & Slocum, T. A. (1993). Teaching phonological awareness to young children with learning disabilities. *Exceptional Children, 59*, 532-546.

Oakhill, J. & Kyle, F. (2000). The Relation between Phonological and Working Memory. *Journal of Experimental Child Psychology, 75,* 152–164.

O'Brien, B., Wolf, M., Morris, R., & Lovett, M. (2004). An Investigation of subtypes of developmental dyslexia using taxometric classification. Annual Meeting Brain, Neurosciences, and Education SIG Paper Session.

Olson, R. Forsberg, H., Wise, B., & Rack, J. (1994). Measurement of word recognition, orthographic, and phonological skills. In G. R. Lyon (Ed.), *Frames of reference for the assessment of learningt disabilities: New views on measurement issues* (pp. 243-277). Baltimore: Brookes.

Ostrander, C. (1998). The relationship between phonological coding and reading achievement in deaf children: Is cued speech a special case? Unpublished manuscript.

Padden, C., & Ramsey, C. (2000). Americans Sign Language and reading ability in deaf children. In C. Chamberlain, J. P. Morford, & R. I. Mayberry (Eds.), *Language Acquisition by Eye* (pp. 165-89). Mahwah, NJ: Earlbaum.

Paul, P. V. (1998). *Literacy and deafness.* Boston: Allyn and Bacon. Paul, P. V. (2001). *Language and deafness*. San Diego, CA: Singular.

Paulesu, E., Démonet, J., Fazio, F., McCrory, E., Chanoine, V., Brunswick, N., Cappa, S., Cossu, G., Habib, M., Frith, C., Frith, U. (2001). Dyslexia: cultural diversity and biological unity, *Science 291*, 2165-2167.

Penhune, V. B., Zatorre, R. J., MacDonald, J. D., & Evens, A. C. (1996). Interhemispheric anatomical differences in human primary auditory cortex; probabilistic mapping and volume measurement from magnetic resonance scans. *Cerebral Cortex, 6,* 661-672.

Perfetti, C. A. (1985). *Reading ability.* New York: Oxford University Press.

Perfetti, C. A.(1992). The representation problem in reading acquisition. In P. Gough, L. Ehri, & R. Treiman (Eds.), *Reading acquisition* (pp. 107-143). San Diego: Acadmeic Press.

Perfetti, C. A., & Sandak, R. (2000). Reading optimally builds on spoken language: Implications for deaf literacy. *Journal of Deaf Studies and Deaf Education, 5,* 31-50.

Peters, S. A., Grievink, E. H., van Bon, W. H., & Schilder, A. G. (1994). The effects of early bilateral otitis media with effusion on educational attainment: a prospective cohort study. *Journal of Learning Disabilities. 27,* 111-21.

Plapinger, D. S., & Sikora, D. M. (1995). The Use of Standardized Test Batteries in Assessing the Skill Development of Children With Mild-to-Moderate Sensorineural Hearing Loss. *Language, Speech, and Hearing Services in Schools, 26*, 39-44.

Porpodas, C. D. (1999). Patterns of phonological and memory processing in beginning readers and spellers of Greek. *Journal of Learning Disabilities, 32,* 406-416.

Powell, D**.,** Stainthorp, R**.,** Stuart, M, Garwood, H & Quinlan, P. (2007). An experimental comparison between rival theories of rapid automatized naming performance and its relationship to reading. *Journal of Experimental Child Psychology, 98*, 46-68.

Ramus, F. (2001a). Dyslexia - Talk of two theories. *Nature, 412,* 393-395.

Ramus, F. (2001b). Outstanding questions about phonological processing. *Dyslexia, 7,* 197-216.

Ramus, F. (2002). The neural basis of reading acquisition. In M. S. Gazzaniga (Ed.), *The Cognitive Neurosciences* (3rd ed., pp. 815-824). Cambridge, MA: MIT Press.

Ramus, F. (2003). Developmental dyslexia: specific phonological deficit or general sensorimotor dysfunction? *Current Opinion in Neurobiology, 13,* 212-218.

Ramus, F., Pidgeon, E., & Frith, U. (2003). The relationship between motor control and phonology in dyslexic children. *Journal of Child Psychology and Psychiatry, 44* (5), 712-722.

Ramus, F., Rosen, S., Dakin, S. C., Day, B. L., Castellote, J. M., White, S., & Frith, U. (2003). Theories of developmental dyslexia: Insights from a multiple case study of dyslexic adults. *Brain, 126,* 1-25.

Rayner, K., Foorman, B. R., Perfetti, C. A., Pesetsky, D. & Seidenberg, M. S. (2001). How psychological science informs the teaching of reading*. Psychological Science in the Public Interest, 2*, 31-74.

Rice, M., & Wexler, K. (1996). Toward Tense as a clinical marker of specific language impairment in English-speaking children, *Journal of Speech and Hearing Research 39,* 1239-1257.

Roberts, J. E., Burchinal, M. R., & Zeisel, S. A. (2002). Otitis media in early childhood in relation to children's school-age language and academic skills. *Pediatrics, 110,* 696-706.

Roberts, J. E., Hunter, L., Gravel, J., Rosenfeld, R., Berman, S., Haggard, M., Hall, J., Lannon, C., Moore, D., Lynne, V., & Wallace, I. (2004). Otitis media, hearing loss, and language learning: controversies and current research. *Journal of Developmental & Behavioral Pediatrics, 25, 110*-122.

Roberts, J. E., Rosenfeld, R. M., & Zeisel, S. A. (2004). Otitis media and speech and language: a meta-analysis of prospective studies. *Pediatrics, 113,* 238-48.

Rom, A., & Leonard, L. (1990). Interpreting deficits in grammatical morphology in specifically language-impaired children: Preliminary evidence from Hebrew. *Clinical Linguistics and Phonetics, 4,* 93-105.

Rosen, S. (2003) Auditory processing in dyslexia and specific language impairment: Is there a deficit? What is its nature? Does it explain anything? *Journal of Phonetics, 31,* 509-527.

Ruben, R. J. (1972). The ear. In H. Barnett & A. Einhorn (Eds.) *Pediatrics* (15th ed., pp. 1881-92). New York: Appleton, Century, Crofts.

Rutter, M., & Yule, W. (1975). The concept of specific reading retardation. *Journal of Child Psychology and* Psychiatry*, 16,*181-197.

Scanlon, D. M. & Vellutino, F. R. (1997). A comparison of the instructional backgrounds and cognitive profiles of poor, average, and good readers who were initially identified as at risk for reading failure. *Scientific Studies of Reading, 1,*191-215.

Schirmer, B. R. (1994). *Language and Literacy Development in Children Who are Deaf.* Merrill: Merrill/ Macmillan Publishing Company.

Schirmer, B. R., & McGough, S. M. (2005). Teaching reading to children who are deaf: Do the conclusions of the National Reading Panel apply? *Review of Educational Research, 75*, 83-117.

Service, E., Maury, S., Luotoniemi, E. (2005). Forgetting and redintegration of consonants and vowels in pseudoword lists. *Memory, 13,* 340–348.

Shankweiler, D., & Crain, S. (1986) Language mechanisms and reading disorder: A modular approach. *Cognition, 24,* 139-168.

Share, D. L. (1995). Phonological recoding and self-teaching: Sine qua non of reading acquisition. *Cognition, 55,* 151–218.

Share, D. L. (1999). Phonological recoding and orthographic learning: A direct test of the self-teaching hypothesis. *Journal of Experimental Child Psychology, 72,* 95–129.

Share, D. L., Chalmers, D., Silva P. A., & Stewart, I. A. (1986). Reading disability and middle ear disease. *Archives of Disease in Childhood, 61,* 400-401,

Sharma, A., Dorman, M., & Spahr, A. (2002). A sensitive period for the development of the central auditory system in children with cochlear implants: Implications for age of implantation, *Ear & Hearing 23*, 532–539.

Shaywitz, S. (1998). "Current concepts: Dyslexia." *The New England Journal of Medicine*, 338, 307-312.

Shaywitz, S. (2003). *Overcoming dyslexia: A new and complete science-based program for reading problems at any level.* New York: Knopf.

Shaywitz, S. E., Fletcher, J. M., Holahan, J. M., Shneider, A. E., Marchione, K. E., Stuebing, K. K., et al. (1999). Persistence of dyslexia: The Connecticut Longitudinal Study at adolescence. *Pediatrics, 104,* 1351-1359.

Shaywitz, S., & Shaywitz, B. (2005). Dyslexia (Specific Reading Disability). *Biological Psychiatry*, 57, 1301–1309.

Shaywitz, S., Fletcher, J., Holahan, J., Shneider, A., Marchione, K., Stuebing, K., et al. (1999). Persistence of dyslexia: The Connecticut Longitudinal Study at adolescence. *Pediatrics, 104*(6), 1351–1359.

Siok, W. T., & Fletcher, P. (2001). The role of phonological awareness and visual-orthographic skills in Chinese reading acquisition. *Developmental Psychology, 37*, 886-899.

Snow, C. E., Burns, M. S., & Griffin, P. (1998). *Preventing Reading Difficulties in Young Children.* Washington, DC: National Academy Press.

Snowling, M. & Hulme, C. (1989). A longitudinal case study of developmental phonological dyslexia. *Cognitive Neuropsychology 6*, 379–401.

Snowling, M. J. (1998). Reading development and its difficulties. *Educational and Child Psychology, 15,* 44-58.

Snowling, M. J. (2001). From language to reading and dyslexia. *Dyslexia, 7,* 37-46.

Snowling, M. J., Goulandris, N., Bowlby, M., & Howell, P. (1986). Segmentation and speech perception in relation to reading skill: a developemental analysis. *Journal of Experimental Child Psychology, 41*, 489-507.

Snowling, M., Bishop, D. V. M., & Stothard, S. E. (2000). Is pre-school language impairment a risk factor for dyslexia in adolescence? *Journal of Child Psychology and Psychiatry, 41,* 587-600.

Snowling, M., Nation, K., Moxham, P., Gallagher, A., & Frith, U. (1997). Phonological processing skills of dyslexic students in higher education: A preliminary report. *Journal of Research in Reading, 29,* 31-41.

Spector, J. (1995). Phonemic awareness training: Application of principles of direct instruction. *Reading and Writing Quarterly, 11*, 37-51.

Stanovich, K. E. (1980). Toward an interactive-compensatory model of individual differences in the development of reading fluency. *Reading Research Quarterly, 16,* 32-71

Stanovich, K. E. (1994). Annotation: Does dyslexia exist? *Journal of Child Psychology and Psychiatry, 35,* 579–595.

Stanovich, K. E. (1998). Twenty-five years of research on the reading process: The grand synthesis and what it means for our field. In T. Shanahan & F. Rodriguez-Brown (Eds.), *Forty-Seventh Yearbook of the National Reading Conference* (pp. 44-58). Chicago: NRC.

Stanovich, K. E., & Siegal, L. S. (1994). Phenotypic performance profile of children with reading disabilities: A regresson-based test of the phonological-core variable-difference model. *Journal of Educational Psychology, 86,* 24-53.

Stanovich, K.E. (1981). Relationships between word decoding speed, general name-retrieval ability, and reading progress in first-grade children*. Journal of Educational Psychology, 73*, 809-815.

Stanovich, K.E. (1986). Matthew Effects in Reading: Some consequences of individual Differences in the acquisition of literacy. *Reading Research Quarterly, 21,* 360-407.

Stanovich, K.E. (1988). Explaining the differences between the dyslexic and the Garden-variety poor reader: The phonological-core variable difference modes. *Journal of Learning Disabilities, 21,* 590-612.

Stanovich, K.E. (1992). Speculations on the causes and consequences of individual Differences in early reading acquisition. In P. Gough, L. Ehri, and R. Treiman (Eds.), *Reading acquisition* (pp. 307-342). Hillsdale, NJ: Lawrence Erlbaum Associates.

Stanovich, K.E. (1993). Does reading make you smarter? Literacy and the development of verbal intelligence. In H. Reese (Ed.), *Advances in Child Development and Behavior* (Vol. 24, pp. 133-180). San Diego, CA: Academic Press.

Stanovich, K.E., and West, R.F. (1989). Exposure to print and orthographic processing. *Reading Research Quarterly, 24,* 402-433.

Stelmachowicz, P.G., Pittman, A.L., Hoover, B.M., & Lewis, D.E. (2004). Novel-word learning in children with normal hearing and hearing loss. *Ear and Hearing*, 25, 47-56.

Sterne, A., & Goswami, U. (1998). Deaf children can make rhymes: evidence from a simple rhyme task. *Surdite et acces a la langue ecrite.* 137-155.

Strong, M., & Prinz, P. (2000). Is American Sign Language skill related to English literacy? In C. Chamberlain, J. P. Morford, & R. I. Mayberry (Eds.), *Language Acquisition by Eye (*pp. 165-89). Mahwah, NJ: Earlbaum.

Svirsky, M. A., Robbins, A. M., Kirk, K. I., Pisoni, D. B., & Miyamoto, R. T. (2000). Language development in profoundly deaf children with cochlear implants. *Psychological Science, 11,* 153-158.

Svirsky, M. A., Stallings, L. M., Lento, C. L., Ying, E., & Leonard, L. B. (2002). Grammatical morphologic development in paediatric cochlear implantation users may be affected by the perceptual prominence of the relevant markers. *Annals of Otology Rhinology and Laryngology, 189(Suppl.),* 109–112.

Swan, D., & Goswami, U. (1997a). Phonological awareness deficits in developmental dyslexia and the phonological representations hypothesis. *Journal of Experimental Child Psychology, 66, 18*-41.

Swan, D., & Goswami, U. (1997b). Picture-naming deficits in developmental dyslexia: The phonological representations hypothesis. *Brain and Language, 56,* 334-353.

Tallal, P. (1980). Auditory temporal perception, phonics, and reading disabilities in children. *Brain and Language, 9,* 182–98.

Tallal, P., Miller, S. L., Bedi, G., Byma, G., Wang, X., Nagarajan, S. S., Schreiner, C., Jenkins, W. M., & Merzerich, M. M. (1996). Language comprehension in language-learning impaired children improved with acoustically modified speech. *Science, 271,* 81-84.

Tallal, P., Miller, S., & Fitch, R. (1993). Neurological basis of speech: A case for the prominence of temporal processing? In P. Tallal, A. Galaburda, R. Llinas, & C. von Euler (Eds.), *Annals of the New York Academy of Sciences: Vol. 682.* Temporal information processing in the nervous system (pp. 27-37). New York: New York Academy of Sciences.

Tijms, J. (2004). Verbal memory and phonological processing in dyslexia. *Journal of Research in Reading, 27,* 300-310.

Torgesen, J. K. (1997). The prevention and remediation of reading difficulties: Evaluating what we know from research. *Journal of Academic Language Therapy, 1,* 11–47.

Torgesen, J. K. (2000). Individual differences in response to early interventions in reading: The lingering problem of treatment resisters. *Learning Disabilities Research and Practice, 51*(1), 55–64.

Torgesen, J. K., & Bryant, B. (1994). *Test of Phonological Awareness*. Austin, TX: PRO-Ed.

Torgesen, J. K., & Burgess, S. R. (1998). Consistency of reading-related phonological processes throughout early childhood: Evidence from longitudinal-correlational and instructional studies. In J. Metsala & L. Ehri (Eds.). *Word Recognition in Beginning Reading.* Hillsdale, NJ: Lawrence Erlbaum Associates.

Torgesen, J. K., & Mathes, P. G. (2000). *A basic guide to understanding, assessing, and teaching phonological awareness.* Austin, TX: Pro-Ed.

Torgesen, J. K., & Wagner, R. K. (1998). Alternative diagnostic approaches for specific developmental reading disabilities. *Learning Disabilities Research and Practice, 13,* 220-232.

Torgesen, J. K., Rashotte, C. A., & Wagner, R. K. (1994). Longitudinal studies of phonological processing and reading. *Journal of Learning Disabilities, 27,* 276–286.

Torgesen, J. K., Wagner, R. K., & Rashotte, C. A. (1997a). The prevention and remediation of severe reading disabilities: Keeping the end in mind. Scientific *Studies of Reading, 1,* 217-234.

Torgesen, J. K., Wagner, R. K., Rashotte, C. A., Burgess, S., & Hecht, S. (1997b). Contributions of phonological awareness and rapid automatic naming ability to the growth of word-reading skills in second- to fifth-grade children. *Scientific Studies of Reading, 1,* 161-185.

Torgesen, J.K., Wagner, R. K., & Rashotte, C.A. (1999). *Test of Word Reading Efficiency*.Austin, TX: PRO-ED Publishing, Inc.

Treiman, R., & Bourassa, D. (2000). Children's written and oral spelling. *Applied Psycholinguistics, 21,* 183-204.

Treiman, R., & Bourassa, D. (2000). The development of spelling skill. *Topics in Language Disorders, 20,* 1-18.

Treiman, R., & Hirsh-Pasek, K. (1983). Silent reading: Insights from second-generation deaf readers. *Cognitive Psychology, 15,* 39-65.

Trezek, J., & Malmgren, K. W. (2005). The Efficacy of Utilizing a Phonics Treatment Package with Middle School Deaf and Hard-of-Hearing Students. *Journal of Deaf Studies and Deaf Education, 10,* 256 - 271.

Vellutino, F. R. (1979). *Dyslexia: Theory and research.* Cambridge, MA: MIT Press.

Vellutino, F. R., Fletcher, J.M., Snowling, M. J., & Scanlon, D. M. (2004). Specific reading disability (dyslexia): What have we learned in the past four decades? *Journal of Child Psychology and Psychiatry,* 45, 2–40.

Vellutino, F. R., Scanlon, D. M., Sipay, E. R., Small, S. G., Pratt, A., Chen, R. S., & Denckla, M. B. (1996). Cognitive profiles of difficult to remediate and readily remediated poor readers: Early intervention as a vehicle for distinguishing between cognitive and experiential deficits as basic causes of specific reading disability. *Journal of Educational Psychology, 88,* 601-638.

Wagner, R. K., Torgesen, J. K., & Rashotte, C. A. (1994). Development of reading-related phonological processing abilities: New evidence of bidirectional causality from a latent variable longitudinal study. *Developmental Psychology, 30,* 73-87.

Wagner, R. K., Torgesen, J.K., & Rashotte, C.A. (1999*). Comprehensive Test of Phonological Processes*. Austin, TX: PRO-ED Publishing, Inc.

Wagner, R. K., Torgeson, J. K., Laughon, P. L., Sommons, K., & Rashotte, C. A. (1993). Development of young readers' phonological processing abilities. *Journal of Educational Psychology, 85, 83*-103.

Wagner, R., & Torgesen, J. (1987). The nature of phonological processing and its causal role in the acquisition of reading skills. *Psychological Bulletin, 101*, 192-212.

Wake, M., & Poulakis, Z. (2004). Slight and mild hearing loss in primary school children. *Journal of Paediatric Child Health, 40,* 11-13.

Wake, M., Hughes, E., Poulakis, Z., Collins, C., & Rickards, W. (2004). Outcomes of children with mild-profound congenital hearing impairment at 7-8 years: a population study. *Ear and Hearing, 25*, 1-8.

Walley, A. (1993). The role of vocabulary development in children's spoken word recognition and segmentation ability. *Developmental Review, 13,* 286-350.

Wandel, J. (1989). Use of Internal Speech by Hearing and Hearing-Impaired Students in Oral, Total Communication, and Cued Speech Programs. Unpublished Doctoral Dissertation, Columbia University, New York.

Wesseling, R. F., & Reitsma, P. (1998). Phonemically aware in a hop, skip, and a jump. In P. Reitsma & L. Verhoeven (Eds.) *Problems and interventions in literacy development* (pp. 81-94). Dordrecht: Kluwer.

Wiederholt, J. L., & Bryant, B. R. (2001). *Gray Oral ReadingTests, Fourth Edition*. Austin, TX: Pro-Ed.

Williams, K. T. (1997). *Expressive Vocabulary Test* Circle Pines, MN: American Guidance Service. Leonard, L. (1998). *Children with specific language impairment*. Cambridge, MA: MIT Press.

Wimmer, H. (1993). Characteristics of developmental dyslexia in a regular writing system. *Applied Psycholinguistics, 14,* 1-33.

Wolf, M. & Bowers, P. G. (2000). The question of naming-speed deficits in developmental reading disability: An introduction to the double-deficit hypothesis. *Journal of Learning Disabilities, 33,* 322-324.

Wolf, M. (1997). A provisional, integrative account of phonological naming speed deficits in dyslexia: Implications for diagnosis and intervention. In B. Blachman (Ed.). *Foundations of reading acquisition and dyslexia* (pp. 67-93). Mahwah, NJ: Lawrence Erlbaum Associates.

Wolf, M., & Bowers, P. G. (1999). The double-deficit hypothesis for the developmental dyslexia. *Journal of Educational Psychology, 91,* 124.

Wolf, M., Bowers, P. G., & Biddle, K. (2000). Naming-speed processes, timing, and reading: A conceptual review. *Journal of Learning Disabilities, 33,* 387-407.

Wolf, M., Goldberg O'Rourke, A., Gidney, C., Lovett, M., Cirino, P., & Morris, R. (2002). The second deficit: An investigation of the independence of phonological and naming-speed deficits in developmental dyslexia*. Reading and Writing, 15*, 43-72.

Woodcock, R. W. (1987). *Woodcock reading mastery test–Revised.* Circle Pines, MN:American Guidance Service.

Woodcock, R. W., & Johnson, M. B. (1989). *Woodcock– Johnson Psycho-Educational Battery-Revised.* Allen, TX: DLM Teaching Resources.

Woodcock, R.W. (1987).*Woodcock Reading Mastery Tests–Revised*, American Guidance Service, Circle Pines, MN.

Wren, S. (2005). The double-deficit hypothesis for decoding fluency. Personal manuscript.

Yopp, H. K. (1988). The validity and reliability of phonemic awareness tests. Reading *Research Quarterly, 23,* 159-177.

Yopp, H. K. (1992). Developing phonemic awareness in young children. *Reading Teacher, 45,* 696-703.

Yoshinaga-Itano, C. (1999). Benefits of early intervention for children with hearing loss. *Otolaryngology and Clinic of North America, 32,* 1089-1102.

Yoshinga-Itano, C., Sedey, A. L., & Coulter, D. (1998). Language of early- and later-identified children with hearing loss. *Pediatrics,* 102, 1161-1171.

Ziegler, J. C. (2006). Do differences in brain activation challenge universal theories of dyslexia? *Brain and Language, 98,* 341–343.

BIOGRAPHICAL SKETCH

Jungjun Park was born and raised in Seoul, Korea. Jungjun earned his Bachelor of Arts degree in 1990 and a Master of Arts degree in Linguistics in 1994 from the Seoul National University. After his doctoral coursework in Linguistics at the Seoul National University in 1997 followed by four years of teaching experience, Jungjun began his doctoral work at the Department of Communication Sciences and Disorders at the University of Florida in August 2001 with a concentration in reading disorder and child language development. In August 2007, Jungjun will join the faculty of the Department of Communication Sciences and Disorders at the Baylor University in Waco, Texas as an assistant professor.