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Empirical Article

A Comparison of the Letter-Processing Skills of Hearing and Deaf Readers: Evidence From Five Orthographies

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This study was designed to examine the letter-processing skills of prelingually deaf and hearing students recruited from five different orthographic backgrounds (Hebrew, Arabic, English, German, and Turkish). Participants were 128 hearing and 133 deaf 6th–7th graders. They were tested with a same/different paradigm that assessed their ability to process letters under perceptual and conceptual conditions. Findings suggest that the letter-processing skills of deaf readers from some orthographic backgrounds may be underdeveloped in comparison to hearing counterparts. The finding that such letter-processing deficits were restricted to readers of some but not all of the tested orthographies warrants the conclusion that prelingual deafness, per se, does not impede the development of effective letter processing. Evidence for this study is discussed with reference to potential orthography-inherent and educational factors that may explain the existence of letter-processing deficits found in some of the prelingually deaf readers examined in this study.

Reading is defined as the process of extracting and constructing meaning from written text (Tunmer, 2008). In general, researchers hypothesize that two potential factors cause difficulties in the retrieval of meaning from written text: (a) various delays in the reader's spoken language and (b) deficiencies in the processes by means of which print is connected to the reader's spoken language (Gough & Tunmer, 1986; Tunmer, 2008). Given this to be the case, reading problems may originate from the reader's insufficient competency at the spoken language level (e.g., phonetic-phonological perception and production, lexical knowledge, knowledge and processing of morphological, and syntactic and semantic properties), from a processing failure at the lexical decoding level or both (Hoover & Tunmer, 1993; Leach, Scarborough, & Rescorla, 2003; Scarborough, 2005).

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 & Gough, 1990; Kargin et al., 2011; Lewis & Doorlag, 1983; Miller, Kargin, & Guldenoglu, 2012; Ross, 1976). This position has been incorporated in a strong phonological grain-size-based word-reading model (e.g., Frost, 2006; Frost, Katz, & Bentin, 1987; Ziegler & Goswami, 2005, 2006). This model has also been suggested as a means for dealing with potential reading difficulties. According to this model, readers first recognize written words phonologically via their spoken lexicon and, subsequently, apply their linguistic (morphological, syntactic, semantic, pragmatic) knowledge to determine their meaning within the context of a sentence.

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An alternative model to the grain-size-based word-reading model is the Dual Route Cascaded word-reading model (e.g., Jackson & Coltheart, 2001). This model theorizes that word recognition proceeds simultaneously along two distinct reading routes, a lexical and a nonlexical reading route. Word processing along the nonlexical route is hypothesized to involve a grapheme-to-phoneme conversion procedure, whereas the lexical reading route is assumed to rely on a process that connects letter strings of written words with permanent orthographic representations that mediate their meaning (Jackson & Coltheart, 2001; Miller et al., 2012). A further assumption of this model is that readers use the nonlexical reading route for the identification of words/letter strings for which they have not yet established orthographic representations, whereas the lexical route recognizes words that—as a consequence of previous frequent encounter in text—have available orthographic entries (Kargin et al., 2011; Miller et al., 2012; Share, 1995).

Both grain-size-based and Dual Route models assume that in order to recognize orthographically unfamiliar words, readers have to process words' letter graphemes by means of a grapheme-to-phoneme conversion procedure. Therefore, failure to develop phonemically based word-processing skills is likely to inhibit the efficient recognition and comprehension of many written words. This hypothesis would reasonably explain why reading programs in schools often focus most exclusively on development of phonological skills (phonemic awareness, phonetic-phonological decoding) in order to teach reading. Interestingly, the processing of letters or letter clusters as a basic step in the processing of written words along a lexical and a nonlexical word-reading route has received little attention in relation to the acquisition of reading skills despite the fact that all real words and pseudowords are basically composed of letter strings that the reader has to process (recognize) in order to associate them with their corresponding phonemes. In other words, effective letter-processing skills seemed to be a crucial precondition to proficient reading skills (Frost, 1998; Miller, 2005c; Share, 1995).

Although letter processing is one of the fundamental skills upon which word processing operates, the degree of its importance for the reader has been claimed to be further modified by the orthographic depth of a particular language (Frost, 2009). Orthographic depth is defined as the consistency with which the phonetic/phonological form of spoken words can be derived based upon grapheme-to-phoneme conversion processes applied to a particular letter string (Seymour, Aro, & Erskine, 2003; Frost, 2006; Frost et al., 1987; Katz & Feldman, 1981). The operation of such processes has been argued to be determined, at least partly, by the orthographic transparency of the language (Spencer & Hanley, 2003).

Research investigating the development of word-reading skills in various orthographies (Durgunoğlu & Öney, 1999; Frost, 2006, 2009; Frost et al., 1987; Katz & Frost, 1992; Oney & Goldman, 1984; Wimmer & Goswami, 1994) indeed suggests that grapheme-to-phoneme conversion may be more difficult for readers reading in deep orthographies (e.g., English and French) than in shallow ones (e.g., Turkish, German, and Spanish). The reason for this difficulty has been assigned to the fact that the pronunciation of specific graphemes in the former often varies within the letter strings of different words. For example, the grapheme <a> in English is pronounced differently in the words "case," "cat," "car," and "call" (Davis, 2005; Frost, 2006; Miller et al., 2012; Vaknin & Miller, 2011). This fact leads to the conclusion that readers of deep orthographies primarily have to develop an efficient grapheme-to-phoneme conversion strategy.

In contrast, the grapheme–phoneme conversion processes in shallow orthographies are assumed to be more efficient due to grapheme-to-phoneme conversion consistency, that is, letter graphemes predominantly are associated with one and the same phoneme (Seymour et al., 2003). Indeed, research indicates that—in comparison to counterparts reading in deep orthographies—children reading in shallow orthographies have an advantage in processing familiar and unfamiliar letter strings by the end of the first year of formal instruction (Goswami, Gombert, & de Barrera, 1998; Landerl, 2000; Oney & Durgunoglu, 1997; Raman, 2006; Wimmer & Goswami, 1994).

As stated earlier, letter processing provides the basis for the effective recognition of written words by virtue of a grapheme-to-phoneme conversion process that assembles phonological forms the reader eventually

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recognizes as familiar entries in his/her phonological lexicon. It is also fundamental to processes underlying the retrieval of orthographic knowledge (representations), knowledge that mediates word meaning along a more direct and rapid lexical reading route (Jackson & Coltheart, 2001). Of note, however, past research has focused primarily on the word level in order to explain word-processing differences in regular readers (Cossu, Shankweiler, Liberman, & Gugliotta, 1995; Durgunoğlu & Öney, 1999; Drieghe & Brysbaert, 2002; Frost, 1998, 2006, 2009; Frost et al., 1987; Oney & Durgunoglu, 1997; Oney & Goldman, 1984; Raman, 2006; Raman, Baluch, & Besner, 2004; Van Orden, Johnston, & Hale, 1988; Wimmer & Hummer, 1990). A similar approach has been taken in investigations trying to disclose word-reading difficulties manifested by prelingually deaf readers (Miller et al., 2012; Miller, 2000, 2001, 2002, 2004a, 2004b, 2004c, 2005a, 2005b, 2006a, 2006b, 2010; Nemeth, 1992; Waters & Doehring, 1990; Wauters, Van Bon, & Tellings, 2006) and dyslexic readers (Frith, 1985; Martin, Pratt, & Fraser, 2000; Shaywitz & Shaywitz, 2005; Vellutino et al., 2004; Ziegler & Goswami, 2005). On the other hand, attempts to determine whether readers with markedly different reading comprehension skills can be distinguished at the letter-processing level are strikingly rare (e.g., Badian, 1995; Biemiller, 1977; Wolf, 1991).

In this study, we examined whether letter-processing skills distinguish between deaf and hearing readers. Many researchers assume that reading difficulties in prelingually deaf readers originate from difficulties in processing written text at the lexical level and postulate that, like hearing readers, they rely on phonological decoding skills for the recognition of written words (Alegria, Leybaert, Charlier, & Hage, 1992; Beech & Harris, 1997; Dyer, MacSweeney, Szczerbinski, Green, & Campbell, 2003; Harris & Beech, 1995; Leybaert, 2000; Nielsen & Luetke-Stahlman, 2002; Padden & Hanson, 2000; Paul, Wang, Trezek, & Luckner, 2009; Perfetti & Sandak 2000; Sterne & Goswami, 2000; Transler, Gombert, & Leybaert, 2001; Wang, Trezek, Luckner, & Paul, 2008). On the other hand, others argue that phonological word decoding may not play a crucial role in the way deaf readers access the meaning of written words (Allen et al., 2009; Kargin et al., 2011; Mayberry, del Giudice, & Lieberman, 2011; Miller, 2001, 2002, 2004a, 2004b, 2004c, 2005a, 2005b, 2006a, 2006b; Wauters & Doehring, 1990; for a review see Miller & Clark, 2011). However, given that the processing of letter graphemes, in a sense, proceeds the processing of written words both along the grapheme-to-phoneme conversion based nonlexical reading route and the more direct orthographic knowledge-based lexical reading route, its efficiency must be considered as a crucial step in the proper recognition of written words.

Regrettably, evidence related to deaf readers' letter-processing skills and the way they are modified by a permanent absence of auditory stimulation are surprisingly rare except for one study on Hebrew deaf readers (Miller, 2001). Hebrew has an orthography that essentially differs from those used by languages with Roman alphabet. In this study, deaf and hearing students were asked to determine as quickly as possible whether two simultaneously presented four-letter series were comprised of the same letters. Results suggested that the two groups had similar letter-processing skills with regard to both speed and accuracy of processing. It was concluded that individuals who are deaf are capable of accessing and processing the basic components of the written language—the letter graphemes—effectively, a capability considered to be a prerequisite to proficient reading.

The lack of significant differences found between deaf and hearing Hebrew readers at the most basic level of text processing is encouraging (Miller, 2001). It is, however, not clear how far evidence from Hebrew can be generalized to orthographies with a far less consistent relationship between graphemes and their corresponding phonemes and/or with visual properties that essentially deviate from those of Hebrew letters. This study was conducted to fill this gap by examining the letter-processing skills of deaf and hearing students reading in different orthographies (English, German, Turkish, Hebrew, and Arabic). Its central aim was to clarify similarities and/or differences in the letter-processing skills of deaf readers compared with age-matched hearing readers.

The research paradigm used in the present investigation required participants to determine as fast as possible whether the two letters comprised in a letter pair were the same or different. The paradigm comprised two conditions: a perceptual condition that did

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not require knowledge of the language and its orthography to make a same/different decision (e.g., a ***ɑ***, b ***ƙ***) and a conceptual condition (a ***ɑ***, b ***ƙ***) in which knowing the language and its orthography was a prerequisite for making such a decision.

Research Questions and Hypotheses

This study was designed to answer three core questions: (a) Are there meaningful differences in the perceptual and conceptual processing of letters for all participants, regardless of the nature of orthography?; (b) Are there meaningful differences between deaf and hearing readers with regard to their perceptual and conceptual processing of letters, regardless of the nature of orthography?; and (c) Are the letter-processing skills of deaf and hearing readers biased by qualities such as the orthographic depth of the language under study?

In order to provide satisfactory answers to the above questions, we tested the following research hypotheses:

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

   In order to make a decision under perceptual condition whether two letters are the same or not, it is sufficient to process the visual/perceptual properties of the letter stimuli (e.g., a ***ɑ*** vs. b ***t***). In contrast, making a decision under conceptual conditions, the reader has to access some form of specific linguistic knowledge about the language and its relationship to the orthography (e.g., letter name knowledge, letter sound knowledge, and fingerspelling knowledge) in order to bridge the visual incongruity between two conventionally only identical letters in a stimulus pair (e.g., a ***ɑ*** vs. b ***t***).
2. Deaf readers will be slower and less accurate than hearing readers in the processing of letters under conceptual conditions but not under perceptual conditions.

   The perceptual condition does not require access to knowledge, such as letter pronunciation knowledge, for making a same/different decision. As a consequence, a lack of complete phonological processing skills as a result of deafness from birth should not significantly impact performance. In contrast, as stated earlier, determining whether or not two letters are the same under conceptual conditions requires retrieval of some form of knowledge (phonological, orthographic, and so forth) and experience that may be underdeveloped due to prelingual deafness.
3. We expect that the conceptual letter-processing skills (speed and accuracy) of deaf and hearing readers will differentiate with direct reference to the transparency of the spoken language's orthography.

   In deep orthographies in which the relationship between letter graphemes and phonemes is inconsistent, the ability to rapidly and accurately process written words' letters is likely to be more demanding than in shallow orthographies, in which the relationship between letter graphemes and phonemes is consistent. Given this to be the case, we hypothesized that deaf and hearing readers who read in shallow orthographies (Turkish, German) will be faster and more accurate than deaf and hearing readers who read in deep orthographies (Hebrew, Arabic, English).

Method

Participants

Participants were 128 hearing and 133 deaf 6th–7th graders recruited from five different orthographic backgrounds (Hebrew, Arabic, English, German, and Turkish) (see Table 1). Hearing and deaf participants were matched with regard to level of education and average chronological age.

Deaf participants were recruited in all countries according to the following criteria: (a) had unaided

Table 1 Demographic characteristics of the participants

Orthography	Hearing	Deaf	Total
Hebrew	32	24	56
Arabic	23	34	57
English	20	17	37
German	25	30	55
Turkish	28	28	56
Total	128	133	261

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pure tone hearing losses of 85 dB or higher (American National Standards Institute, 1989) in the better ear; (b) were born deaf or became deaf prelingually; and (c) reported using Sign Language as the daily means of communication; none of them was diagnosed as having additional disabilities.

All deaf participants—except those tested in Turkey—were enrolled in classes where teachers used some form of signing (Sign Language or varieties of signed forms of the neighboring spoken language) as a means of instruction. The Turkish Ministry of Education advocates since 1953 a strictly oral philosophy with regard to the education of the deaf (Zeshan, 2003). As a consequence, although all of the participants claimed Sign Language to be their preferred communication mode, the deaf students we tested in Turkey were actually all taught in spoken language only.

The hearing control group was comprised of individuals with reading skills defined by their teachers as appropriate for their age. Only students with no record of particular learning or emotional disabilities were included in this study. Note, Arab participants, both hearing and deaf, were raised in a diaglossic context in which Israeli Arabic as the community's everyday language in informal settings and Modern Standard Arabic a highly codified language in formal settings are used.

All participants were tested as a part of an international reading study designed to reveal the origins of prelingually deaf and dyslexic individuals' reading difficulties. On a sentence comprehension test with 16 items, deaf participants from all tested orthographies scored—as a group—markedly lower in comparison to hearing controls.

Stimuli and Design

In order to understand differences between deaf and hearing individuals' letter-processing skills, we used a modified version of the Posner and Mitchell (1967) letter-processing paradigm. The paradigm was developed as part of an international reading study aimed to bring about an enhanced understanding of the factors underlying reading comprehension failure in deaf readers (for details, see Kargin et al., 2011; Mayberry et al., 2011; Miller et al., 2012) and the way they are modified by the orthography. The preparation of the letter stimuli used in relation to the different orthographies was based on exactly the same experimental criteria.

The paradigm asked participants to make rapid same/different decisions for letter pairs presented on a computer display and to indicate their response by pressing a "YES" or "NO" key. It had two distinct experimental conditions—a perceptual processing condition and a conceptual processing condition. In each of these conditions, 60 letter pairs were used for stimulation. Half (30) of them were composed of the same letter twice (e.g., a ***a***) while the other half (30) comprised two different letters (e.g., b ***y***). In the perceptual condition, both letters in the pair were presented either in print (e.g., a ***a***, b ***y***) or in cursive script (e.g., a ***a***, b ***y***). In the conceptual condition, one letter in a stimulus pair was always presented in print and the other in cursive script (e.g., a ***a***, b ***y***), requiring, as stated earlier, the retrieval of some knowledge to determine whether two letters are the same or not.

Procedure

Research assistants were all university students recruited via a flyer. Their suitability for the job was determined through a structured interview. They further underwent a detailed training phase in order to become familiar with the operation of the experimental setup and the experimental instructions. They started their work as experimenters only after establishing that they have mastered and automatized the whole experimental procedure.

All participants were tested individually in a quiet room located in their schools based upon an experimental protocol that was identical in all five orthographies. All Deaf participants received test instructions in their respective sign languages by research assistants who were competent signers. Hearing participants received the instructions in their respective spoken languages, the perceptual letter-processing paradigm was always administered first followed by the conceptual letter-processing paradigm, with an additional unrelated task given between the two to counterbalance for fatigue and routine.

Reaction time and accuracy measurements of the participants' responses were gathered by DMDX experimental software developed by K. I. Forster and J. C. Forster (2003). Stimuli were presented on

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a computer display placed at a comfortable distance (about 60 cm) on a table in front of the participant. The 30 identical and 30 nonidentical letter pairs used in each experimental condition were randomly mixed. The randomization order was the same in all languages. Both conditions were administered in three steps: instruction, practice, and experimentation.

Participants were informed that they would not be graded and that their performance would be kept confidential. In the first step, the experimenter displayed two stimulus letter pairs for task explanation. After the participant confirmed his/her understanding of the task requirements, the experimenter initiated the practice session comprised of 8 letter pairs, which are not used for experiment. In this second step, the experimenter provided feedback to participants when necessary. The experiment itself was administered in a third step after ensuring that the participants understood the task procedure.

Prior to examination, the experimenter told participants that they now would be tested and that they should work as fast as possible because time was being measured. Participants were also instructed that they should not stop in case they made an error, but rather should continue to give their answers by pressing the response buttons. After participants confirmed their readiness, the experimenter initiated stimulus presentation. The 60 letter pairs were displayed in succession with a masked interval "#####" of 500 ms inserted between each stimulus presentation.

Results

The participants' letter-processing speed and letter-processing accuracy was analyzed in two repeated-measure analysis of variance (ANOVAs). In each, we computed group status (hearing, deaf), and orthography (Hebrew, English, German, Arabic, Turkish) as between-subject factors and level of processing (perceptual, conceptual) as a within-subject factor. We used Levene's test to check for homogeneity of variance in each dependant variable across the different participant groups. Findings from this analysis indicated that—in relation to Arab participants—homogeneity could not be assumed. We therefore validated findings obtained from ANOVA by means of nonparametric statistics (Mann–Whitney *U*, Kruskal–Wallis). As findings yielded from this line of analysis were not found to overrule those obtained from ANOVA, we decided to report the latter.

Means for the participant groups' letter-processing speed under perceptual and conceptual conditions are presented in Table 2 and are visualize in Figure 1.

The main effect of level of processing was statistically significant, $F(1,251) = 536.37$, $p < .001$, $\eta^2 = .68$, suggesting that participants processed letter pairs significantly faster in the perceptual condition than in the conceptual condition. The main effect of group status was statistically significant, $F(1,251) = 12.90$, $p < .001$, $\eta^2 = .05$, indicating that, overall, hearing readers processed letters faster than deaf readers (see Table 2). Finally, the main effect of orthography was statistically significant, $F(4,251) = 7.10$, $p < .001$, $\eta^2 = .10$, pointing to the existence of some processing speed related variance across the tested orthographies. We used a Dunnett T3 post-hoc procedure (equal variance not assumed) in order to clarify the final significance of the orthography main effect.[1] Evidence obtained from this analysis revealed that Arab participants—overall—processed letters markedly slower than participants with other orthographic backgrounds.

ANOVA revealed an interaction between the level-of-processing effect and orthography, $F(4,251) = 13.98$, $p < .001$, $\eta^2 = .18$, suggesting that speed of processing differences between perceptual and conceptual conditions were not uniform across the tested orthographies. The interaction between the level-of-processing effect and group status did not reach statistical significance, $F(1,251) = 2.11$, implying that differences between deaf and hearing participants were uniform at the different levels of processing. The absence of a significant triple-interaction group status × level of processing × orthography, $F(4,251) = .19$, suggested this to be true regardless of the participants' orthographic background. Finally, ANOVA disclosed an interaction between the group status and orthography effects, $F(4,251) = 6.20$, $p < .001$, $\eta^2 = .09$, implying that differences in speed of letter processing between deaf and hearing participants varied across orthographies.

We conducted post-hoc analyses in order to clarify the final significance of the group status × orthography interaction. For this purpose, we compared deaf and hearing participants from each of the five

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Table 2 Reaction time means for the perceptual and conceptual processing of letters (SD in parentheses)

Language	Hearing	Deaf	Total
Perceptual processing of letters			
Hebrew	727 (163)	763 (131)	743 (150)
Arabic	762 (96)	860 (191)	821 (166)
English	771 (169)	777 (136)	774 (153)
German	746 (126)	690 (112)	715 (121)
Turkish	688 (84)	892 (171)	790 (168)
All groups	736 (133)	800 (170)	769 (156)
Conceptual processing of letters			
Hebrew	915 (199)	1021 (167)	961 (191)
Arabic	1008 (174)	1146 (231)	1091 (219)
English	889 (194)	837 (144)	865 (173)
German	894 (159)	874 (166)	883 (162)
Turkish	834 (118)	1061 (194)	947 (196)
All groups	906 (177)	1005 (219)	956 (205)
Overall letter processing			
Hebrew	821 (168)	891 (140)	852 (159)
Arabic	885 (128)	1003 (201)	956 (183)
English	830 (175)	807 (129)	820 (154)
German	820 (137)	782 (133)	799 (135)
Turkish	761 (95)	977 (154)	869 (167)
All groups	821 (146)	902 (180)	862 (169)
Level of letter processing effect			
Hebrew	188 (137)	258 (108)	218 (130)
Arabic	246 (114)	287 (138)	270 (129)
English	117 (101)	60 (110)	91 (108)
German	148 (83)	184 (97)	168 (92)
Turkish	145 (77)	169 (97)	157 (149)
All groups	170 (113)	204 (154)	188 (136)

orthographic backgrounds separately using multivariate ANOVA (*MANOVA*), with speed of perceptual and conceptual letter processing computed as two dependant variables. Evidence from these analyses suggested that, overall, the Arab and Turkish deaf participants processed letters significantly slower in comparison to hearing counterparts, $F(2,54) = 3.08$, $p = 05$, $\eta^2 = .10$, $F(2,53) = 19.72$, $p < 001$, $\eta^2 = .43$, respectively. Of note, however, German deaf participants, overall, processed letters faster that their hearing controls, $F(2,52) = 3.12$, $p = 05$, $\eta^2 = .11$. There was no further evidence suggesting the existence of marked difference in the letter-processing skills of deaf and hearing participants from the other orthographic backgrounds.

In order to clarify the final significance of overall speed of processing differences found between deaf and hearing participants in some of the tested orthographies, we considered between-subject effects for the perceptual and conceptual conditions separately. Evidence yielded by this line of analysis indicates that Arab and Turkish deaf participants—under both processing conditions—took longer to determine whether two letters are the same or not, $F(1,55) = 5.14$, $p < 05$, $\eta^2 = .09$; $F(1,55) = 5.97$, $p < 05$, $\eta^2 = .10$; $F(1,54) = 32.02$, $p < 001$, $\eta^2 = .37$; $F(1,54) = 27.99$, $p < 001$, $\eta^2 = .34$, respectively. However, analyses focusing on the two processing conditions separately did not corroborate that German deaf participants processed letters more rapidly than their hearing counterparts.

In a last line of analysis, we considered speed of perceptual and conceptual letter processing for deaf and hearing participants separately. For this purpose, we conducted two *MANOVA*, each computing speed of perceptual and conceptual letter processing as two dependant variables and orthography as a between-subject factor. The main effect of orthographic background was found to be statistically significant for both deaf and hearing participants, $F(8,256) = 8.94$, $p < .001$, $\eta^2 = .22$; $F(8,246) = 3.22$, $p < .01$, $\eta^2 = .10$, respectively. We run a Dunnett T3 post-hoc procedure to

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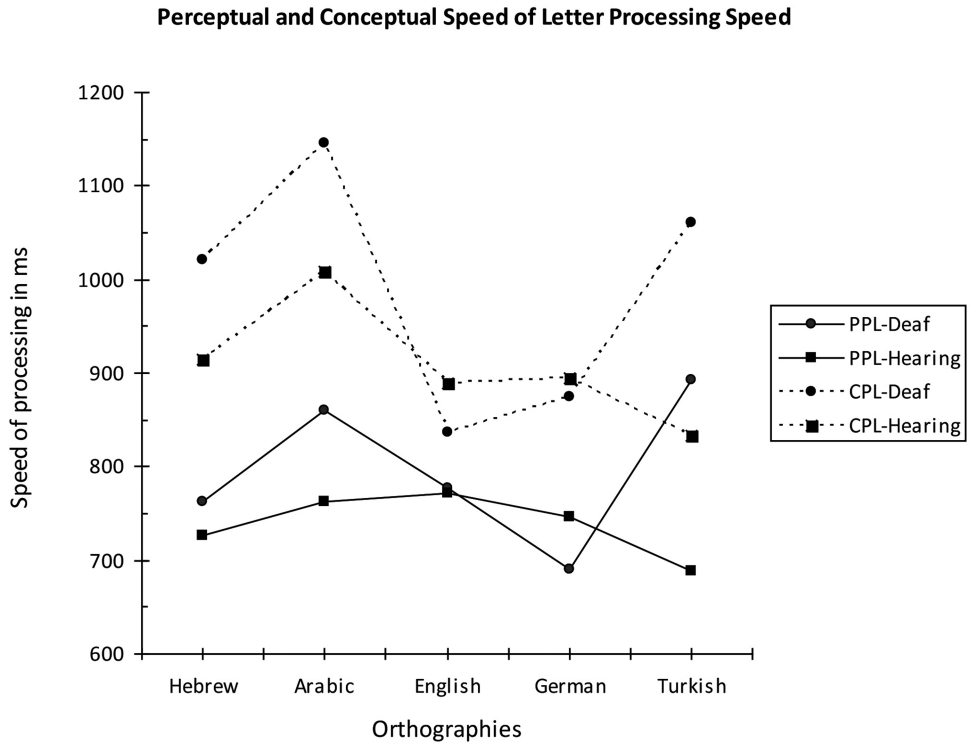

Figure 1 Reaction time means for the perceptual and conceptual processing of letters.

contrast the orthographic background effects found for deaf and for hearing participants with respect to both perceptual and conceptual letter processing. Findings obtained from this analysis failed to reveal significant differences in the perceptual letter-processing skills of hearing participants across the five orthographies. However, hearing Arab participants' letter-processing speed under conceptual conditions was to be significantly slower in comparison to their Turkish counterparts. With regard to deaf participants' perceptual letter-processing skills, Turkish and Arab participants were found to process letters markedly slower than their German counterparts. Turkish participants were also found to be slower than Hebrew participants in this regard. With regard to the conceptual processing of letters, Hebrew, Arab, and Turkish deaf students were found to process letters slower in comparison to their English and German counterparts.

Error Rates

Error rates for the participant groups' letter-processing accuracy under perceptual and conceptual conditions are presented in Table 3 and are visualize in Figure 2.

The main effect of level of processing was statistically significant, $F(1,251) = 88.93$, $p < .001$, $\eta^2 = .26$, suggesting that participants, overall, processed letter pairs more accurately under perceptual conditions than under conceptual conditions (see Table 3). The main effect of group status was of borderline significance, $F(1,671) = 3.71$, $p = .06$, indicating that, overall, hearing readers tended to process letters somewhat more accurate than deaf readers (see Table 3). Finally, the main effect of orthography was statistically significant, $F(4,251) = 6.14$, $p < .001$, $\eta^2 = .09$, pointing to marked variance in the participants' error rates across the tested orthographies. We used a Dunnett T3 post-hoc procedure (equal variance not assumed) to clarify the final significance of the orthography main effect. Findings yielded from this analysis indicated that—overall—the letter processing of Turkish and Arab participants was significantly less accurate than that of participants from the other orthographic backgrounds.

ANOVA revealed an interaction between the level-of-processing effect and orthography, $F(4,251) = 2.86$,

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Table 3 Error rates for the perceptual and conceptual processing of letters (SD in parentheses)

Language	Hearing	Deaf	Total
Perceptual processing of letters			
Hebrew	1.94 (1.62)	2.21 (3.10)	2.05 (2.35)
Arabic	2.65 (1.79)	5.53 (6.91)	4.37 (5.60)
English	2.60 (2.41)	2.65 (1.93)	2.62 (2.17)
German	2.92 (1.68)	2.87 (2.22)	2.89 (1.97)
Turkish	4.50 (4.04)	3.86 (4.25)	4.18 (4.12)
All groups	2.92 (2.62)	3.61 (4.52)	3.27 (3.72)
Conceptual processing of letters			
Hebrew	4.59 (2.65)	5.42 (3.21)	4.95 (2.90)
Arabic	4.83 (2.91)	9.68 (7.11)	7.72 (6.23)
English	4.00 (3.56)	3.35 (2.17)	3.70 (2.98)
German	4.16 (2.62)	4.60 (2.23)	4.40 (2.40)
Turkish	6.50 (4.67)	6.61 (4.01)	6.55 (4.31)
All groups	4.88 (3.44)	6.31 (4.92)	5.61 (4.31)
Overall letter processing			
Hebrew	3.26 (1.72)	3.81 (2.70)	3.50 (2.19)
Arabic	3.73 (1.98)	7.60 (6.46)	6.04 (5.46)
English	3.30 (2.55)	3.00 (1.71)	3.16 (2.18)
German	3.54 (1.65)	3.73 (1.78)	3.64 (1.71)
Turkish	5.50 (3.61)	5.23 (3.59)	5.36 (3.57)
All groups	3.89 (2.53)	4.95 (4.28)	4.43 (3.56)
Level of letter processing effect			
Hebrew	2.65 (2.71)	3.20 (3.28)	2.89 (2.95)
Arabic	2.17 (2.77)	4.14 (5.41)	3.35 (4.60)
English	1.40 (3.33)	.70 (2.28)	1.08 (2.88)
German	1.24 (2.91)	1.73 (2.66)	1.50 (2.76)
Turkish	2.00 (4.92)	2.75 (4.09)	2.37 (4.50)
All groups	1.95 (3.44)	2.69 (4.01)	2.33 (3.75)

$p < .05$, $\eta^2 = .04$, suggesting that error rate differences between perceptual and conceptual conditions were not uniform across the tested orthographies. The interaction between the level-of-processing effect and group status did not reach statistical significance, $F(1,251) = 1.74$, implying that processing accuracy differences between deaf and hearing participants were uniform at the different levels of processing. The absence of a triple-interaction group status × level of processing × orthography, $F(4,251) = .75$, suggested this to be true regardless of the participants' orthographic background. Finally, ANOVA disclosed an interaction between the group status and orthography effects, $F(4,251) = 3.67$, $p < .01$, $\eta^2 = .06$, implying that differences in accuracy of letter processing between deaf and hearing participants varied across orthographies.

We conducted post-hoc analyses in order to clarify the final significance of the group status × orthography interaction. For this purpose, we compared deaf and hearing participants from each of the five orthographic backgrounds separately, using *MANOVA* with accuracy of perceptual and conceptual letter processing computed as two dependant variables. Evidence from these analyses suggested that Arab deaf participants, overall, processed letters significantly less accurate in comparison to their hearing counterparts, $F(2,54) = 4.71$, $p < 05$, $\eta^2 = .15$. There was no evidence pointing to marked difference in the letter-processing accuracy of deaf and hearing participants from the other orthographic backgrounds.

In order to clarify the final significance of overall letter-processing accuracy differences found between Arab deaf and hearing participants, we considered between-subject effects for the perceptual and conceptual conditions separately. Evidence obtained from this line of analysis indicates that Arab deaf participants were markedly less accurate letter processor under conceptual conditions $F(1,55) = 9.56$, $p < 01$, $\eta^2 = .15$. Moreover, processing accuracy differences between

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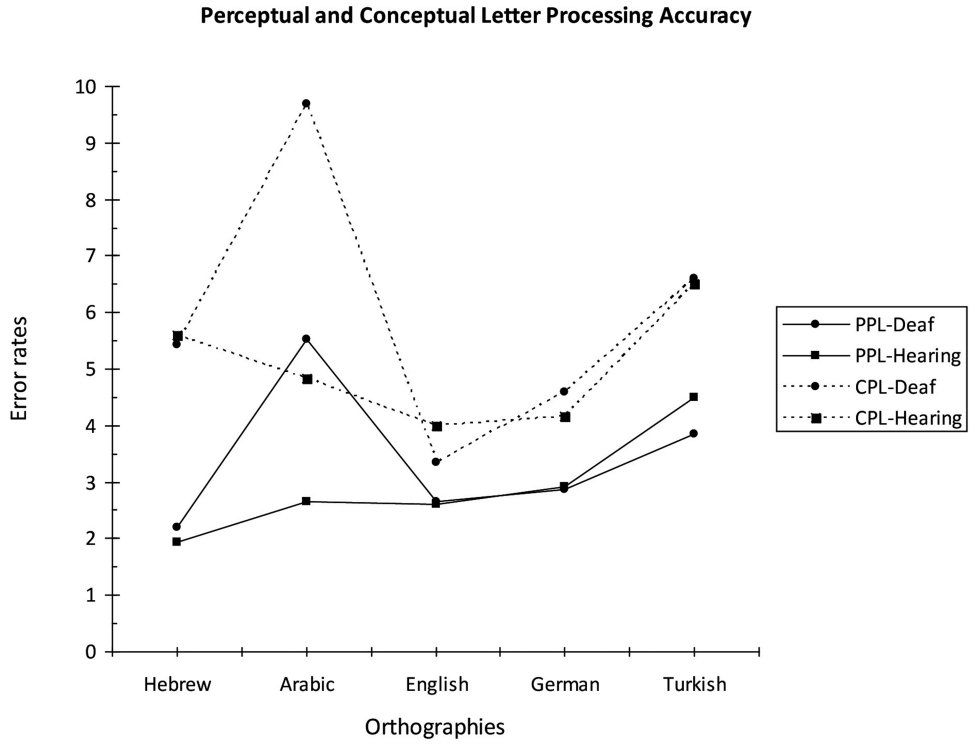

Figure 2 Error rate means for the perceptual and conceptual processing of letters.

Arab deaf and hearing participants with regard to the perceptual letter-processing condition failed to reach statistical significance, but were found to be borderline in this regard, $F(1,55) = 3.79$, $p = .06$.

Finally, we considered accuracy of perceptual and conceptual letter processing for deaf and hearing participants separately. For this purpose, we conducted two *MANOVA's*, each computing perceptual and conceptual letter-processing accuracy as two dependant variables and orthography as a between-subject factor. The main effect orthographic background was found to be statistically significant for both deaf and hearing participants, $F(8,256) = 3.96$, $p < .001$, $\eta^2 = .11$; $F(8,246) = 2.55$, $p < .05$, $\eta^2 = .08$, respectively.

We run Dunnett T3 post-hoc procedures to contrast the orthographic background effects found for deaf and for hearing participants with respect to both perceptual and conceptual letter processings. Findings obtained from these analyses indicated that hearing Turkish participants were less accurate in the perceptual processing of letters than Hebrew counterparts. There were, however, no further differences between the five orthographies in this regard. Moreover, the hearing participants from the different orthographic backgrounds did not differ with regard to letter processing accuracy under conceptual conditions. With regard to the deaf participants, no statistically significant orthography-related processing accuracy differences were found for the perceptual condition. However, under conceptual letter-processing conditions, deaf Arab participants made significantly more errors than counterparts from other orthographic backgrounds, except Turkish counterparts. In addition, deaf Turkish participants produced more errors in comparison to German counterparts.

Discussion

This study was designed to examine the letter-processing skills of prelingually deaf and hearing students reading in different orthographies (English, German, Turkish, Hebrew, and Arabic). The first hypothesis tested by this study was that readers—regardless of their hearing status or their orthographic background—will be faster and more accurate under the perceptual letter-processing condition than under the conceptual condition (see Posner & Mitchell, 1967).

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Our basic assumption was that in making a same/different decision under the perceptual condition, it is sufficient to process the visual properties of the letter stimuli. In contrast, making a decision under conceptual conditions the reader has to access some form of conceptual knowledge (e.g., letter names, letter sound, and fingerspelling) in order to make a decision.

Our results supported this hypothesis, in that evidence found in relation to processing speed and processing accuracy differences indeed indicates that determining whether two letters are the same or not was significantly more demanding under the conceptual condition than under the perceptual condition in all tested orthographies and for both deaf and hearing participants. This is in line with the assumption that, under the conceptual condition, processing went beyond a perceptual level, that is, readers needed to access some form of conceptual knowledge that bridges visual incongruity between two merely conventionally identical letters (Miller, 2005c; Vaknin & Miller, 2011). It also lines up with findings that point to similar level-of-processing effects in relation to the processing of written words (Kargin et al., 2011; Miller, 2005c; Miller et al., 2012).

A second hypothesis tested was that deaf readers would be slower and less accurate than hearing readers in the processing of letters under conceptual conditions but not under perceptual conditions. This hypothesis was only partly supported by evidence. Indeed, as predicted, in comparison to hearing controls Arab and Turkish deaf participants manifested significantly poorer letter-processing skills in instances in which they had to process letters beyond a perceptual level. This was reflected in markedly increased response latencies and, with regard to Arab deaf participants, also in notably poorer response accuracy. Of note, however, deaf participants with other orthographic backgrounds (Hebrew, English, and German) were not found to have less efficient letter-processing skills than their hearing counterparts. This was found to be true whether they processed letters under perceptual or conceptual conditions. This seems to contradict that prelingual deafness per se creates conditions that interfere with the development of effective letter-processing skills (see also Miller, 2001).

As already stated, the conceptual letter-processing condition required participants to access some form of specific linguistic knowledge (e.g., letter pronunciation, letter names, and abstract letter representations) that negotiates the visual incongruity between two conceptually identical, yet visually dissimilar letters. Initially, it seemed therefore tempting to draw the conclusion that in relation to some orthographies prelingual deafness undermines the development of knowledge readers had to access for mediating letter processing under the conceptual condition. For example, if one assumes phonological knowledge to take on this mediating function (Wang, Trezek, Luckner, & Paul, 2008), the finding that Arab and Turkish deaf participants underperformed their hearing controls under the conceptual condition would make sense. This is because hearing loss from infancy has been reported to hamper the development of deaf readers' phonological abilities (Alegria et al., 1992; Dyer et al., 2003; Guardino, Selznick, & Syverud, 2009; Transler & Reitsma, 2005). However, interpreting their deficits at the conceptual level in a straightforward manner as being the result of underdeveloped phonetic-phonological skills may actually oversimplify the matter. This becomes obvious when taking into account that—in comparison to their hearing counterparts—these deaf participants were also less effective letter processors in the perceptual condition. As this condition did not require accessing linguistic properties of the stimuli for determining whether two letters are the same or not, their poor performance under conceptual processing condition may therefore not reflect underdeveloped phonetic-phonological processing.

The finding that deaf Arab and Turkish participants—but not deaf participants from the other orthographies—were found to have reduced letter-processing skills also under the perceptual condition is of particular interest and worthy of closer consideration. The requirement to retrieve some form of knowledge (phonological, orthographic, and so forth) under the conceptual condition does not mean that the participants did not have to initially process the letter stimuli perceptually. Given this to be the case, processing differences found between the two groups at the conceptual level may reflect, at least partly, differences that originated from less efficient perceptual processing of the letter stimuli. However, it is not sufficiently clear why there were marked perceptual processing

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differences between deaf and hearing participants; the perceptual processing of letters does not require accessing knowledge the development of which is likely to be hampered by prelingual deafness.

It is, of course, tempting to interpret the differences between deaf and hearing Arab and Turkish participants by assuming that the former may have been compelled to process letters without being in possession of well-internalized phonological representations. Such an interpretation sounds reasonable given that the deaf participants, we tested were all prelingually deaf, meaning that due to prelingual deafness they may not have fully acquired and internalized the phonetic-phonological properties of spoken language. At the same time, looking at differences between hearing and deaf participants from across different orthographies, a theory that postulates a phonological weakness caused by deafness as the underlying factor for failure to process letters efficiently is not tenable. This is obvious from the finding that in three of the tested orthographies (Hebrew, English, and German) the deaf participants processed letters as efficiently as their hearing peers. These findings seem to suggest that—in spite of their prelingual deafness—deaf individuals develop representations that sustain the effective processing of letters. It also implies that the failure of Arab and Turkish deaf participants to do so must be assigned to a different cause other than their prelingual deafness.

As has been reported elsewhere (e.g., Eviatar & Ibrahim, 2001), the processing of the Arab alphabet is considered to be particularly demanding given that a limited number of basic shapes, modified by dots varying in number and placement, are used for the realization of its letters. As a consequence, Arab letters tend to exhibit significant visual confusability (overlap), a property that may prove detrimental to their efficient processing (see error rates in Table 3). This is because the basic shape of the letter may cause the coactivation of more than one letter representation of which it is a part. Given this to be true, Arab readers may be forced to disambiguate the identity of a particular letter by making a thorough analysis of its modifying dots prior to making a same/different decision with respect to another letter. Doing this effectively is likely to require more intensified exposure to letters than is necessary for optimizing letter processing in orthographies with visually less-confusing alphabets. Because such intensified exposure is likely to be missing in the majority of deaf Arab readers due to significantly reduced reading experience, the finding that their letter-processing skills were less effective than those of their hearing counterparts should not come as a surprise.

The finding that the letter-processing deficits of Turkish prelingually deaf participants were found to be the most prominent is puzzling in many regards. This is because Turkish letters—unlike those of the Arab alphabet—are visually distinct to about the same degree as those processed by their English and German counterparts, who did not manifest letter-processing deficits in comparison to regular hearing readers. This strongly suggests that their impoverished letter-processing skills were not rooted in characteristics inherent to the letters themselves. Rather, they seem to reflect constrains of the strategy Turkish deaf readers rely on for their processing.

It is noteworthy in this regard that education for the deaf in Turkey advocates an oral philosophy (Zeshan, 2003) that puts strong emphasis on phonetic-phonological mediation in reading. This is reflected in the fact that letters are taught to the novice deaf reader by stressing their articulation as a means for developing their spoken language proficiency, including the processing of letter strings along a grapheme-to-phoneme conversion-based reading route for their recognition. Overt or subvocal voicing letters, thus, is likely to become an automatic response to their encounter and has been reported by the responsible research assistant to characterize the Turkish deaf participants tested in this study. Given that early profound hearing loss is likely to undermine the phonological processing skills of the prelingually deaf (e.g., Alegria et al., 1992; Dyer et al., 2003; Guardino et al., 2009; Miller, 2010; Transler & Reitsma, 2005), the poor letter-processing skills of Turkish deaf participants would make sense. This conclusion is also in line with evidence that suggests the word processing skills of Turkish deaf readers to be strikingly underdeveloped in comparison to counterparts reading in other orthographies (Kargin et al., 2011; Kubus et al., 2012).

A basic assumption of this study (Hypothesis 3) was that the conceptual letter-processing skills of deaf and hearing readers would be determined, at least

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partly, by the transparency of the orthography (shallow vs. deep). More specifically, we assumed that it will be easier to process letters in orthographies with consistent grapheme-to-phoneme correspondence (shallow orthography) than in orthographies in which letter graphemes are not reliably associated with one and the same phoneme (deep orthography). This hypothesis was not supported by findings of this study. Although marked differences in letter-processing efficiency were found between the five tested languages, the pattern of these differences did not comply with predictions made by an Orthographic Depth Hypothesis. For example, conceptual letter-processing speed in Turkish and German, both shallow orthographies, was not enhanced in comparison to English, a truly deep orthography. Moreover, Turkish participants manifested markedly reduced letter-processing accuracy in comparison to their English counterparts even though their orthography is of an entirely shallow nature.

Taken the above findings together, it seems that factors other than orthographic depth determined letter-processing efficiency in different orthographies, with some of them related to the ease with which letters can be processed at the perceptual level. Indeed, there is growing evidence that letter-processing efficiency differences between different alphabets may be related to the visual properties of their letters (Eviatar & Ibrahim, 2001; Eviatar, Ibrahim, & Ganayim, 2004; Ibrahim, Eviatar, & Aharon-Peretz, 2002, 2007). As stated earlier, the Arab alphabet uses letters that are composed of one and the same basic shape, modified by dots varying in number and placement. Due to such increased visual and compositional between letter similarity, it has been claimed that processing Arab letters is more challenging, that is, slower and less accurate than processing the Hebrew alphabet that uses letters that are visually more distinguished (Ibrahim et al., 2002, 2007). The finding that, in our study, Arab participants—both deaf and hearing—manifested marked letter-processing deficits even when asked to process letter identity under perceptual conditions seems to be in line with this theory.

In conclusion, evidence from the analysis of deaf and hearing participants' performance in this study highlights that in some orthographies deaf readers' reading skills deviate from those of their hearing counterparts already at the most basic level of reading, the letter-processing level. This suggests that investigations of the poor reading comprehension of the majority of this population has to start on this initial level in order to establish its relation to their word processing and reading comprehension skills.

Findings in general suggest that prelingual deafness per se does not hamper the development of effective letter-processing skills (Miller, 2001). In orthographies in which prelingually deaf readers have been found to manifest deficits in this regard, such deficits seem to be rooted in characteristics of the orthography (e.g., between-letter similarity) or in the educational approach advocated by schools in teaching deaf students to read (e.g., strict oral approach). The former seems to create a disadvantage for both deaf and hearing readers, the consequences of the latter, however, are likely to be restricted to the deaf (see also Kargin et al., 2011). Whereas the basic characteristic of an orthography are not likely to change in favor of the deaf, educational policy definitely can and should be modified in ways that provide prelingual deaf readers optimal opportunities to become fully literate.

Implication for Theory and Practice and Direction of Future Research

A marked weakness manifested by the majority of prelingually deaf readers with regard to phonological decoding of written words has been interpreted by some researchers as being the central cause of their poor reading comprehension skills (Paul, Wang, Trezek, & Luckner, 2009; Perfetti & Sandak 2000; Wang, Trezek, Luckner, & Paul, 2008). Evidence from this study seems to challenge the validity of such a phonological coding deficit theory as a valid explanation of deaf readers' marked reading comprehension deficits. Our research results actually show that despite permanent hearing loss, deaf readers develop letter-processing strategies that sustain the effective processing of written words (see also Kargin et al., 2011; Miller, 2001, 2002, 2004a, 2004b, 2004c, 2005a, 2005b, 2006a, 2006b; Miller & Clark, 2011; Wauters, Van Bon, & Tellings, 2006). Moreover, the findings suggest that in instances in which deaf readers manifest letter-processing skills that are significantly poorer than those of hearing counterparts (e.g., Arabic and Turkish participants), particularities of the processed orthography such as

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visual complexity (e.g., Eviatar & Ibrahim, 2001; Eviatar, Ibrahim, & Ganayim, 2004; Ibrahim, Eviatar, & Aharon-Peretz, 2002, 2007) or strict oral reading instruction (Zeshan, 2003), may be the major cause for such deficits. The impact of these conditions may prove particularly detrimental in conjunction with markedly reduced reading experience.

Evidence from this study suggests that orthographic depth (Frost, 2006) is not a significant factor that determines the processing of letters, in general, nor does it explain differences between deaf and hearing readers, in particular. The finding that participants processing letters in shallow orthography (e.g., German, Turkish) did not manifest significantly enhanced letter-processing skills in comparison to those processing letters in deep orthography (e.g., English) actually suggests that they may have used abstract orthographic rather than phonological representations to mediate letter processing in the conceptual condition (Miller, 2001). Given this to be the case, it makes sense to assume that Turkish deaf participants were disadvantaged due to a strict oral educational philosophy that explicitly encourages phonological processing as a default strategy. Moreover, orthographic representations are likely to reflect letter graphemes' visual properties. Increased visual complexity/confusability characteristic of the Arab alphabet may therefore hamper their optimal internalization. The impact of such visual complexity/confusability may prove particularly detrimental in conjunction with a markedly reduced reading experience. The weak letter-processing skills of deaf Arab readers are likely to just show the consequences of this problematic combination.

Findings from the present study—beyond their theoretical contribution—also bear some practical implications. As stated earlier, the efficient recognition of letter graphemes is a fundamental step in the recognition of written words (Jackson & Coltheart, 2001). For this purpose, novice students are taught the shapes of letters and learn to associate them with specific phonemes. Once their students reliably recognize the letters and retrieve their sounds, teachers tend to move on to the next stage—the reading of words. They do so mostly unaware of the fact that having acquired the alphabetic principle is not sufficient, but it is the automation of its underlying processes that is required to guarantee the efficient processing of written words.

Evidence from this study suggests that both deaf and hearing readers from the majority of orthographies achieved such automation in the course of a prolonged reading experience. However, evidence also shows that readers, especially deaf readers, may fail to optimize their letter-recognition skills in the presence of particular orthography-inherent characteristics (e.g., visual complexity/confusability of the Arab alphabet's letters). The same seems to hold true in instances in which they learn the alphabetic principle according to an educational philosophy (oralism) that stresses the phonological processing of letters as a default strategy. In both these instances, the involvement of novice readers in activities (games) that foster rapid and accurate letter recognition, parallel to initial reading, may prove effective in fostering the automation of processes that underlie letters' effective processing. Given the central role letter processing plays in written word recognition, ascertaining its proper development should logically be given high priority.

Evidence regarding differences between deaf and hearing readers presented here is not of a developmental nature. In fact, it portrays the letter-processing skills of individuals with at least 5 years of formal reading experience. The finding that—in the majority of the tested orthographies—deaf participants manifested norm-comparable letter-processing skills, although undoubtedly encouraging, must therefore be read with some caution. Equality at this point of education does not necessarily reflect a normal development of their letter-processing skills at earlier stages. It actually may be that deaf readers—due to reduced reading experience/exposure—may take more time to optimize their letter-processing skills. This possibility requires an expansion of this study that would include participants from lower and from higher grade levels. Such research is particularly warranted given that the ability to process letters effectively must be considered fundamental from the very beginning of novice readers' efforts to make sense of written text. Such research would further allow testing to determine whether prolonged reading experience eventually leads to the development of norm-comparable letter-processing skills even in orthographies in which visual properties of letters may hamper the optimization of processes underlying the rapid and accurate processing of letters.

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Evidence from this study shows that, in principle, deaf readers are capable of developing letter-processing skills that are as effective as those of hearing readers. However, the same evidence is not indicative of whether the processing strategy the two groups relied on for this achievement was the same. It also does not disclose whether the nature of deaf readers' letter-processing strategy was modified by the nature of the reading instruction they received to foster the development of their reading skills (e.g., emphasis on an oral strategy). As a more complete understanding of these issues has significant implications for the development of adequate reading instruction, future research should put emphasis on the development of sophisticated research paradigms that allow tracking the nature of the strategies/knowledge readers rely on in the processing of isolated letters (e.g., Miller & Vaknin, 2012).

Note

1. The significance level in post-hoc analyses conducted with Dunnett T3 was set to 0.05.

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Conflicts of Interest

No conflicts of interest were reported.

References

Alegria, J., Leybaert, J., Charlier, B., & Hage, C. (1992). On the origin of phonological representations in the deaf: Hearing lips and hands. In J. Alegria, D. Holender, J. Junça de Morais, & M. Radeau (Eds.), *Analytic approaches to human cognition* (pp. 107–132). Bruxelles, BE: Elsevier Science.

Allen, T. E., Clark, M. D., del Giudice, A., Koo, D., Lieberman, A., Mayberry, R., & Miller, P. (2009). Phonology and reading: A response to Wang, Trezek, Luckner, and Paul. *American Annals of the Deaf*, *145*, 338–345. doi:10.1353/aad.0.0109

American National Standards Institute. (1989). *Specifications for audiometers* (ANSI S3.6-1989). New York, NY: Author.

Badian, N. (1995). Predicting reading ability over the long term: The changing roles of letter naming, phonological awareness and orthographic processing. *Annals of Dyslexia*, *45*, 79–96. doi:10.1007/BF02648213

Beech, J. R., & Harris, M. (1997). The prelingually deaf young reader: A case of reliance on direct lexical access? *Journal of Research in Reading*, *20*, 105–121. doi:10.1111/1467–9817.00024

Biemiller, A. (1977). Relationships between oral reading rates for letters, words, and simple text in the development of reading achievement. *Reading Research Quarterly*, *13*, 223–253. doi:10.2307/747307

Cossu, G., Shankweiler, D., Liberman, I. Y., & Gugliotta, M. (1995). Visual and phonological determinants of misreadings in a transparent orthography. *Reading and Writing*, *7*, 237–256. doi:10.1007/BF02539523

Davis, C. (2005). Shallow vs. non-shallow orthographies and learning to read workshop. *Report of the OECD-CERI Learning Sciences and Brain Research*. Retrieved from http://www.oecd.org/dataoecd/54/39/35562310.pdf.

Drieghe, D., & Brysbaert, M. (2002). Strategic effects in associative priming with words, homophones, and pseudohomophones. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *28*, 951–961. doi:10.1037/0278-7393.28.5.951

Durgunoğlu, A., & Öney, B. (1999). A cross-linguistic comparison of phonological awareness and word recognition. *Reading and Writing: An Interdisciplinary Journal*, *11*, 281–299. doi:10.1023/A:1008093232622

Dyer, A., MacSweeney, M., Szczerbinski, M., Green, L., & Campbell, R. (2003). Predictors of reading delay in deaf adolescents: The relative contributions of rapid automatized naming speed and phonological awareness and decoding. *Journal of Deaf Studies and Deaf Education*, *8*, 215–229. doi:10.1093/deafed/eng012

Eviatar, Z., & Ibrahim, R. (2001). Bilingual is as bilingual does: Metalinguistic abilities of Arabic speaking children. *Applied Psycholinguistics*, *21*, 451–471. doi:10.1017/S0142716400004021

Eviatar, Z., Ibrahim, R., & Ganayim, D. (2004). Orthography and the hemispheres: Visual and linguistic aspects of letter processing. *Neuropsychology*, *18*, 174–184, doi:10.1037/0894-4105.18.1.174

Frith, U. (1985). A developmental framework for developmental dyslexia. *Annuals of Dyslexia*, *36*, 69–81, doi:10.1007/BF02648022

Frost, R. (1998). Toward a strong phonological theory of visual word recognition: True issues and false trials. *Psychological Bulletin*, *123*, 71–99, doi:10.1037/0033-2909.123.1.71

Frost, R. (2006). Becoming literate in Hebrew: The grain-size hypothesis and Semitic orthographic systems. *Developmental Science*, *9*, 439–440. doi:10.1111/j.1467-7687.2006.00523.x

Frost, R. (2009). Reading in Hebrew versus reading in English: Is there a qualitative difference? In K. Pugh & P. McCardle (Eds.), *How children learn to read: Current issues and new directions in the integration of cognition, neurobiology and genetics of reading and dyslexia research and practice* (pp. 235–254). New York, NY: Psychology Press.

Frost, R., Katz, L., & Bentin, S. (1987). Strategies for visual word recognition and orthographic depth: A multilingual comparison. *Journal of Experimental Psychology: Human Perception and Performance*, *13*, 104–115. doi:10.1037/0096-1523.13.1.104

Froster, K. I., & Froster, J. C. (2003). DMDX: A Windows display program with millisecond accuracy. *Behavior Research*

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Methods, Instruments & Computers, *35*, 116–124. doi:10.3758/BF03195503

Goswami, U., Gombert, J. E., & de Barrera, L. (1998). Children's orthographic representations and linguistic transparency: Nonsense word reading in English, French, and Spanish. *Applied Psycholinguistics*, *19*, 19–52. doi:10.1017/S0142716400010560

Gough, P. B., & Tunmer, W. E. (1986). Decoding, reading and reading disability. *Remedial and Special Education*, *7*, 6–10. doi:10.1177/074193258600700104

Guardino, C., Selznick, D. N., & Syverud, S. M. (2009). Teaching phonological skills to a deaf first grader: A Promising Strategy. *American Annals of the Deaf*, *154*, 382–388. doi:10.1353/aad.0.0113

Harris, M., & Beech, J. R. (1995). Reading development in prelingually deaf children. In K. E. Nelson & Z. Reger (Eds.), *Children's language* (pp. 181–202). Hillsdale, NJ: Erlbaum.

Hoover, W. A., & Tunmer, W. E. (1993). The components of reading. In G. B. Thompson, W. E. Tunmer, & T. Nicholson (Eds.), *Reading acquisition processes* (pp. 1–19). Clevedon, UK: Multilingual Matters.

Hoover, W. A., & Gough, P. B. (1990). The simple view of reading. *Reading and Writing: An Interdisciplinary Journal*, *2*, 127–160. doi:10.1007/BF00401799

Ibrahim, R., Eviatar, Z., & Aharon-Peretz, J. (2002). The characteristics of the Arabic orthography slow its cognitive processing. *Neuropsychology*, *16*, 322–326, doi:10.1037/0894-4105.16.3.322

Ibrahim, R., Eviatar, Z., & Aharon-Peretz, J. (2007). Metalinguistic awareness and reading performance: A cross language comparison. *Journal of Psycholinguistic Research*, *36*, 297–317. doi:10.1007/s10936-006-9046-3

Jackson, N. E., & Coltheart, M. (2001). *Routes to reading success and failure: Toward an integrated cognitive psychology of atypical reading*. New York, NY: Psychological Press.

Kargin, T., Guldenoglu, I. B., Miller, P., Hauser, P., Rathmann, C., Kubus, O., & Superegon, E. (2011). Differences in word processing skills of deaf and hearing individuals reading in different orthographies. *Journal of Developmental and Physical Disabilities*, *24*, 64–83. doi:10.1007/s10882-011-9255-z

Katz, L., & Frost, R. (1992). Orthography, phonology, morphology, and meaning: An overview. In R. Frost & L. Katz (Eds.), *Orthography, phonology, morphology, and meaning* (pp. 1–8). Amsterdam, NL: Elsevier North Holland Press.

Katz, L., & Feldman, L. B. (1981). Linguistic coding in word recognition: Comparisons between a deep and a shallow orthography. In A. Lesgold & C. Perfetti (Eds.), *Interactive processes in reading*. (pp. 85–106). Hillsdale, NJ: Erlbaum.

Kubus, O., Rathman, C., Hauser, P., Miller, P., Kargin, T., & Guldenoglu, B. (2012). *Effect of orthographical systems and age of acquisition (AoA) on deaf reading*. 34th Annual Conference of the German Linguistic Society (DGfS), Frankfurt, Germany.

Landerl, K. (2000). Influences of orthographic consistency and reading instruction on the development of nonword reading skills. *European Journal of Psychology of Education*, *15*, 239–257. doi:10.1007/BF03173177

Leach, J. M., Scarborough, H. S., & Rescorla, L. (2003). Late-emerging reading disabilities. *Journal of Educational Psychology*, *95*, 211–224. doi:10.1037/0022-0663.95.2.211

Lewis, R. B., & Doorlag, D. H. (1983). *Teaching special studies in mainstream*. Columbus, OH: Charles E. Merill Publishing Company.

Leybaert, J. (2000). Phonology acquired through the eyes and spelling in deaf children. *Journal of Experimental Child Psychology*, *75*, 291–318. doi:10.1006/jecp.1999.2539

Martin, F., Pratt, C., & Fraser, J. (2000). The use of orthographic and phonological strategies for the decoding of words in children with developmental dyslexia and average readers. *Dyslexia*, *6*, 231–247. doi:10.1111/1467–9817.00196

Mayberry, R. I., del Giudice, A. A., & Lieberman, A. M. (2011). Reading achievement in relation to phonological coding and awareness in deaf readers: A meta-analysis. *Journal of Deaf Studies and Deaf Education*, *16*, 164–188. doi:10.1093/deafed/enq049

Miller, P. (2000). Syntactic and semantic processing in deaf and hearing readers. *American Annals of the Deaf*, *145*, 436–448. doi:10.1353/aad.2012.0116

Miller, P. (2001). Communication mode and the information processing capacity of Hebrew readers with prelingually acquired deafness. *Journal of Developmental and Physical Disabilities*, *13*, 83–96. doi:10.1023/A:1026561417325

Miller, P. (2002). Another look at the STM capacity of prelingually deafened individuals and its relation to reading comprehension. *American Annals of the Deaf*, *147*, 56–70. doi:10.1353/aad.2012.0226

Miller, P. (2004a). The importance of vowel diacritics for reading in Hebrew: What can be learned from readers with prelingual deafness? *Reading and Writing: An Interdisciplinary Journal*, *17*, 593–615. doi:10.3758/s13421-010-0026-3

Miller, P. (2004b). Processing of written word and non-word visual information by individuals with prelingual deafness. *Journal of Speech, Language, and Hearing Research*, *47*, 990–1000. doi:10.1044/1092–4388(2004/073)

Miller, P. (2004c). Processing of written words by individuals with prelingual deafness. *Journal of Speech, Language, and Hearing Research*, *47*, 979–989. doi:10.1044/1092–4388(2004/072)

Miller, P. (2005a). Reading comprehension and its relation to the quality of functional hearing: Evidence from readers with different functional hearing abilities. *American Annals of the Deaf*, *150*, 305–323. doi:10.1353/aad.2005.0031

Miller, P. (2005b). What the word recognition skills of prelingually deafened readers tell about the roots of dyslexia. *Journal of Development & Physical Disabilities*, *17*, 369–393. doi:10.1007/s10882-005-6620-9

Miller, P. (2005c). Reading experience and changes in the processing of letters, written words and pseudohomophones: Comparing fifth grades students and university students. *The Journal of Genetic Psychology*, *166*, 407–434. doi:10.3200/GNTP.166.4.407-434

Miller, P. (2006a). What the processing of real words and pseudohomophones tell about the development of orthographic knowledge in prelingually deafened individuals. *Journal of Deaf Studies and Deaf Education*, *11*, 21–38. doi:10.1093/deafed/enj001

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Miller, P. (2006b). What the visual word recognition skills of prelingually deafened readers tell about their reading comprehension problems. *Journal of Developmental and Physical Disabilities*, *18*, 91–121. doi:10.1007/s10882-006-9002-z

Miller, P. (2010). Phonological, orthographic, and syntactic awareness and their relation to reading comprehension in prelingually deaf individuals: What can we learn from skilled readers? *Journal of Development and Physical Disabilities*, *22*, 549–561. doi:10.1007/s10882-010-9195-z

Miller, P., & Clark, M. D. (2011). Phonological Awareness is not necessary to become a skilled deaf reader. *Journal of Development and Physical Disabilities*, *23*, 459–476. doi:10.1007/s10882-011-9246-0

Miller, P., Kargin, T., & Guldenoglu, B. (2012). Differences in the reading of shallow and deep orthography: Developmental evidence from Hebrew and Turkish readers. *Journal of Research in Reading*, *00*, 1–24. doi:10.1111/j.1467-9817.2012.01540.x

Miller, P., Kargin, T., Guldenoglu, I. B., Hauser, P., Rathmann, C., Kubus, O., & Superegon, E. (2012). Factors distinguishing skilled and less skilled deaf readers: Evidence from four orthographies. *Journals of Deaf Studies and Deaf Education*, *17*, 439–462. doi:10.1093/deafed/ens02

Miller, P., & Vaknin, V. (2012). The involvement of letter names in the silent processing of isolated letters: A developmental perspective. *Memory & Cognition*, *40*, 1276–1288. doi:10.3758/s13421-012-0223-3

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

Nielsen, D. C., & Luetke-Stahlman, B. (2002). Phonological awareness: One key to the reading proficiency of deaf children. *American Annals of the Deaf*, *147*, 11–19. doi:10.1353/aad.2012.0213

Oney, B., & Durgunoglu, A. Y. (1997). Beginning to read in Turkish: A phonologically transparent orthography. *Applied Psycholinguistics*, *18*, 1–15. doi:10.1017/S014271640000984X

Oney, B., & Goldman, S. (1984). Decoding and comprehension skills in Turkish and English: Effects of the regularity of grapheme-phoneme correspondences. *Journal of Educational Psychology*, *76*, 557–568. doi:10.1037/0022-0663.76.4.557

Padden, C., & Hanson, V. L. (2000). Search for the missing link: The development of skilled reading in deaf children. In K. Emmorey & H. Lane (Eds.), *The signs of language revisited* (pp. 435–447). Hillsdale, NJ: Erlbaum.

Paul, P. V., Wang, Y., Trezek, B. J., & Luckner, J. L. (2009). Phonology is necessary, but not sufficient: A rejoinder. *American Annals of the Deaf*, *154*, 346–356. doi:10.1353/aad.0.0110

Perfetti, C. A., & Sandak, R. (2000). Reading optimally builds on spoken language: Implications for deaf readers. *Journal of Deaf Studies and Deaf Education*, *5*, 32–50. doi:10.1093/deafed/5.1.32

Posner, M. I., & Mitchell, R. F. (1967). Chronometric analysis of classification. *Psychological Review*, *74*, 392–409. doi:10.1037/h0024913

Raman, I. (2006). On the age-of-acquisition effects in word naming and orthographic transparency: Mapping specific or universal? *Visual Cognition*, *13*, 1044–1053. doi:10.1080/13506280500153200

Raman, I., Baluch, B., & Besner, D. (2004). On the control of visual word recognition: Changing routes versus changing deadlines. *Memory & Cognition*, *32*, 489–500. doi:10.3758/BF03195841

Ross, A. O. (1976). *Psychological aspects of learning disabilities and reading disorders*. New York, NY: MacGraw-Hill Book Company.

Scarborough, H. (2005). Development relationships between language and reading: Reconciling a beautiful hypothesis with some ugly fact. In H. W. Catts, & A. G. Kamhi (Eds.), *The connections between language and reading disabilities* (pp. 3–24). Mahwah, NJ: Erlbaum.

Seymour, P. H. K., Aro, M., & Erskine, J. M. (2003). Foundation literacy acquisition in European orthographies. *British Journal of Psychology*, *94*, 143–174. doi:10.1348/000712603321661859

Share, D. L. (1995). Phonological recoding and self-teaching: Sine qua non of reading acquisition. *Cognition*, *55*, 151–218. doi:10.1016/0010-0277(94)00645-2

Shaywitz, S. E., & Shaywitz, B. A. (2005). Dyslexia (specific reading disability). *Biological Psychiatry*, *57*, 1301–1309. doi:10.1016/j.biopsych.2005.01.043

Spencer, L. H., & Hanley, J. R. (2003). The effects of orthographic consistency on reading development and phonological awareness in children learning to read in Wales. *British Journal of Psychology*, *94*, 1–28. doi:10.1348/000712603762842075

Sterne, A., & Goswami, U. (2000). Phonological awareness of syllables, rhymes and phonemes in deaf children. *Journal of Child Psychology and Psychiatry*, *41*, 609–625. doi:10.1111/1469–7610.00648

Transler, C., & Reitsma, P. (2005). Phonological coding in reading of deaf children. Pseudohomophone effects in deaf children. *British Journal of Developmental Psychology*, *23*, 525–542. doi:10.1348/026151005X26796

Transler, C., Gombert, J. E., & Leybaert, J. (2001). Phonological decoding in severely and profoundly deaf children: Similarity judgment between written pseudowords. *Applied Psycholinguistics*, *22*, 61–82. doi:10.1017/S0142716401001047

Tunmer, W. E. (2008). Recent developments in reading intervention research: Introduction to special issue. *Reading and Writing*, *21*, 299–316. doi:10.1007/s11145-007-9108-4

Vaknin, V., & Miller, P. (2011). The importance of vowel diacritics for the temporary retention of high and low frequency Hebrew words of varying syllabic length. *Memory & Cognition*, *39*, 516–526. doi:10.3758/s13421-010-0026-3

Van Orden, G. C., Johnston, J. C., & Hale, B. L. (1988). Word identification in reading proceeds from spelling to sound to meaning. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *14*, 371–386. doi:10.1037/0278-7393.14.3.371

Vellutino, F. R., Fletcher, J. M., Snowling, M. J., & Scanlon, D. M. (2004). Specific reading disability (dyslexia): What have we learned in the past four decades? *Journal of Child Psychology and Psychiatry*, *45*, 2–40. doi:10.1046/j.0021-9630.2003.00305.x

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Wang, Y., Trezek, B. J., Luckner, J., & Paul, P. V. (2008). The role of phonology and phonologically related skills in reading instruction for students who are deaf or hard of hearing. *American Annals of the Deaf*, *153*, 396–407. doi:10.1353/aad.0.0061

Waters, G. S., & Doehring, D. B. (1990). Reading acquisition in congenitally deaf children who communicate orally: Insights from an analysis of component reading, language, and memory skills. In T. H. Carr & B. A. Levy (Eds.), *Reading and its development: Component skills approaches* (pp. 323–373). San Diego, CA: Academic.

Wauters, L. N., Van Bon, W. H. J., & Tellings, A. J. M. (2006). Reading comprehension of Dutch deaf children. *Reading and Writing*, *19*, 49–76. doi:10.1007/s11145-004-5894-0

Wimmer, H., & Goswami, U. (1994). The influence of orthographic consistency on reading development: Word recognition in English and German children. *Cognition*, *51*, 91–103. doi:10.1016/0010-0277(94)90010–8

Wimmer, H., & Hummer, P. (1990). How German-speaking first graders read and spell: Doubts on the importance of the logographic stage. *Applied Psycholinguistics*, *11*, 349–368. doi:10.1017/S0142716400009620

Wolf, M. (1991). Naming speed and reading: The contribution of the cognitive neurosciences. *Reading Research Quarterly*, *26*, 123–141. doi:10.2307/747978

Zeshan, U. (2003). Aspects of Türk Isaret Dili (Turkish Sign Language). *Sign Language and Linguistics*, *6*, 43–75. doi:10.1075/sll.6.1.04zes

Ziegler, J. C., & Goswami, U. (2005). Reading acquisition, developmental dyslexia, and skilled reading across languages: A psycholinguistic grain size theory. *Psychological Bulletin*, *131*, 3–29. doi:10.1037/0033-2909.131.1.3

Ziegler, J. C., & Goswami, U. (2006). Becoming literate in different languages: Similar problems, different solutions. *Developmental Science*, *9*, 429–436. doi:10.1111/j.1467-7687.2006.00509.x

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