



# Examining the Relationship between Letter Processing and Word Processing Skills in Deaf and Hearing Readers

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## Abstract

The present study aimed to examine the relationship between letter processing and word processing skills in deaf and hearing readers. The participants were 105 students (51 of them hearing, 54 of them deaf) who were evenly and randomly recruited from two levels of education (primary = 3rd-4th graders; middle = 6th-7th graders). The students were tested with four computerized paradigms assessing their processing of isolated letter/word pairs under perceptual and conceptual conditions. In both the computerized paradigms, we used the DMASTR software developed at Monash University and at the University of Arizona by K. I. Forster and J. C. Forster for stimulus presentation and data collection. All the experiments were conducted in a quiet room in the participants' schools by a trained experimenter. Findings from the present study show that deaf participants processed letter/word pairs more slowly than their hearing counterparts but with similar accuracy, and that a significant relationship existed between letter and word processing skills in both the deaf and hearing readers tested in this study.

## Keywords

Deaf, Reading, Letter Processing Skills, Word Processing Skills, Dual-Route Reading Theory.

Reading is defined as the process of extracting and constructing meaning from written text (Gough & Tunmer, 1986; Tunmer, 2008). In general, reading is hypothesized to involve decoding and comprehension. Decoding is defined as the process underlying word recognition, whereas comprehension describes the processes related to making sense of the words

encountered and recognized in a sentence (Hoover & Gough, 1990; Lewis & Doorlag, 1983; Ross, 1976). The ultimate goal of reading is comprehension. Although it is not a sufficient condition for the proper development of reading comprehension, adequate word processing skills are undoubtedly the basic requirement underlying reading proficiency (Hoover

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& Tunmer, 1993; Leach, Scarborough, & Rescorla, 2003; Scarborough, 2005; Kargin et al., 2011; Miller, Kargin, & Guldenoglu, 2012).

Various reading theories (Phonological Reading Theory: Frost, 1998, 2006; Frost, Katz, & Bentin, 1987; Dual-Route Cascaded Reading Theory: Jackson & Coltheart, 2001) have been proposed for the involvement of phonological and orthographic knowledge in the acquisition of reading. Phonological reading theory has been proposed as a single-route model, a procedure that converts graphemes into phonemes and thus decodes written words into phonological forms that the reader may be able to recognize as familiar spoken words (Frost, 2006; Frost et al., 1987). A second theory, the Dual-route reading theory, postulates that readers use two routes (a lexical and a nonlexical route) to recognize written words. According to this model, readers use a phonologically-based nonlexical route (grapheme-to-phoneme conversion) to recognize new and unknown words but tend to rely on a lexical route to recognize familiar written words. This lexical route mediates word recognition via detailed orthographic representations stored in a permanent orthographic lexicon (Jackson & Coltheart, 2001).

Both models assume that to recognize unfamiliar words, readers have to phonologically process their letter graphemes using a grapheme-to-phoneme conversion procedure. Thus, failure to develop phonemically-based word processing skills is likely to impede the efficient recognition and comprehension of many written words. This would reasonably explain why reading programs in schools often focus almost exclusively on the development of phonological skills (phonemic awareness, phonological decoding) to teach reading (Tunmer, 2008).

Although the processing of letters or letter clusters appears to be a basic step in the processing of written words along a lexical as well as a nonlexical word reading route, letter processing has received little attention in relation to reading acquisition. Research has emphasized that letter naming is not only a consistently significant predictor of phonemic awareness skills in early readers but also contributes to word reading and reading comprehension skills in later reading (Badian, 1995). This conclusion is also consistent with research investigating the relationship between letter naming and word reading skills (Biemiller, 1995; Wolf, 1991). In the present study, we examined the relationship between letter processing and word processing skills in deaf and hearing readers.

The reading skills of deaf individuals have been extensively researched over the last five decades. Studies

consistently show that on an average deaf readers finish high school with reading levels comparable to those of normally developing hearing third or fourth graders (Center for Assessment and Demographic Studies, 1993; Chamberlain & Mayberry, 2000; Conrad, 1979; Holt, 1993; Marschark & Harris, 1996). Researchers who have studied factors associated with reading failure in deaf readers tend to concentrate on their phonological and word processing skills to explain their lack of reading efficiency (Alegria, Leybaert, Charlier, & Hage, 1992; Beech & Harris, 1997; Dyer, MacSweeney, Szczerbinski, Green, & Campbell, 2003; Harris & Beech, 1995; Kargin et al., 2011; Leybaert, 2000; Miller, 2001, 2002a, 2004a, 2004b, 2004c, 2005a, 2005b, 2006a, 2006b, 2010; Miller, Kargin, Guldenoglu, Hauser et al., 2012; Nielsen & Luetke-Stahlman, 2002; Padden & Hanson, 2000; Perfetti & Sandak, 2000; Sterne & Goswami, 2000; Transler, Gombert, & Leybaert, 2001; Waters & Doehring, 1990; Wauters, Van Bon, & Tellings, 2006).

Several explanations have been proposed in the literature for why deaf readers have reading skill difficulties. Most studies investigating the reading skills of deaf readers have suggested that deaf readers are seriously limited in the phonological skills required to process the written words (Alegria et al., 1992; Beech & Harris, 1997; Campbell & Wright, 1988; Dyer et al., 2003; Guardino, Selznick, & Syverud, 2009; Hanson & Fowler, 1987; Hanson & McGarr, 1989; Harris & Beech, 1995; Miller, 1997, 2010; Nielsen & Luetke-Stahlman, 2002; Padden & Hanson, 2000; Perfetti & Sandak, 2000; Share, 1995; Sterne & Goswami, 2000; Transler et al., 2001; Transler & Reitsma, 2005). In contrast, a long line of research examining the word processing skills of deaf readers in a straightforward manner suggests that prelingually deaf readers at different levels of education—their impoverished phonological skills notwithstanding—process written words with comparable efficiency to a hearing control group (Hanson & Fowler, 1987; Hanson & McGarr, 1989; Harris & Beech, 1998; Izzo, 2002; Kargin et al., 2011; Miller, 1997, 2000, 2001, 2002a, 2002b, 2004a, 2004b, 2005a, 2005b, 2005c, 2006a, 2006b; Waters & Doehring, 1990; Wauters et al., 2006).

Regrettably, strikingly few studies have focused on deaf readers' letter processing skills and their relationship to their word processing skills. In order to understand how deafness affects letter and word processing skills, this study tested and examined the relationship between the letter processing and word processing skills of deaf and hearing participants of different grade levels.

### Aim of the Study

The present study was designed to examine the relationship between the letter processing and word processing skills of deaf and hearing participants of different grade levels. With this aim in mind, the present study was designed to test the following research hypothesis:

1a. Overall, readers will be faster and more accurate in the perceptual than the conceptual processing of letters.

1b. Speed of letter processing and letter processing accuracy will be similar for deaf and hearing readers under the perceptual processing condition. However, under the conceptual processing condition, hearing participants will process letters faster and more accurately than deaf participants.

1c. Overall, both the speed of letter processing and letter processing accuracy will increase with ascending levels of education.

2a. Overall, readers will be faster and more accurate in the perceptual than the conceptual processing of words.

2b. Speed of word processing and word processing accuracy will be similar for deaf and hearing readers under the perceptual processing condition. However, under the conceptual processing condition, hearing participants will process written words faster and more accurately than deaf participants.

2c. Overall, both speed of word processing and word processing accuracy will increase with ascending levels of education.

3a. There will be a statistically significant correlation between the letter processing and word processing skills of deaf and hearing readers.

3b. The relationship between letter processing and word processing skills will decrease with ascending levels of education.

### Method

#### Participants

105 students (51 hearing and 54 deaf) evenly and randomly recruited from two levels of education (3<sup>rd</sup>-4<sup>th</sup> graders and 6<sup>th</sup>-7<sup>th</sup> graders) participated in this study. All the participants in this study came from low and average socioeconomic backgrounds. Only students with no record of particular learning or emotional disorders were included in this study.

### Stimuli

In order to examine the relationship between readers' letter processing and word processing skills, we used four research paradigms, two of which asked participants to make rapid same/different decisions under the perceptual and conceptual conditions for letters presented on a computer monitor; the other two asking participants to make rapid same/different decisions under the perceptual and conceptual conditions for written words presented on a computer monitor.

All paradigms were originally developed within a large-scale international reading project executed in four different countries (Israel, Turkey, Germany, and the USA) whose goal was to bring about a better understanding of the factors underlying reading comprehension failure in individuals with different orthographic backgrounds.

### Results

In order to test our research questions, we analyzed the data in three steps: (1) We compared readers' letter processing speed and processing accuracy with respect to their hearing status (HS) and level of education (LoE), (2) we compared their word processing speed and processing accuracy with respect to their hearing status and level of education, (3) we correlated their letter processing and word processing skills.

#### Letter Processing Skills

**Reaction Time:** The main effect of Level of Processing (LoP) was highly significant statistically, ( $F(1.101) = 102.72, p < .001, \eta^2 = .50$ ), suggesting that participants processed letter stimulus pairs significantly faster in the perceptual condition than in the conceptual condition. The main effect of HS was statistically significant, ( $F(1.101) = 30.31, p < .001, \eta^2 = .23$ ), suggesting that overall, hearing readers processed letters faster than deaf readers. The main effect of LoE was statistically significant, ( $F(1.101) = 16.11, p < .001, \eta^2 = .13$ ), suggesting that, overall, participants became faster with ascending levels of education.

The interaction between LoP and HS was not statistically significant, ( $F(1.101) = 2.55, p > .05, \eta^2 = .02$ ) indicating that the difference in speed of processing under the perceptual and conceptual conditions was similar for hearing and deaf participants. The interaction between LoP and LoE was likewise not statistically significant, ( $F(1.101) = .92, p > .05, \eta^2 = .009$ ), indicating that the differences

in processing speed under the perceptual and conceptual conditions were similar for all levels of education. The triple-interaction between HS, LoP, and LoE was statistically significant, suggesting that the difference between processing speeds under the perceptual and conceptual conditions in deaf and hearing readers differed in the low- and mid-levels of education ( $F(1.101) = 3.85, p = .05, \eta^2 = .03$ ).

In order to clarify possible speed-of-processing differences between deaf and hearing participants under the perceptual and conceptual conditions, we conducted two one-way analyses, one comparing the participants' performance under perceptual conditions and another under conceptual conditions. In both these analyses, the between-group effect was statistically significant, suggesting that hearing participants process experimental stimuli significantly faster ( $F(1.104) = 38.32, p < .01, F(1.104) = 14.59, p < .01$ ).

**Error Rates:** The main effect of LoP was statistically significant ( $F(1.101) = 15.38, p < .001, \eta^2 = .13$ ), suggesting that participants processed letter pairs more accurately in the perceptual condition than in the conceptual condition. The main effect of HS was not statistically significant ( $F(1.101) = .13, p > .05, \eta^2 = .001$ ), suggesting that overall, deaf and hearing readers processed letters with similar accuracy. The main effect of LoE was statistically significant, ( $F(1.101) = 4.31, p < .05, \eta^2 = .04$ ) suggesting that overall, participants from mid-levels of education and up processed letter pairs more accurately than their counterparts from lower levels of education.

The interaction between LoP and HS was not statistically significant ( $F(1.101) = .13, p > .05, \eta^2 = .02$ ), indicating that the difference in processing accuracy under the perceptual and conceptual conditions was similar for hearing and deaf participants. The interaction between LoP and LoE was statistically significant ( $F(1.101) = 5.49, p < .05, \eta^2 = .01$ ), suggesting that the difference in processing accuracy under perceptual and conceptual condition was not similar according to tested levels of education.

In order to clarify possible processing accuracy differences between deaf and hearing participants under the perceptual and conceptual conditions, we conducted two one-way analyses, one comparing the participants' accuracy under perceptual conditions and another under conceptual conditions. In both these analyses, the between-group effect was not statistically significant, suggesting that hearing and deaf participants process experimental stimuli with similar accuracy ( $F(1.104) = .01, p > .05, F(1.104) = .47, p > .05$ ).

## Word Processing Skills

**Reaction Time:** The main effect of Level of Processing (LoP) was highly significant statistically ( $F(1.101) = 43.86, p < .01, \eta^2 = .30$ ), suggesting that participants processed word stimulus pairs significantly faster in the perceptual condition than in the conceptual condition. The main effect of HS was statistically significant ( $F(1.101) = 76.10, p < .001, \eta^2 = .43$ ), suggesting that overall, hearing readers processed written words faster than deaf readers. The main effect of LoE was statistically significant ( $F(1.101) = 46.59, p < .001, \eta^2 = .31$ ), suggesting that, overall, participants became faster with ascending levels of education.

The interaction between LoP and HS was not statistically significant ( $F(1.101) = .43, p > .05, \eta^2 = .004$ ) indicating that the difference in speed of processing under the perceptual and conceptual conditions was similar for hearing and deaf participants. The interaction between LoP and LoE was not significant ( $F(1.101) = 1.48, p > .05, \eta^2 = .01$ ), indicating that the difference in speed of processing under perceptual and conceptual conditions was similar at all levels of education.

In order to clarify possible speed-of-processing differences between deaf and hearing participants under the perceptual and conceptual conditions, we conducted two one-way analyses, one comparing the participants' performance under perceptual conditions and another under conceptual conditions. In both these analyses, the between-group effect was statistically significant, suggesting that hearing participants processed experimental stimuli significantly faster ( $F(1.104) = 62.00, p < .01, F(1.104) = 40.71, p < .01$ ).

**Error Rates:** The main effect of LoP was statistically significant ( $F(1.101) = 15.38, p < .001, \eta^2 = .13$ ), suggesting that participants processed word stimulus pairs more accurately in the perceptual condition than in the conceptual condition. The main effect of HS was not statistically significant ( $F(1.101) = .45, p > .05, \eta^2 = .004$ ), suggesting that overall, deaf and hearing readers processed written words with similar accuracy. The main effect of LoE was statistically significant, ( $F(1.101) = 5.95, p < .05, \eta^2 = .05$ ) suggesting that, overall, error rates varied across the tested levels of education.

The interaction between LoP and HS was not statistically significant ( $F(1.101) = 1.78, p > .05, \eta^2 = .01$ ), indicating that the difference in processing accuracy under the perceptual and conceptual conditions was similar for hearing and deaf

participants. The interaction between LoP and LoE was statistically significant, ( $F(1.101) = 6.57$ ,  $p < .05$ ,  $\eta^2 = .06$ ), suggesting that the difference in processing accuracy under perceptual and conceptual conditions was not similar according to tested levels of education.

The interaction between HS and LoE was statistically significant ( $F(1.101) = 5.10$ ,  $p < .05$ ,  $\eta^2 = .04$ ), indicating that the differences between the two participant groups were not similar for all levels of education.

In order to clarify the possible processing accuracy differences between deaf and hearing participants under the perceptual and conceptual conditions, we conducted two one-way analyses, one comparing the participants' accuracy under the perceptual condition and another under the conceptual condition. In both these analyses, the between-group effect was not statistically significant, suggesting that hearing and deaf participants processed experimental stimuli with similar accuracy ( $F(1.104) = .01$ ,  $p > .05$ ,  $F(1.104) = .94$ ,  $p > .05$ ).

### The Relationship between Letter Processing and Word Processing Skills

Correlation analyses revealed a statistically significant relationship between the participants' letter processing and word processing speed and accuracy (speed- deaf,  $r = .59$ ,  $p < .01$ ; hearing,  $r = .63$ ,  $p < .01$ ), (accuracy- deaf,  $r = .73$ ,  $p < .01$ ; hearing,  $r = .51$ ,  $p < .01$ ), suggesting that better letter processors were also more efficient in processing of written words and vice versa.

To clarify the separates between letter processing and word processing skills in deaf and hearing readers at all educational levels, we conducted a series of correlation analyses. Evidence from these analyses suggested a significant relationship between the letter processing and word processing skills of hearing readers at all educational levels (speed- low,  $r = .51$ ,  $p < .01$ ; middle,  $r = .48$ ,  $p < .01$ ; accuracy- low,  $r = .57$ ,  $p < .01$ ; middle,  $r = .46$ ,  $p < .01$ ). Results further indicated that although there was a significant relationship between the letter processing and word processing speeds of deaf readers at all educational levels (speed- low,  $r = .56$ ,  $p < .01$ ; middle,  $r = .66$ ,  $p < .01$ ), no such relationship was found for the letter processing and word-processing accuracy of deaf readers at any educational level (accuracy- low,  $r = .81$ ,  $p < .01$ ; middle,  $r = .19$ ,  $p > .05$ ).

### Discussion

The present study was designed to examine the relationship between the letter processing and word processing skills of deaf and hearing participants of different grade levels. For this purpose, 105 participants (51 of them hearing, 54 of them deaf) evenly and randomly recruited from two levels of education (low = 3<sup>rd</sup>-4<sup>th</sup> graders; middle = 6<sup>th</sup>-7<sup>th</sup> graders) were included in this study. In this study, we discussed the participants' letter and word processing skills under three aspects: (1) letter processing skills, (2) word processing skills, and (3) the relationship between these.

### Letter Processing Skills

The first hypothesis tested by this study was that participants will be faster and more accurate in the perceptual than the conceptual letter processing condition. This hypothesis was fully supported in this study. Our basic assumption was that to make a same/different decision in the perceptual condition, it is sufficient to process only the visual properties of the letter stimuli. In contrast, to make a decision under conceptual conditions, the reader must also access some form of conceptual knowledge (Miller, 2005c; Vaknin & Miller, 2011). The highly significant levels of processing effects related to processing speed and processing accuracy indeed indicate that processing same/different letters was more demanding in the conceptual condition than in the perceptual condition.

A second hypothesis tested was that both deaf and hearing readers would have similar processing speeds and accuracy in the perceptual condition, but hearing readers would be faster and more accurate in the conceptual processing condition than deaf readers. The results of this study only partly supported this hypothesis. This is because permanent hearing loss from early infancy likely undermines the development of conceptual knowledge they could exploit to identify identical letters in the conceptual condition. However, contrary to predictions, they were found to process same/different letters more slowly than their hearing counterparts even under perceptual conditions, which were hypothesized to not require the type of knowledge hampered by prelingual deafness. The need to retrieve some form of knowledge in the conceptual condition does not imply the absence of perceptual processing; the participants still had to process the letter stimuli perceptually as a first step. If this is true, the processing differences

found between the two groups at the conceptual level may reflect, at least partly, differences originating from the perceptual processing of letter stimuli. One reasonable explanation may be that, contrary to predictions, identifying same/different letters in the perceptual condition was not a purely perceptual process. In other words, participants processed letter stimuli using more than an analysis of their visual properties because letters were familiar linguistic materials for them and automatically triggered processing beyond a perceptual level. Secondly, reading experience leads to an enhancement of readers' perceptual processing skills. If this is so, deaf readers may be slower perceptual processors simply because they read less than their hearing peers.

Finally, we hypothesized that the participants' letter processing skills would become faster and more accurate with at higher levels of education. This hypothesis was supported in this study. This suggests that increased reading experience optimizes perceptual as well as conceptual letter processing.

### **Word Processing Skills**

Firstly, we assumed that participants would be faster and more accurate in their perceptual than conceptual processing of words. This hypothesis was also fully supported in this study. It was assumed that in making a same/different decision in the perceptual condition, it is sufficient to process the visual properties of the word stimuli. On the other hand, to make such a decision in the conceptual condition, readers must access some form of knowledge (phonological knowledge, orthographic knowledge, etc.) in order to bridge the visual incongruity between the two words in identical word pairs (Kargin et al., 2011; Miller, 2004b, 2004c, 2005b, 2006a, 2006b). The highly significant level of processing effects found for processing speed and processing accuracy for both deaf and hearing readers indeed indicates that processing same and different word in the perceptual condition was less demanding than processing same and different words in the conceptual condition.

The second hypothesis was that deaf readers would be slower and less accurate than hearing readers in processing words under conceptual conditions but not under perceptual conditions. This hypothesis was only partly supported in the study. In line with our hypotheses, deaf participants indeed processed written words with accuracy comparable to that of

hearing participants in the perceptual condition. However, contrary to predictions, they were found to process same and different words more slowly than their hearing counterparts, even under conditions hypothesized not to require the type of knowledge hampered by prelingual deafness. One reasonable explanation may be that deaf readers may be slower perceptual processors simply because they read less than their hearing peers, a weakness that—in the present study - was reflected in their perceptual processing skills. In addition, deaf participants were also slower in the conceptual condition; prelingual deafness may be responsible for reduced efficiency in accessing some forms of conceptual knowledge for proper task performance. Lastly, in both conditions the participants had to initially process word stimuli perceptually in order to identify sameness or difference; the finding of such uniform differences in both processing conditions actually suggests that the deficits of deaf participants were primarily rooted in their reduced speed in perceptual processing.

Finally, we hypothesized that the participants' word processing skills would become faster and more accurate as their levels of education increased. This hypothesis was fully supported in this study. This suggests that increased reading experience optimizes perceptual as well as conceptual word processing.

### **The Relationship between Letter Processing and Word Processing Skills**

First, we assumed a statistically significant correlation between letter and word processing skills in deaf and hearing readers. This hypothesis was fully supported in this study. Results showed that there was a statistically significant relationship between the participants' letter processing and word processing speed and accuracy. According to both the phonological and dual route reading models, processing of letters or letter clusters is a basic step in processing written words, in both a lexical and nonlexical word-reading route. If this is true, then during the word processing task, participants in this study may have initially processed the letters/letter clusters of the presented words.

Second, it was hypothesized that the relationship between the letter and word processing skills in deaf and hearing readers will decrease with ascending levels of education. This hypothesis was only supported in relation to participants' processing accuracy. The basic assumption behind

this hypothesis was that according to the dual route reading model (Jackson & Coltheart, 2001), the lexical and the nonlexical reading routes operate in parallel or simultaneously. However, it is hypothesized that in the majority of instances, proficient readers recognize written words along

the faster, orthographic-knowledge-based reading route. Although significant relationships between the letter and word processing skills of deaf and hearing readers were found, the pattern of these relationships were not consistent with the predictions made in this hypothesis.

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