The Nature and Efficiency of the Word Reading Strategies of Orally Raised Deaf Students

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The main objective of this study was to unveil similarities and differences in the word reading strategies of orally raised individuals with prelingual deafness and hearing individuals. Relevant data were gathered by a computerized research paradigm asking participants to make rapid same/different judgments for words. There were three distinct study conditions: (a) a visual condition manipulating the visual–perceptual properties of the target word pairs, (b) a phonological condition manipulating their phonological properties, and (c) a control condition. Participants were 31 high school and postgraduate students with prelingual deafness and 59 hearing students (the control group). Analysis of response latencies and accuracy in the three study conditions suggests that the word reading strategies the groups relied upon to process the stimulus materials were of the same nature. Evidence further suggests that prelingual deafness does not undermine the efficiency with which readers use these strategies. To gain a broader understanding of the obtained evidence, participants’ performance in the word processing experiment was correlated with their phonemic awareness—the hypothesized hallmark of proficient word reading—and their reading comprehension skills. Findings are discussed with reference to a reading theory that assigns phonology a central role in proficient word reading.

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Theories associating proficient reading skills with proper phonological abilities have dominated the field of reading instruction and the explanations of reading failure for at least three decades (Ehri, Nunes, Stahl, & Willows, 2001; Hulme, Snowling, Caravolas, & Carroll, 2005; Report of the National Reading Panel, 2000; Share, 1995; Shaywitz & Shaywitz, 2005; Snow, Burns, & Griffin, 1998; Troia, 2004; Vellutino, Fletcher, Snowling, & Scanlon, 2004). According to this approach, efficient access to the meaning of written words as the basis for reading comprehension is either directly or indirectly mediated by permanent phonological entries in the reader’s phonological lexicon. Thus, readers who fail to develop adequate phonological knowledge, as well as phonemic awareness (PA) that allows the conscious monitoring of words’ phonological properties, are at risk of developing reading disorders (Frost, 1998; Ramus, Pidgeon, & Frith, 2003; Share, 1995).

A long line of research has shown that the majority of individuals who are prelingually deaf remain poor readers (Gallaudet Research Institute, 2005; Holt, 1993; Pintner & Patterson, 1916; Traxler, 2000; Wolk & Allen, 1984; see also Monreal & Hernandez, 2005; Wauters, Van Bon, & Telling, 2006). Going by a phonological reading theory, this finding makes intuitive sense, given that permanent lack of auditory stimulation drastically interferes with the internalization of fully detailed representations of spoken words, including the development of awareness of their phonological structure (Charlier & Leybaert, 2000; Dyer, MacSweeney, Szczersinski, & Campbell, 2003; Hanson & Fowler, 1987; Hanson & McGarr, 1989; Miller, 1997, 2006b, 2007a; Sutcliffe, Dowker, & Campbell, 1999; Transfer, Leybaert, & Gombert, 1999). In other words, what prevents individuals with prelingual deafness from becoming fully literate is a failure to efficiently process written words phonologically (e.g., Nielsen & Luetke-Stahlman, 2002; Padden & Hanson, 2000, Perfetti & Sandak, 2000).

The conclusion that phonological coding deficits prevent individuals with prelingual deafness from becoming proficient readers also makes sense in view of...
findings, suggesting that those with hearing norm approaching reading comprehension skills rely on a phonological memory code for the temporary retention of written words (e.g., Conrad, 1979; Hanson, 1982; Hanson, Liberman, & Shankweiler, 1984; Hanson & Lichtenstein, 1990; Harris & Moreno, 2006; Krakow & Hanson, 1985; for a review, see Perfetti & Sandak, 2000). This phonological coding deficit hypothesis is also appealing in light of evidence that posits that intensive training in sensitivity to the phonological structure of words prior to reading acquisition benefits such individuals as they learn to read later on (e.g., Colin, Magnan, Ecalle, & Leybaert, 2007). This hypothesis is further strengthened by a substantial body of research, suggesting that for such individuals PA is positively correlated with reading comprehension (e.g., Campbell & Wright, 1988; Charlier & Leybaert, 2000; Hanson & McGarr, 1989; Stern & Goswami, 2000; Trezek & Malmgren, 2005; Trezek & Wang, 2006).

Although the role of PA in reading is still under dispute, one claim argues that it primarily enhances the processing of text at the lexical level (Frost, 1998). Such enhancement is said to manifest in accelerated grapheme-to-phoneme conversion sustaining the identification of written words based upon their phonological form (Jackson & Coltheart, 2001). Phonological decoding skills, in turn, have also been hypothesized to underlie the acquisition of permanent word-specific graphemic knowledge fundamental to fluent reading (Share, 1995, 2004). If these assumptions are correct, individuals with prelingual deafness—owing to their impoverished awareness of the phonological building blocks of words—should manifest notable deficits related to the processing of written words at the lexical level, deficits that are carried over to higher order processes underlying the elaboration of sentence meaning. Indeed, Kelly and Barac-Cikoja (2007), discussing possible factors underlying the reading comprehension problems of deaf readers, argue that “… other problems evidenced by deaf readers are likely to be secondary to, and possibly even caused by, their problems at the word level.”

Interestingly, the majority of studies examining the relationship between the PA and reading comprehension of individuals with prelingual deafness have failed to reveal significant correlations (e.g., Hanson & Fowler, 1987; Hanson & McGarr, 1989; Izzo, 2002; Kyle & Harris, 2006; Leybaert & Alegria, 1993; Miller, 1997). Moreover, contrary to the assumption that their impoverished phonological skills undermines their word reading skills, members of this population have been found to process written words with hearing-comparable efficiency (Miller, 2001, 2002, 2004a, 2004b, 2005b, 2005c, 2006a, 2006b; Wauters et al., 2006). This has been observed even for individuals from a native signing background, who proved to be largely insensitive to phonological manipulations applied to the processed material (Miller, 2002). Such evidence suggests that prelingual deafness may not necessarily cause individuals to fail in efficiently processing written words at the lexical level. This conclusion is corroborated by findings from a study comparing the word processing skills of readers with prelingual deafness with those of chronological age-matched hearing readers with diagnosed phonological dyslexia and a control group of normally developing hearing readers (Miller, 2005c, 2007b). Both the deaf and the dyslectic groups manifested drastically impoverished PA and phonological decoding skills in comparison to the control group, with such deficits being markedly more emphasized for the former. However, contrary to expectations, the word processing skills of the deaf reader group proved surprisingly unimpaired (norm comparable), whereas readers with dyslexia manifested notable word processing deficits.

This article examines the efficiency of the word reading strategies used by adult individuals with prelingual deafness as well as hearing individuals for the processing of isolated (decontextualized) written words in an attempt to shed further light upon the nature of these strategies. To prevent possible bias from sign language, only deaf participants educated according to oral philosophy were included. The study was designed to answer two specific research questions: (a) Are adult readers with prelingual deafness less efficient than hearing counterparts in the processing of written words at the lexical level? and (b) Do these two groups rely on word reading strategies that reference different information for the lexical processing of the stimulus material, that is, are their reading strategies different in nature? A more general question...
that this study tried to clarify is whether the participant groups’ PA—as predicted by current reading theories (Report of the National Reading Panel, 2000)—is indicative of the efficiency of their word reading strategies and whether their word reading strategies are related to their comprehension of written sentences.

Traditionally, “naming” or “lexical decision” paradigms, sometimes in conjunction with priming, have been the predominant methods for studying how readers process written words under decontextualized conditions. Findings gathered from such experiments have brought about a gradually growing understanding of how regular readers access the meaning of written words (for a review, see Vellutino et al., 2004). However, reliance on these paradigms is problematic if the aim is to understand the word reading skills of individuals who are prelingually deaf. For one thing, both paradigms are based upon the axiom that the frequency of the vocabulary used for stimulation is similar for all tested participants. This presumption, however, is likely to prove wrong for individuals with prelingual deafness who, due to a permanent lack of auditory stimulation, fail to acquire spoken language spontaneously and for whom reading experience—both qualitative and quantitative—is likely to substantially deviate from that of hearing readers. In addition, producing a voiced response, as required by the naming paradigm, may not be as automated for such individuals as it is for their hearing counterparts. As a result, their response—both quantitatively (response onset) and qualitatively (accuracy)—is likely to reflect an additional effort that becomes confounded with their actual ability to read the words they are called to name. Moreover, and in a more general sense, the inclusion of nonwords as stimuli, as well as the explicit request to name stimulus words aloud, have the potential to trigger reliance on word reading strategies that individuals may not use when reading under normal circumstances.

In light of the above concerns, this article used a paradigm that has participants make rapid same/different judgments for single word pairs presented on a computer display. Different versions of this basic paradigm have proven fruitful in revealing subtle processing differences related to the categorization of numbers, letters, letter strings, and pictures by both regular and deviant readers (Miller, 2004a, 2004b, 2005b, 2006a; Posner & Mitchell, 1967). It also has been shown to be highly sensitive to processing differences related to the lexical status of the processed materials (Miller, 2005a). The paradigm does not request a voiced response, and it allows rigorous control over word frequency, that is, it does not create problematic conditions for individuals who are prelingually deaf. Finally, the paradigm has no intrinsic features suspected to direct participants toward reliance on a particular word processing strategy.

The paradigm includes three distinct study conditions. In each one, the words in a word pair used for stimulation are similar on a particular processing dimension but dissimilar on all other relevant processing dimensions. In the first condition (the visual condition), the manipulated dimension creates visual (perceptual) similarity versus visual dissimilarity between two nonidentical words. The aim of this manipulation is to reveal whether participant groups consider the visual properties of the words when determining whether they are identical. It was assumed that, due to their predominantly visual orientation, participants with prelingual deafness would be particularly sensitive to similarities in the visual properties of written words. It was therefore predicted that they would find it harder to categorize two nonidentical, yet visually similar words as different than to categorize two nonidentical, visually distinct words as different. Accordingly, they were expected to manifest significantly longer decision latencies and markedly greater rates of erroneous responses for the visually similar nonidentical pairs. No such negative interference was forecasted for hearing participants, who were assumed to process the identity of written words consistently by means of a phonological strategy that should not prove sensitive to visual similarities in the stimulus word pairs.

The second condition in the paradigm (the phonological condition) manipulates the dimension of phonological similarity between the two words in nonidentical word pairs (two rhyming as opposed to two nonrhyming words). The aim of this manipulation is to reveal whether participant groups consider the phonetic properties of the words when determining
between-word identity. It was predicted that categorizing two nonidentical, yet phonetically similar words as different would be harder for hearing participants than categorizing two nonidentical, phonetically distinct words as different. It was therefore anticipated that they would manifest significantly delayed decision latencies and markedly increased rates of erroneous responses for the former. Phonological manipulations, however, were not forecasted to bias task performance for participants with prelingual deafness. More specifically, given their visual orientation, on the one hand, and their insufficiently developed phonological skills (PA), on the other hand, such individuals were assumed to evade processing subtleties related to the phonetic dimension of written words, making them insensitive to the introduced phonological manipulations.

In the third (control) condition, nonidentical word pairs had signs that were either similar or dissimilar in formation. It was hypothesized that neither the hearing nor the orally raised participants would prove sensitive to this type of manipulation, given that sign language was not a relevant psycholinguistic reality for either group. In other words, in the control condition—unlike in the two experimental conditions—response latencies and response error rates for the two nonidentical word categories were anticipated to be similar. Such uniformity was predicted for both participant groups.

In general, based on the postulate that rapid phonological decoding is at the core of proficient word reading (e.g., Frost, 1998; Ramus et al., 2003), it was forecasted that the word processing strategy of participants with deafness would be less effective, given its hypothesized nonphonological nature. Specifically, it was predicted that, in comparison to hearing readers, such individuals would judge identical word pairs slower and less accurately. In line with the same strong phonological theory, it was also anticipated that participants with increased sensitivity to phonological manipulations (phonological condition) would be found to manifest more PA and vice versa. Finally, a significant positive relationship was expected between the participants’ word processing efficiency, their sensitivity to phonological manipulations, and their reading comprehension.

Method

Participants

The experiment was conducted with 31 individuals with prelingual deafness and a control group of 59 hearing individuals. Among those who were deaf, 16 were 11th- or 12th-grade students, and the remainder was comprised of individuals studying at one of the academic institutions in Israel. The hearing group was comprised of twenty-nine 11th and 12th graders and 30 University of Haifa students. For additional demographic details about both groups of participants, see Table 1.

All the participants used Hebrew as their first spoken language at home and at school. They all had intact or corrected-to-normal vision. Their intelligence was within a range considered as normal. For participants at the high school level, this information was obtained from school files, whereas at the postgraduate level, normal intelligence was assumed. None of the participants was diagnosed as having a specific learning disability.

All participants with deafness were selected according to the following criteria: (a) their hearing loss measured at the frequencies 0.5, 1.0, and 2.0 kHz was 85 dBHL or higher in the better ear with regard to American National Standards Institute (1989), (b) their deafness was diagnosed prior to age 2 years (prelingual hearing loss), (c) both their parents had intact hearing, (d) the source of their hearing impairment was not hereditary, that is, there were no other individuals with prelingual hearing losses in their family or among their close and distant relatives, (e) they came from families advocating an oral philosophy, that is, communication at home was principally oral, the use of hearing aids in and out of home was

<table>
<thead>
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<th>Educational integration</th>
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<tr>
<td>Male</td>
<td>Female</td>
</tr>
<tr>
<td>Deaf</td>
<td>15</td>
</tr>
<tr>
<td>Hearing</td>
<td>25</td>
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Note. For participants from an academic level, information regarding educational integration refers to the period of their formal schooling.
considered imperative, and speech rehabilitation was an integral part of the participant’s weekly educational program, (f) they attended educational settings where spoken language was used as the language of instruction, and (g) their competence in Israeli Sign Language (ISL)1 or Signed Hebrew2—if at all—was very limited.

The individuals participating in this study also participated in several experiments conducted during the same experimental session. One of these experiments assessed their PA based upon the identification of picture dyads with specific joint phonetic properties (e.g., same first phoneme) among a series of four pictures (for a detailed description of the PA test, see Miller, 1997, 2008). A second experiment examined their comprehension of 36 written sentences varying in syntactic complexity and semantic plausibility (for a detailed description of the sentence comprehension test, see Miller, 2005b, 2008). An examination of the data gathered in the above mentioned areas showed that individuals with deafness who participated in this article manifested drastically impoverished PA, both relative to the test scale, 6.97 (3.06) on a 12-point scale, and in comparison to the PA of the hearing control group, 10.64 (1.45); $F(1, 88) = 56.05, p < .001$. The same was true with regard to their comprehension of isolated written sentences, which was significantly below the maximum score of the test (correct comprehension of 31.68 [5.05] out of 36 sentences), as well as the average test score of the control group, 35.44 (1.01); $F(1, 88) = 30.76, p < .001$.

Stimuli and Design

The paradigm used in the present experiment, as mentioned earlier, asked participants to decide as quickly as possible whether two Hebrew words presented simultaneously on a computer monitor were the same or not and to indicate their decision by pressing a “Yes (identical)” or “No (nonidentical)” button accordingly. The word pairs were presented to the participants in three blocks. Two blocks represented the two experimental conditions: the visual condition, designed to reveal whether the participants referenced visual information to determine the identity of word pairs, and the phonological condition, examining whether participants accessed the phonological properties of words to determine their identity. The third block of word pairs was the control condition.

A total of 240 word pairs—80 pairs for each condition—was used as test stimuli. All the words used to build the pairs were basic monosyllabic or bisyllabic Hebrew words composed of three- to five-letter graphemes. They were presented in unpointed Hebrew.3 These words were rated by two speech therapists and two teachers of the deaf to be within the active vocabulary of hearing-impaired third graders and, hence, were well below the grade level of students included in this article. In addition to the test stimuli, a separate set of word pairs were prepared for explanation and practice.

In each condition, half of the word pairs (40) were made up of the same word twice (identical word pairs) and their presentation on the computer display required an “identical” response (pressing a key marked “Yes [identical]”). The other half of the word pairs (40) was made up of two different words (nonidentical word pairs), and their display on the computer monitor called for a “nonidentical” response (pressing a key marked “No [nonidentical]”). Among the 40 nonidentical word pairs, 20 were prepared from two words that were distinct on all relevant processing dimensions (visual, orthographic, phonological, formational, and semantic/thematic). The remaining 20 nonidentical pairs were built from two words similar on a particular processing dimension (visual, phonological, or formational [control]) but differed as much as possible in all other regards. It was anticipated that quantitative (response time [RT]) and qualitative (response accuracy) processing differences between the two nonidentical word pair pools would reflect the nature of the participants’ word processing strategy.

Visual Condition

The procedure underlying the preparation of the word pairs used for stimulation in the visual condition included three basic steps. In a first step, 20 word pairs were prepared, each built from two nonidentical, yet visually (not orthographically) similar words. Visual similarity was created by matching words composed of nonidentical letters which, in combination, exhibited a
very similar visual overall appearance (see, e.g., Figure 1). It was ascertained that such words were notably distinct on all other processing dimensions (orthographic, phonological, formational, and semantic/thematic). The syllabic length of words comprised in a pair was always the same although—due to particularities of the Hebrew orthography—there was occasionally some variation regarding the number of their letters.

In a second step, an additional pool of 20 nonidentical word pairs was created by recombining the words used for preparing the first pool into 20 different word pairs. In the course of this reshuffling, words were assigned to each other in a way that—unlike in the first pool—did not create noticeable visual between-word similarity (BWS). It was further ascertained that they were clearly distinct with regard to other relevant processing dimensions, including their semantic and thematic relationship (see, e.g., Figure 1).

In a third step, the 40 nonidentical word pairs created in the previous two steps were supplemented with 40 word pairs each built from the same word twice (identical word pairs). In order to prevent participants from determining the identity of each pair on a purely perceptual basis, without the need to process the words as linguistic material, one of the words in an identical pair was always presented in print (שנה = sun) and the other in cursive script (שנה = sun). Consequently, the two words in identical word pairs ceased to be perceptually the same, obliging participants to access conventionalized linguistic knowledge to judge their identity (see, e.g., Figure 1).

It should be stressed that the (visually similar) nonidentical word pairs prepared in Step 1 and the (visually dissimilar) word pairs prepared in Step 2 were built from exactly the same words. Thus, word frequency became irrelevant for the explanation of quantitative and qualitative processing differences between the two word pair categories. As such differences were hypothesized to reflect the nature of the information (word processing strategy) participants relied on to determine between-word identity, the neutralization of word frequency as a potential contributor to such differences strengthens the validity of the research paradigm, as well as of the findings revealed by it.

Phonological Condition

As in the visual condition, the preparation of the stimuli for the phonological condition comprised three steps. The principles underlying these steps were

<table>
<thead>
<tr>
<th>Condition</th>
<th>Example</th>
<th>Identical pairs</th>
<th>Non-identical similar pairs</th>
<th>Non-identical dissimilar pairs</th>
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Stimuli Description

- **Visual condition, example 1**: קָטֶף - Katof (shoulder); רְעוֹר - Ozer (helper); שָהוֹר - Shahor (black). Example 2: אָדָם - Or (skin); בָּהִי - Reheb (cat); יָמִינָה - Baha (cried).
- **Phonological condition, example 1**: שֵׁלֶג - Sheleg (snow); שֵׁלֶט - Shelet (sign); דְּלֵט - Delet (door). Example 2: שֵׁמוֹש - Shemesh (sun); חָטָא - Hut (thread); חָטָא - Tut (strawberry).
- **Control condition, example 1**: בֵּגֵד - Beged (clothing); פָּגָישָה - Pgsisha (meeting); אֱוָל - Ehel (tent). Example 2: אָדָם - Adam (person); סֶפֶר - Sipa (reason); חַשְׁמוֹל - Hashmal (electricity).

Figure 1  Two examples of the stimulus material used in each of the three study conditions.
basically identical to those used to prepare the stimulus word pairs of the visual condition, except that it manipulated the phonetic rather than the visual dimension of words and that—to further avoid visual BWS—one word in any given pair was always in print and the other in cursive. In a first step, 20 word pairs were prepared, each built from two nonidentical, yet phonetically similar words, that is, two rhyming words.

A rhyme between two words normally tends to be reflected in accompanying similarity at their orthographic level, which may lead to confusion when the aim is to track the nature of an individual’s reading strategy. In this article, two particular features of Hebrew orthography were used to avoid rhymes in word pairs from being detectable at the orthographic level. First, Hebrew orthography comprises some homophonetic letter graphemes. For example, the letter grapheme מ (’taf) in the word תות (tut) and the letter grapheme נ (’tet) in the word חת (hut) are both read as the phoneme/t/ (see, e.g., Figure 1). Second, the phonetic value of certain Hebrew letter graphemes is sometimes determined by vowel diacritics (pointing) rather than by the grapheme itself. For example, the vowel diacritic (patach) assigns to the letter grapheme ג (ayin) in the word מגד (mada) and the letter grapheme י (hey) in the word גדה (gada) the same phonetic value/a/. In unpointed Hebrew, where such words appear without vowel diacritics (pointing) rather than by the grapheme itself, the phonetic identity ceases to be recognizable at the graphemic level. By taking advantage of the above mentioned features when building the nonidentical rhyming word pairs in the phonological condition, phonetic similarity between the words was not reflected at the graphemic level. It was also ascertained that such words were notably distinct on all other processing dimensions (orthographic, formational, and semantic/thematic).

The principles applied in Step 2 (the preparation of nonrhyming, nonidentical word pairs) and step three (the preparation of identical word pairs) were exactly the same as those outlined earlier in relation to the visual condition (see, e.g., Figure 1).

Control Condition

In instances where manipulations applied to word pairs are not directly observable, their detection requires the recruitment of meta-linguistic (e.g., phonological) awareness that allows a thorough inspection of the stimuli based upon the possession of specific (e.g., phonological) knowledge. For example, in the phonological condition described above, participants will prove sensitive to the introduced phonetic manipulation only if they bring into the task proper knowledge of letter–sound correspondence in Hebrew, as well as PA, allowing them to consciously monitor the phonological structure of spoken words. If these assumptions are correct, then introducing a manipulation to the processing of the identity of written words that is not detectable by participants at the perceptual or conceptual level, due to lack of knowledge and meta-linguistic awareness, was assumed to provide a perfect control to both the visual and the phonological conditions of the experiment.

Accordingly, the control condition varied the words in nonidentical word pairs with regard to the formational similarity of their parallel signs. Although formational similarity is addressed by native signing deaf individuals during reading (e.g., Bonvillian, 1983; Miller, 2007a; Siedlecki, Votaw, Bonvillian, & Jordan, 1990), it was anticipated to be irrelevant in the present experiment given the participants’ deficient knowledge of ISL and Signed Hebrew.

Signs are generated by altering three distinct basic formational parameters: hand shape, hand movement, and place of sign articulation relative to the body of the signer (Stokoe, 2005). Similar to phonetic similarity between spoken words (e.g., rhymes), signs occasionally exhibit formational similarity. Such similarity is most evident in instances where two signs differ on only a single formational dimension (e.g., same hand shape, same movement, different place of articulation). The manipulation of the stimulus pairs in the control condition took advantage of these formational principles. In a first step, 20 word pairs were prepared, each built from two nonidentical written words whose parallel signs were distinct on only a single formational dimension (hand shape, movement, place of articulation), yet clearly distinguishable in all other regards (visually, orthographically, phonologically and semantically/thematically; see, e.g., Figure 1). The principles guiding the preparation of formationally distinct nonidentical word pairs (Step 2) and identical
word pairs (Step 3) were the same as those applied in the other two conditions (see, e.g., Figure 1).

Procedure

The experiment was administered by a hired trained experimenter who was also a teacher of the deaf. Instructions were provided orally and were accompanied by physical demonstrations to guarantee proper understanding. All high school participants were tested in a quiet room located on their school grounds. They were tested individually and were exempted from regular school lessons for the time of experimentation. Only participants volunteering for the experiment were examined. Postgraduate students were recruited in response to an announcement of the experiment published on the campus grounds of several academic institutions in northern and central Israel. Most were tested at the author’s research laboratory at the University of Haifa. Some, however, were tested in a quiet room in their home. All of them were paid for participating.

DMDX software installed on a computer placed on an empty table served for stimulus presentation and reaction time measurements. Word pairs used for stimulation were displayed within a rectangular frame located at the center of the computer display. The actual experiment was preceded by an explanation and practice phase. At the beginning of that phase, participants were informed that the aim of the experiment was to see how fast they could determine whether two written words were identical. The experimenter stressed that this was not an exam and that performance would be treated as confidential. She then displayed the first practice word pair within the frame and instructed participants to position their index fingers comfortably on the two marked buttons on the computer keyboard, one labeled “Yes (identical)” and the other “No (nonidentical).” She asked them to press “Yes” when they saw word pairs comprised of two identical words and “No” for pairs composed of two different words. None of the participants exhibited difficulties in understanding the task requirements. After the initial explanation of the task requirements, the participants received some more practice trials in succession for warm up and practice. The experimenter went on to administer the experiment only after being confident that the participants properly understood the task requirements.

The experiment was executed immediately after the practice phase. The 80 word pairs of each of the three study conditions (visual, phonological, control) were presented in three separate blocks, administered consecutively, with a break of about 3 min between them. To counteract bias from practice and fatigue, the order in which the participants received the blocks was rotated in each participant group. The presentation order of the word pairs was the same for all participants. The distribution of identical and nonidentical word pairs within a word pair block was randomized. The same was true also with regard to the distribution of similar and dissimilar nonidentical pairs. The same word pair distribution pattern was applied in all three blocks.

Prior to execution of the experiment, the experimenter stressed to participants that performance would now be measured and that it was therefore important to work as quickly as possible. She further instructed them not to stop in case of error but to go on without hesitation. She then asked if they were ready. Following their confirmation, she verified that their index fingers were properly placed on the two response buttons and told them to concentrate on the frame where the word pairs would appear. She then displayed the first word pair.

The presentation of each word pair within the frame was preceded by the filler mask “####” for 800 ms, so as to empty word memory storage. The filler mask was automatically displayed the moment the participants operated one of the response buttons. Participants’ RTs and response accuracy were automatically recorded by DMDX software for later analysis. All 80 word pairs of a particular block were presented in succession. The display of “*****” indicated the end of a block.

Results

The aim of the study was to elucidate the nature of the reading strategies that participant groups relied on to determine the identity of written words. The analyses compared the three study conditions with respect to
two dimensions of performance: speed of processing (how long it took to make identity decisions) and error rates.

Prior to the statistical analysis, the RT data gathered for the three study conditions (80 measures per condition, half of them identical responses and the remainder nonidentical responses) was cleaned of invalid as well as outlier responses. Responses were marked by DMDX as invalid in instances where participants did not designate their identity decision within 3,500 ms measured from the moment of stimuli presentation (an indication of temporary mental black-out). Outlier responses were defined as RTs that were two or more standard deviations above or below the group mean. The decision was made a priori to include in statistical analyses only participants with 64 valid RTs (80%) or higher in each study condition (maximum 80 valid response), assuming that high rates of invalid RTs may point to lacking concentration or may even reflect a processing or attention deficit disorder. Based upon this criterion, none of the tested participants had to be excluded.

Quantitative Word Processing: RTs

The first set of analyses considered the participants’ general word processing capacity, overall and in each of the three study conditions, in terms of RT. A multivariate analysis of variance (MANOVA) computed RT as the study dimension, with group (deaf, hearing) as a between-subject factor and answer (identical, nonidentical) and study condition (visual, phonological, control) as within-subject factors. The groups’ mean RT measures, for all responses and for identical and nonidentical answers separately, are presented in Table 2.

The main group effect was statistically nonsignificant, suggesting that the average time it took to determine the identity of words was comparable for the two participant groups. However, the effect produced by study condition was statistically marked, $F(1, 88) = 50.29$, $p < .001$, $\eta^2 = .36$, indicating that it biased the participants’ speed of processing (decision making). This condition effect did not interact with the group effect, signifying that this condition-related bias was similar for the two participant groups. As can be seen in Table 2, processing of word identity was markedly faster in the control condition than in the visual and phonological ones, overall and for each group separately.

Post hoc analyses (paired $t$-tests) were performed to further clarify the significance of the study condition effect. Findings revealed, overall, significantly slower mean RTs for the visual and phonological conditions than the control condition, $t(89) = -9.62$, $p < .001$; $t(89) = -7.33$, $p = .001$, respectively. Moreover, word processing was slower in the visual condition than in the phonological one, $t(89) = 2.66$, $p < .01$.

The main effect of the answer (identical/nonidentical) was also statistically significant, $F(1, 88) = 128.14$, $p < .001$, $\eta^2 = .59$, suggesting that it took less time to determine that two words were identical than to determine that they were different. As

<table>
<thead>
<tr>
<th>Group</th>
<th>Condition</th>
<th>All (ms)</th>
<th>Identical (ms)</th>
<th>Nonidentical (ms)</th>
<th>Similar nonidentical (ms)</th>
<th>Dissimilar nonidentical (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deaf</td>
<td>Visual</td>
<td>839 (117)</td>
<td>799 (102)</td>
<td>880 (139)</td>
<td>921 (146)</td>
<td>840 (136)</td>
</tr>
<tr>
<td></td>
<td>Phonological</td>
<td>812 (126)</td>
<td>781 (112)</td>
<td>841 (150)</td>
<td>859 (147)</td>
<td>824 (159)</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>750 (131)</td>
<td>722 (118)</td>
<td>778 (146)</td>
<td>776 (145)</td>
<td>781 (152)</td>
</tr>
<tr>
<td></td>
<td>All</td>
<td>801 (112)</td>
<td>768 (101)</td>
<td>833 (128)</td>
<td>851 (129)</td>
<td>815 (130)</td>
</tr>
<tr>
<td>Hearing</td>
<td>Visual</td>
<td>780 (111)</td>
<td>770 (107)</td>
<td>828 (117)</td>
<td>859 (125)</td>
<td>798 (115)</td>
</tr>
<tr>
<td></td>
<td>Phonological</td>
<td>783 (117)</td>
<td>765 (118)</td>
<td>799 (120)</td>
<td>811 (123)</td>
<td>787 (120)</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>726 (102)</td>
<td>703 (101)</td>
<td>748 (107)</td>
<td>745 (104)</td>
<td>751 (114)</td>
</tr>
<tr>
<td></td>
<td>All</td>
<td>769 (103)</td>
<td>747 (102)</td>
<td>792 (108)</td>
<td>805 (108)</td>
<td>778 (108)</td>
</tr>
<tr>
<td>All</td>
<td>Visual</td>
<td>813 (114)</td>
<td>780 (106)</td>
<td>846 (127)</td>
<td>880 (135)</td>
<td>812 (123)</td>
</tr>
<tr>
<td></td>
<td>Phonological</td>
<td>793 (120)</td>
<td>771 (116)</td>
<td>813 (132)</td>
<td>827 (133)</td>
<td>800 (136)</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>734 (112)</td>
<td>709 (106)</td>
<td>759 (122)</td>
<td>756 (119)</td>
<td>762 (128)</td>
</tr>
<tr>
<td></td>
<td>All</td>
<td>780 (107)</td>
<td>754 (102)</td>
<td>806 (116)</td>
<td>821 (117)</td>
<td>791 (117)</td>
</tr>
</tbody>
</table>
suggested by an insignificant interaction between answer and group, this advantage of identical responses over nonidentical responses equally characterized the performance of both participant groups. Moreover, the lack of a significant triple interaction between the three main effects indicates that the uniformity of this processing pattern was evident for all three study conditions.

Qualitative Word Processing: Error Rates

The focus of the second set of analyses was the participants’ qualitative processing of the stimulus pairs, as reflected in error rates overall and in each of the three study conditions. Error rates for all responses, and for identical and nonidentical responses separately, are presented in Table 3. As is obvious from the table, they were rather small for both groups, suggesting that participants had effective strategies for determining the identity of words, that is, for processing written words.

Ad hoc analyses of error rates showed that identical and nonidentical responses produced comparable error rates. To simplify the statistical model, it was therefore decided to ignore this factor in analyses of participants’ response accuracy. MANOVA was performed, with error rate as the study dimension, group (deaf, hearing) as a between-subject factor, and study condition (visual, phonological, control) as a within-subject factor. The main group effect was statistically nonsignificant, suggesting that the accuracy of the two groups in processing the identity of words was comparable. Here, too, the effect produced by the study conditions was statistically marked, $F(1, 88) = 34.92$, $p < .001$, $\eta^2 = .28$, indicating that they impacted the participants’ accuracy in making an identity decision. There was no significant interaction between condition effect and group effect, demonstrating that the pattern of such bias was uniform for the two participant groups. As can be seen from Table 3, error rates for both groups were highest in the visual condition, followed by the phonological condition, and then the control condition.

Post hoc analyses using paired $t$-tests confirmed that the error rate for the control condition was markedly lower than those found for the two experimental conditions, phonological $t(89) = -2.89$, $p < .01$, and visual $t(89) = -5.33$, $p = .001$. The error rate of the visual condition was notably higher than the one for the phonological condition, $t(89) = 9.00$, $p < .001$.

A Comparison of Similar and Dissimilar Nonidentical Responses

The findings thus far establish the suitability of the research paradigm for reliably detecting subtleties in participants’ responses to differences related to the processed stimulus pairs. The third set of analyses addressed the core issue of the study: processing differences between similar and dissimilar nonidentical responses with reference to the three study conditions. For this purpose, two MANOVAs were executed, one comparing RTs and another comparing error rates.

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**Table 3** Number of erroneous responses, overall and for identical and nonidentical responses (means and SD)

<table>
<thead>
<tr>
<th>Group</th>
<th>Condition</th>
<th>Response type</th>
<th>All</th>
<th>Identical</th>
<th>Nonidentical</th>
<th>Similar nonidentical</th>
<th>Dissimilar nonidentical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deaf</td>
<td>Visual</td>
<td>2.68 (2.83)</td>
<td>0.94 (1.15)</td>
<td>1.13 (1.31)</td>
<td>0.90 (1.22)</td>
<td>0.23 (0.67)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Phonological</td>
<td>1.90 (2.01)</td>
<td>1.13 (1.41)</td>
<td>0.77 (0.99)</td>
<td>0.58 (0.77)</td>
<td>0.19 (0.40)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>1.29 (1.79)</td>
<td>0.74 (1.26)</td>
<td>0.55 (0.93)</td>
<td>0.16 (0.37)</td>
<td>0.39 (0.67)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>All</td>
<td>1.96 (1.89)</td>
<td>0.93 (0.90)</td>
<td>0.81 (0.58)</td>
<td>0.54 (0.31)</td>
<td>0.26 (0.39)</td>
<td></td>
</tr>
<tr>
<td>Hearing</td>
<td>Visual</td>
<td>2.69 (2.71)</td>
<td>0.73 (0.89)</td>
<td>1.47 (1.31)</td>
<td>1.03 (1.02)</td>
<td>0.44 (0.68)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Phonological</td>
<td>1.75 (1.72)</td>
<td>0.80 (0.98)</td>
<td>0.95 (1.09)</td>
<td>0.61 (0.83)</td>
<td>0.34 (0.58)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>1.22 (1.30)</td>
<td>0.76 (0.94)</td>
<td>0.46 (0.68)</td>
<td>0.19 (0.39)</td>
<td>0.27 (0.55)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>All</td>
<td>1.89 (1.70)</td>
<td>0.76 (0.75)</td>
<td>0.96 (0.82)</td>
<td>0.61 (0.58)</td>
<td>0.35 (0.39)</td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>Visual</td>
<td>2.69 (2.73)</td>
<td>0.80 (0.99)</td>
<td>1.36 (1.31)</td>
<td>0.99 (1.09)</td>
<td>0.37 (0.68)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Phonological</td>
<td>1.80 (1.81)</td>
<td>0.91 (1.15)</td>
<td>0.89 (1.05)</td>
<td>0.60 (0.80)</td>
<td>0.29 (0.53)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>1.24 (1.48)</td>
<td>0.76 (1.05)</td>
<td>0.49 (0.77)</td>
<td>0.18 (0.38)</td>
<td>0.31 (0.59)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>All</td>
<td>1.91 (1.76)</td>
<td>0.82 (0.80)</td>
<td>0.91 (0.75)</td>
<td>0.59 (0.56)</td>
<td>0.32 (0.38)</td>
<td></td>
</tr>
</tbody>
</table>
In the analysis conducted with RTs for nonidentical responses as the study dimension, group was computed as between-subject factor (deaf, hearing) and BWS (similar, dissimilar nonidentical responses) and study condition as two within-subject factors. The groups’ mean RTs for similar and dissimilar nonidentical word pairs, overall and for each of the study conditions, are presented in Table 2.

The group effect failed to reach statistical significance, suggesting that, overall, the time the two groups required for the indication of a nonidentical response was comparable. The BWS effect was statistically highly marked, $F(1, 88) = 152.00, p < .001$, $\eta^2 = .63$, implying the existence of notable processing time differences between similar and dissimilar nonidentical responses. A significant interaction between the group effect and the BWS effect, $F(1, 88) = 3.99, p < .05$, $\eta^2 = .04$, further suggests that the way word similarity biased the performance of the two groups differed. As can be seen from Table 2, participants with deafness, indeed, exhibited a somewhat higher BWS discrepancy in comparison to hearing controls, 36 ms versus 26 ms.

A noticeable study condition effect was disclosed, $F(1, 88) = 62.38, p < .001$, $\eta^2 = .42$, indicating that making a nonidentical response was not equally time consuming in the different conditions. The lack of a statistically significant interaction between group and condition effects suggests that such variance similarly characterized the performance of both participant groups. It is noteworthy that analyses yielded a highly marked interaction between BWS and condition effects, $F(1, 88) = 87.06, p < .001$, $\eta^2 = .50$, implying that there was notable variance between the three conditions with regard to the size of the BWS effect. The absence of a marked triple interaction suggests this to be true for both participant groups. Indeed, a look at Table 2 reveals that the BWS effects in the visual (68 ms) and phonological conditions (27 ms) were significantly larger than in the control condition (6 ms). This was confirmed by post hoc analyses based upon paired $t$-test comparisons, $t(89) = 10.65, p < .001; t(89) = -3.53, p = .001$, respectively. Moreover, the BWS effect for the visual condition was notably larger than that yielded for the phonological condition, $t(89) = 5.70, p < .001$.

To achieve a deeper understanding of the significance of the BWS effect, overall and for each participant group, a series of paired $t$-test post hoc analyses was conducted comparing RTs for similar and dissimilar nonidentical responses. Findings indicated that, overall, in both visual and phonological conditions, dissimilar word pairs were classified as nonidentical notably faster than similar word pairs, $t(89) = 14.23, p < .001, t(89) = 5.60, p < .001$, respectively (see Table 2). The same was true for each participant group, deaf $t(30) = 10.61, p < .001, t(30) = 3.05, p < .01$; hearing $t(58) = 10.29, p < .001, t(89) = 5.17, p < .001$, respectively. Of note, response latencies for similar and dissimilar nonidentical responses were not significantly different in the control condition. This was true whether analyses were conducted for participants as a whole or for the two distinct groups.

The second analysis of processing differences between similar and dissimilar nonidentical responses was based on a MANOVA comparing participants’ error rates. As with the RT analysis, group was computed as the between-subject factor (deaf, hearing) and word similarity (similar, dissimilar) and study condition as two within-subject factors. The groups’ mean error rates for similar and dissimilar nonidentical word pairs, overall and for each condition, are presented in Table 3.

As for RT, the group effect was statistically non-significant, indicating that the error rates of the two groups for nonidentical responses were comparable. The BWS effect was statistically marked, $F(1, 88) = 16.83, p < .001, \eta^2 = .16$, signifying that the number of erroneous decisions for similar nonidentical responses was notably higher than that for dissimilar nonidentical responses (see Table 3). Lack of a significant interaction between group and BWS effects suggests this was true for both participant groups. The condition effect was also statistically significant, $F(1, 88) = 18.72, p < .001, \eta^2 = .18$, pointing to notable variance in the error rates for nonidentical responses of the three study conditions. Again, the absence of a statistically significant interaction between group and condition effects suggests that this held for both groups of participants.

Of note is a marked interaction between the BWS and condition effects, $F(1, 88) = 22.42, p < .001,$
The second series of analyses correlated the two groups’ performance on the sentence comprehension test with their RTs and error rates. For deaf participants, all correlations failed to reach statistical significance, both with regard to overall performance and for each study condition. In contrast, for hearing participants, the same analyses consistently revealed weak but statistically significant negative associations between the correlated dimensions, for RT: overall, \( r = -0.30, p = 0.01 \); visual condition \( r = -0.30, p < 0.05 \); phonological condition \( r = -0.31, p < 0.01 \); control condition \( r = -0.25, p < 0.05 \) \((n=59)\); and for error rate: overall, \( r = -0.31, p < 0.01 \); visual condition \( r = -0.27, p < 0.05 \); phonological condition \( r = -0.28, p < 0.05 \); control condition \( r = -0.27, p < 0.05 \) \((n=59)\).

It was hypothesized that BWS effects represent the participants’ sensitivity to particular word processing dimensions (visual, phonological, or formational), a sensitivity that was assumed to be indicative of the nature of their word processing strategies. A last series of correlation analyses examined how the size of the quantitative (RT) and qualitative (error rate) BWS effects correlated with PA and sentence comprehension. Neither of these analyses yielded evidence for a significant association between the size of the participants’ BWS effects and their PA or their ability to make sense of written text. This was true for both participant groups and whatever experimental condition was considered.

**Discussion**

This study is an additional attempt (see also Miller, 2002, 2004a, 2004b, 2005b, 2005c, 2006a, 2006b, 2007b) to unveil similarities and differences in the word reading strategies of individuals with prelingual deafness and hearing control by asking participants to determine as quickly as possible whether two written words are identical. The question that is probably most central in this regard is whether the permanent lack of auditory stimulation from infancy prevents individuals from developing efficient strategies for the lexical processing of written words.

The findings show that the answer to this question is a resounding “no.” The results offer no significant evidence that participants with deafness processed the stimulus materials (word pairs) with less efficiency.
than their hearing counterparts. This was the case whether comparison analyses focused on overall performance or on each of the three study conditions separately and whether the processing dimension under investigation was RT or accuracy (see Tables 2 and 3). This conclusion is supported by the findings of a substantial number of other experiments partly conducted with much younger individuals (primary school) and from different communication backgrounds (native signers, nonnative signers) than those tested in this article (e.g., Miller, 2001, 2002, 2004a, 2004b, 2005b, 2005c, 2006a, 2006b; Wauters et al., 2006). Findings revealed by all these experiments suggest that the word reading strategies of prelingually deaf individuals, similar to those of hearing readers, allow for the effective processing of written words at the lexical level. Evidence further suggests this to be true even for those deaf individuals whose reading levels are poorest (e.g., Miller, 2006a).

Unquestionably, the participants with deafness tested in this article had, on the average, seriously impoverished PA (deaf 6.97 [3.06] vs. hearing 10.64 [1.45], on a 12-point scale). Therefore, the finding that in the current experiment their performance was comparable with that of the hearing control group is difficult to bring in line with a strong phonological reading theory (e.g., Frost, 1998; Ramus et al., 2003) as it seems to refute the assumption that PA is a necessary condition for the development of effective word reading strategies (Ehri et al., 2001; Hulme et al., 2005; Report of the National Reading Panel, 2000; Share, 1995; Shaywitz & Shaywitz, 2005; Snow et al., 1998; Troia, 2004; Vellutino et al., 2004; see also Nielsen & Luetke-Stahlman, 2002; Padden & Hanson, 2000; Perfetti & Sandak, 2000). It also appears to contest the claim that reading comprehension problems typically observed in readers with prelingual deafness reflect a primary failure to efficiently process written words at the lexical level (Kelly & Barac-Cikoja, 2007). Indeed, the fact that PA was nonindicative of quantitative or qualitative task performance (RT and accuracy) for either participant group suggests that this conclusion may prove valid not only for deaf readers but also for unimpaired hearing readers.

The discrepancy between the hypothesized efficiency of the word reading skills of the prelingually deaf, as predicted by widely accepted reading theories, and the performance of such individuals in this article warrants a closer look at the results for both groups in the three study conditions, particularly with respect to their sensitivity to the manipulations—the variation of BWS—introduced in each condition. The experiment revealed a marked study condition effect for both RT and accuracy, suggesting that the determination of word-pair identity was not equally efficient in the three conditions. Of particular importance is the finding that this variation in efficiency was uniform for both participant groups. As is clear in Tables 2 and 3, determining between-word identity was easiest in the control condition, harder in the phonological condition, and hardest in the visual one. An intuitive explanation for this differential processing pattern is that participants processed different vocabularies in each study condition. However, although lexical variance in the three conditions certainly contributed its share, the primary source of the difference was the participants’ sensitivity to the manipulations introduced to nonidentical word pairs.

A central research hypothesis was that, owing to their prelingual hearing losses, participants with deafness develop word reading strategies that differ in nature from those of hearing individuals. It was anticipated that individuals who are prelingually deaf would primarily focus on visual properties when processing written words, whereas their hearing counterparts would mainly rely on the phonological constituents of words. It was therefore hypothesized that creating visual BWS in nonidentical word pairs would primarily impact task performance in participants with deafness, whereas phonological BWS would hamper mainly their hearing counterparts. It was further forecasted that manipulating formational BWS (control condition) would have no effect on either group, given that this type of BWS had no psychological reality for them (due to a lack of competence in sign language). Notably, though a highly significant BWS main effect was revealed (see Tables 2 and 3), its nature—as will be demonstrated in the following—failed to corroborate the research hypotheses outlined above.

Before considering the significance of the BWS effects revealed in the two experimental conditions,
it is worthwhile to turn attention to how BWS impacted performance in the control condition. The basic hypothesis underlying the design of this condition was that word identity decisions made by individuals who do not know sign language will not reflect interference from variation in BWS in word pairs. Thus, there would be no significant variance in classifying formationally similar and formationally dissimilar words as different for either participant group. Findings, indeed, confirmed this hypothesis. As can be seen from Tables 2 and 3, quantitative and qualitative discrepancies between these two nonidentical word pair types were strikingly small, both in an absolute sense and in comparison to the BWS effects found for the visual and phonological conditions. This substantiates that the formational condition in the present experiment provided a valid control condition, overall and for each of the participant groups.

A central study hypothesis forecasted that the participants with prelingual deafness and the hearing control would suffer from discriminative interference from the manipulation of BWS in the visual and phonological conditions. Specifically, it was predicted that deaf individuals—but not hearing controls—would show notable interference from visual BWS due to a visual orientation compensating for a permanent lack of auditory stimulation. In addition, it was anticipated that hearing participants—but not those with deafness, due to their insufficiently developed phonological skills—would prove sensitive to phonological manipulations introduced into the stimulus material (phonetic BWS). Surprisingly, findings from this article did not corroborate either of these hypotheses. In fact, for both participant groups, both types of manipulations notably impacted word processing efficiency, reflected in highly marked BWS effects within the two experimental conditions and in notably prolonged RTs, and notably compromised accuracy relative to the control condition (see Tables 2 and 3).

In view of comparable word processing abilities, on the one hand, and an obvious tendency to attend to the very same word processing dimensions while reading, on the other hand, the inevitable conclusion is that word reading strategies of hearing and deaf individuals—at least those who grew up in an oral environment—are much more alike than different with regard to both their efficiency (see also Miller, 2001, 2002, 2004a, 2004b, 2005b, 2005c, 2006a, 2006b; Wauters et al., 2006) and their nature (see Miller, 2002, for similar findings obtained with a different paradigm). If this is true, then a position that considers the reading problems of the prelingually deaf reader to originate primarily from a failure to efficiently process written words at the lexical level (Hanson, 1989; Kelly & Barac-Cikoja, 2007; Padden & Hanson, 2000; Perfetti & Sandak, 2000) seems untenable.

This, of course, is not meant to suggest that, due to their reduced vocabulary, such readers may not eventually fail to effectively process unfamiliar words as they are asked to read a paragraph. However, what findings from this study and many others indicate is that once such words become familiar, their processing ceases to be an obstacle to reading comprehension. Consequently, if such individuals continue to manifest significantly reduced reading comprehension skills—as was the case also for the participants tested in this article—it is likely that such deficits reflect a processing failure at the supraliteral rather than the lexical level (see Hatcher & Robbins, 1978; Miller, 2000, 2005b, 2006a; Quigley, Power, & Steinkamp, 1977). The fact that, in the present experiment, word processing efficiency was associated with reading comprehension only for the hearing control, but not for participants with deafness, is in line with this conclusion.

It is noteworthy that making an identity decision for two words in the control condition was markedly faster (734, 813, 793 ms) and more accurate (1.24, 2.69, 1.80 errors) than making the same decision in the visual and phonological conditions. This rather impressive processing efficiency discrepancy between the control condition and the two experimental conditions was typical for both participant groups (see Tables 2 and 3). Interestingly, however, and contrary to intuition, such decreased processing efficiency was not restricted to identity decisions made for word pairs comprised of two nonidentical words (the manipulated word pairs) but was comparably manifest when processing word pairs built from two identical words. This strongly suggests that the word processing strategies the participants relied upon for determining word identity in the two experimental
conditions was somehow different in nature to the one they applied in the control condition. The fact that this was the case for participants with and without hearing provides further evidence that the cognitive and linguistic mechanisms these groups recruit for the processing of written words are essentially similar in nature.

It may, of course, be argued that processing efficiency differences between the control condition and the two experimental conditions reflect a word frequency effect rather than the reliance on different word reading strategies. Yet, although variance in word frequency is definitely a factor that may impact how efficiently written words are processed, it is rather unlikely to be at the core of the processing discrepancy observed in the present experiment. First, all the words in the three conditions were words rated by three independent judges to be in the active vocabulary of deaf third graders; hence, they were likely to be rather high frequency words. Second, given that the criterion for choosing the words used in a particular condition was substantially a BWS criterion, it is very unlikely that the frequency distribution of the vocabularies used was significantly different in the three study conditions. Finally, processing differences between the two experimental conditions and the control condition proved to be very uniform for the two participant groups (see Tables 2 and 3). Such uniformity would not be expected if word frequency were to play a central role in the emergence of such prominent processing differences. Therefore, it seems reasonable that they reflect the application of different reading strategies. Whatever reading strategy participants with deafness applied, it did not seem to significantly disadvantage them. This suggests that, notwithstanding a lack of auditory stimulation reflected in deficient phonological abilities, the development of skills that guarantee the efficient processing of written words at the lexical level remains surprisingly normal (intact).

A point of particular interest is the distinct intrinsic nature of the two BWS effects. In the visual condition, this effect is entirely perceptual in nature, that is, it must be assigned to a very early level within the word recognition process, a level that does not reflect the application of linguistic and meta-linguistic knowledge. In contrast, the BWS effect in the phonological condition manifests the application of linguistic knowledge (e.g., the identification of graphemes and the application of a grapheme-to-phoneme conversion procedure) and meta-linguistic knowledge (PA that detects phonetic similarity between words). Given this to be true, it is, of course, tempting to conclude that both participant groups primarily processed stimulus words along a phonological reading route—as hypothesized by reading theories that assign phonology a central role in the processing of written words (e.g., Frost, 1998; Ramus et al., 2003). However, some caution is warranted in taking this conclusion too far. The fact that no significant association was found between the phonological BWS effects exhibited by the participant groups (indicative of their PA) and their reading comprehension suggests that phonology, although retrieved during reading, may not be a primary source for making sense of written text (see Musselman, 2000).

It is noteworthy that the effect produced by visual BWS was markedly greater than the phonological BWS effect (more than twice in relation to RT and about twice in relation to accuracy; see Tables 2 and 3). This implies that both groups allocated a substantial amount of processing resources to the visual analysis of the stimulus words. It is reasonable to assume—although directly observable only in the visual condition—that they applied a similarly thorough visual analysis also to the stimulus materials used in the other two study conditions. Such enhanced attention to visual details in the processed stimulus words implies that the participants initially (or parallel to their phonological processing) processed the stimulus words down to their orthographic representations.

Regrettably, the experimental paradigm used in this article was not designed to track orthographic processing—a dearth that should be dealt with in future research. However, as all participants had many years of reading experience at the time of testing and as the word pairs used for stimulation were built mainly from high frequency words, it seems reasonable to assume that their principal strategy in determining word identity was orthographic in nature. This would explain why their PA was not indicative of their performance and why the magnitude of their phonological BWS effects did not predict their reading comprehension and vice versa.
The deaf individuals participating in this article were all raised according to oral philosophy, and they all lacked competence in sign language. Generalization of findings reported with regard to their reading strategies may not be possible in a straightforward manner to readers with prelingual deafness growing up in a signing environment. To allow for such generalization, a replication of the present study with the latter must be seen as a prerequisite. This is particularly true with regard to native signers for whom sign language may take on a mediating function in the processing of written words, as well (see Bonvillian, 1983; Miller, 2007a; Siedlecki et al., 1990).

In sum, evidence from this article suggests that the efficiency of the word reading strategies of individuals with prelingual deafness and their hearing counterparts is comparable. It may, of course, be argued that this word processing equality reflects a dearth of sensitivity of the experimental paradigm used, rather than a psycholinguistic reality. However, this very same paradigm proved highly sensitive to processing differences originating from (a) the use of different stimulus materials in the different study conditions (condition effect), (b) the response to different decision criteria (identical versus nonidentical response), and (c) the bias produced by the manipulation of BWS in the different study conditions. Thus, the assumption that the paradigm would have also tracked between-group processing differences—if there were any—seems defensible.

Results also suggest that the studied groups used reading strategies that were essentially similar in nature, that is, they process the very same dimensions of written words, including their phonology, a dimension that was hypothesized to be ignored by readers with prelingual deafness. However, although both participant groups referenced the phonology of written words to determine their identity, the evidence fails to support a theory assigning phonological decoding a critical role in reading comprehension.

The present research, in accord with evidence from other studies (e.g., Miller, 2000, 2005b, 2006a, 2008), suggests that what prevents readers with prelingual deafness from becoming proficient readers is not rooted in a word processing deficit at the lexical level. Rather, it seems to reflect a dearth in the processing of words at a supralexical level, that is, a failure to process efficiently recognized words by means of structural knowledge that elaborates their final meaning within the context of a sentence.

Notes

1. ISL is the signed language used by the deaf community in Israel. As in ASL, its vocabulary is built systematically according to limited sets of formational parameters, such as hand shape, hand movement, and place of articulation.

2. Signed Hebrew and spoken Hebrew are similar in a limited sense, reflected in a rough matching of sign order to word order. In most other linguistic aspects, there are essential incompatibilities between the two systems, such as an almost complete lack of devices in Signed Hebrew to represent the rich morphological structure of spoken Hebrew.

3. In Hebrew, a significant part of the vowel information is not depicted by letters but by small diacritical marks (pointing), placed physically below the letters of a word’s consonant letter string (e.g., the CVCC string KLeV [dog]). Such vowel diacritics, however, are not mandatory for text comprehension, and they are gradually removed from textbooks (unpointed Hebrew), beginning in second grade, and are almost completely omitted from reading materials above third grade (e.g., the CCC string K-L-V [dog]). For a more detailed description of the orthographic features of Hebrew and their use for detecting peculiarities regarding the processing of Hebrew orthography, see Miller (2002) and Shimron (1993).

4. DMDX software was developed by Jonathan and Ken Forster at the University of Arizona for the execution of psycholinguistic experiments. It allows RT to be measured with a metering precision of at least 1/10,000th of a second.

References


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