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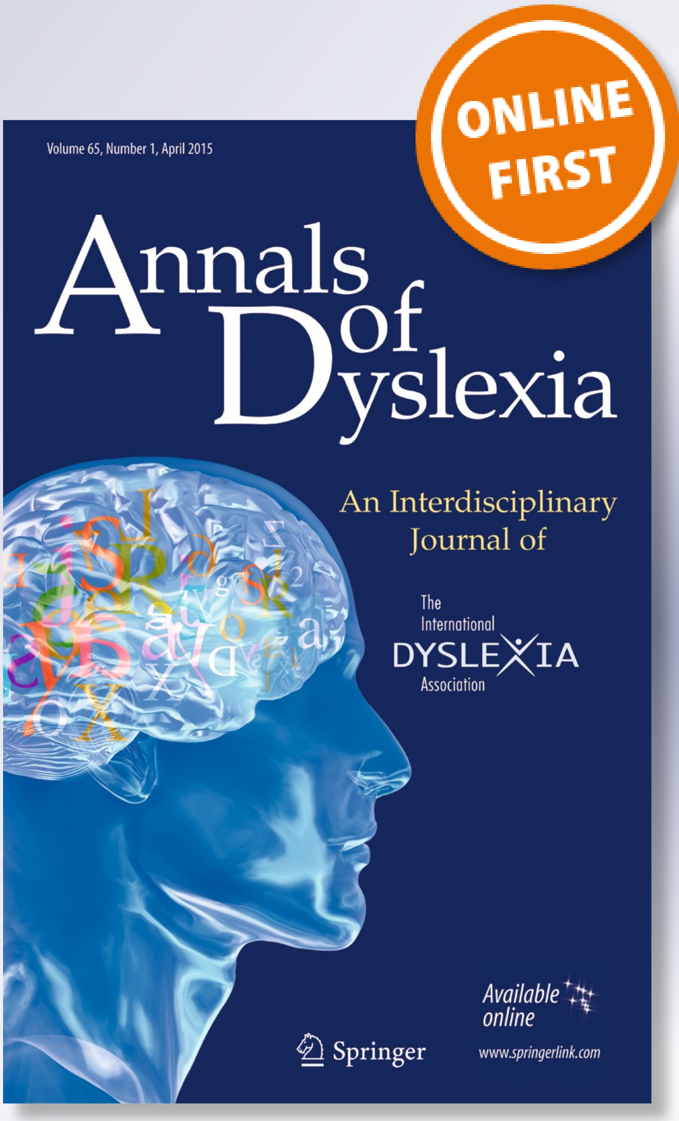

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Abstract The current study examined the effects of transparency and familiarity on word recognition in adult Hebrew dyslexic readers with a phonological processing deficit as compared to typical readers. We measured oral reading response time and accuracy of single nouns in several conditions: diacritics that provide transparent but less familiar information and vowel letters that increase orthographic transparency without compromise familiarity. In line with former studies with adult dyslexics, Hebrew-speaking adults with dyslexia were significantly slower than controls. However, both dyslexic and typical readers read unpointed words faster when vowel letters were present, indicating that they may benefit from increase in orthographic transparency, when the graphemic representations are familiar. Only dyslexics read pointed words slower than unpointed words and were more sensitive to word frequency. In unpointed words, only typical readers benefitted from the reduced competition of orthographic neighbors of longer words. Results indicate that both orthographic transparency and familiarity play an important role in word recognition. Dyslexics are impaired in decoding of smaller units and are more sensitive to reduction in the familiarity of words.

Keywords Adult dyslexics · Hebrew · Orthographic transparency · Phonological deficit

Introduction

The current state of our understanding of how we process written language and the difficulties found in dyslexic readers is largely affected by studies of English speakers reading in their

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native tongue (Share, 2008a). In recent years, significant steps have been made toward developing general theories of reading and reading disabilities that look beyond the English language and beyond the early ages of reading acquisition (Frost, 2005, 2012; Katz & Frost, 1992; Perfetti, Liu, & Tan, 2005; Perfetti, 2011; Seymour, 2006; Ziegler & Goswami, 2005, 2006).

Less is known about adults with dyslexia in Semitic languages, which have a unique orthographic structure that can be either transparent or opaque. Reading acquisition in Semitic languages is unique as initially children are exposed to the transparent version of the orthography that fully represent the phonology, and later on to the less transparent "Abjad" version, that mostly represent the consonants but only partially represent vowels. The influence of the long-lasting effects of the shift to the less transparent script on adult dyslexic readers of Hebrew has scarcely been studied, and classic theories of word recognition do not provide an adequate account for the processes involved in reading and reading acquisition in Semitic languages.

Is reading universal? The effect of orthographic transparency

Learning to read in all languages requires first and foremost the understanding of the universal principle that writing systems represent units of spoken language (Perfetti, 2003). Since writing systems represent units of spoken language, they are structured so that they optimally represent the languages' phonological spaces and their mapping into semantic meanings (Frost, 2012). It is customary to characterize alphabetic writing systems according to their orthographic transparency: In transparent orthographies, such as Italian or Spanish, the grapheme to phoneme correspondence is consistent, while in opaque orthographies, such as English or French, the grapheme to phoneme correspondence is less consistent.

There is a debate in the literature regarding whether phonological information mediates access to the mental visual word lexicon for adult readers. The Orthographic Depth Hypothesis (Katz & Frost, 1992), inspired by the Dual Route Model (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001), suggests that readers rely on one of two routes for reading, depending on the demands of the specific orthography. In more transparent orthographies, readers access to words' meaning through its phonology, by assembled (letter by letter) reading. In more opaque orthographies, access through phonology is not obligatory, and meaning is accessed directly by decoding of large orthographic unit (whole-word) (Katz & Frost, 1992).

In contrast, according to connectionist models (McClelland & Rumelhart, 1981; Seidenberg & McClelland, 1989), access to phonology is obligatory for reading in all orthographies, and there are more than just two possible routes for reading. In addition, the size of the units in the orthography-to-phonology mappings is determined not only by orthographic transparency but also by reading proficiency of the individual reader and the characteristics of the language, such as phonological and morphological structure (Frost, 2005; Perfetti, 2003; Perfetti et al., 2005; Ziegler & Goswami, 2005). In this paper, we will look at the Hebrew orthography that has both an opaque and a transparent version. We will examine the effect of orthographic transparency on the size of the phonological units which are being mapped by adult Hebrew-speaking dyslexics and whether it aids their word recognition.

Does dyslexia have a universal cause? The effect of orthographic transparency on dyslexia in different orthographies

Despite differences among writing systems in the characteristics of individuals with developmental dyslexia (Dulude, 2012; Landerl et al., 2012; Paulesu et al., 2001; Ramus et al., 2003), there are universal patterns characterizing dyslexia across languages. Studies across different alphabetical orthographies show deficient phonological processing in individuals with dyslexia, evident in poor phonological awareness, poor verbal short-term memory, and slow lexical retrieval (Paulesu et al. 2001; Stanovich, 1988; Ziegler et al., 2003; Ziegler & Goswami, 2005). While different subtypes of dyslexia exist (Castles & Coltheart, 1993; Castles, Bates, & Coltheart, 2006; Hadzibeganovic et al., 2010; Manis et al., 1996; Wolf & Bowers, 1999; Zoccolotti & Friedmann, 2010), the phonological deficit appears to be widely associated with dyslexia. Results from studies in different languages suggest that the core deficit for most dyslexics in all languages is in the establishment of efficient small phonological grain size processing (Dehaene, 2014; Ziegler and Goswami 2005; Arabic: Abu-Rabia, Share, & Mansour, 2003; Hebrew: Breznitz, 1997b; Shany & Breznitz, 2011; Korean: Kim & Davis, 2004; Greek: Porpodas, 1999; English: Hatcher et al. 2002; Polish: Reid et al. 2007; Rack et al. 1992; French: Sprenger-Charolles et al., 2000; Dutch: Van der Leij et al., 2002; Callens et al., 2012; German: Wimmer, 1996).

Despite a common core phonological deficit, there is evidence suggesting that the expression of dyslexia in different languages is affected by orthographic transparency. Dyslexics reading transparent orthographies show higher levels of reading accuracy (Breznitz, 1997a; Paulesu et al., 2001; Vellutino et al., 2004; Wimmer & Goswami, 1994; Ziegler et al., 2003; Frith et al., 1998; Landerl et al., 1997; Oren & Breznitz, 2005), reading comprehension (Paulesu et al., 2001), phonological awareness (Bruck, 1992; de Jong and van der Leij 2003), and rapid naming tasks (Katzir et al., 2004), as compared to dyslexics reading opaque orthographies, suggesting that dyslexics benefit from orthographic transparency. However, in the cross-linguistic comparison between different populations, orthographic transparency is confounded by differences in the spoken language as well as cultural, educational, and individual differences. Previous studies did not examine regular words with various levels of transparency within-subjects and within-language. Furthermore, most previous studies examined the effect of transparency on dyslexic children, while this effect was rarely examined in dyslexic adults.

Studies with dyslexic readers in orthographies that have both opaque and transparent writing systems provide opportunity to examine the effect of transparency within-subjects and within-language. In a study in Persian, dyslexic children demonstrated poor accuracy and speed as compared to typically developing children in both transparent (vowelized) and opaque (unvowelized) words. The differences were greater in unvowelized words (Baluch & Danaye-Tousi, 2006). Findings from studies with dyslexic Hebrew readers will be discussed below.

Beyond transparency and phonology

Connectionist models, which look beyond the effect of orthographic transparency, suggest that high quality orthographic representation is the gateway to efficient reading in all orthographies (Perfetti, 2007, 2011). According to some studies, deficient orthographic knowledge contributes to reading disabilities beyond the phonological deficit (Barker et al., 1992; Berninger et al., 2002; Bowers & Wolf, 1993; Cunningham & Stanovich, 1990; Stanovich & West, 1989). Other studies suggest that deficient orthographic representations are caused primarily by an underlying phonological deficit (Booth et al. 2000; Jorm & Share, 1983; Share, 2008b, 1995). Dyslexics' deficient phonological processing in childhood may cause low lexical quality in adulthood, because it hinders the establishment of word-specific orthographic representations (Elbro, 1998; Manis et al. 1996; Perfetti, 2007; Share, 1995). Thus, adult dyslexics may be more vulnerable to low word-form frequency and low familiarity as compared to typical readers. Hebrew provides an interesting case since; especially for adult readers, an increase in transparency may decrease the familiarity of the orthographic word form.

Transparency and familiarity in the Hebrew orthography

Hebrew has one script with two versions that differ in their orthographic transparency: The opaque version is unpointed Abjad orthography that mostly represents consonants and partially represents vowels with vowel letters, creating extensive phonological under-specification as well as pervasive homography (Bar-On, 2010; Share, In prep). The transparent version is pointed, with diacritic marks (in addition to the consonants and vowel letters) that provide full representation of words' phonology. This duality provides a unique opportunity to examine the effect of orthographic transparency on reading in a within-language and within-subject design. However, it should also be noted that pointed words are mostly encountered during early years of reading acquisition and are absent from most texts for skilled readers. Therefore, in the case of adult Hebrew readers, the highly transparent script is also less frequently encountered.

While diacritics provide full and unambiguous vowel information, vowel letters provide only partial and ambiguous vowel information. All vowel letters denote both consonants and vowels, and some of them represent more than one vowel. However, in contrast to diacritics which are superimposed under or above the consonants, vowel letters are written in line with the consonants in a written word and are very common in texts for skilled readers. Importantly, while the presence of diacritics is optional and may decrease familiarity with the words' orthographic pattern for adult readers, most Hebrew words appear consistently either with or without vowel letters, so vowel letter does not change the word familiarity. Thus, comparing the effects of diacritics and vowel letters enables us to examine different degrees of orthographic transparency, with stronger effects expected for diacritics as they provide more phonological information. However, we hypothesized that while vowel letters do not enhance orthographic transparency to the same degree as diacritics, they do not compromise familiarity either; hence, their overall benefit for word recognition may be larger.

A large number of studies have examined the role of diacritics in word recognition for Hebrew readers at various stages of reading acquisition. Diacritics were found to facilitate word recognition in early stages of reading acquisition (Harel-koren, 2007; Navon & Shimron, 1981; Ravid, 1996; Shany et al. 2011; Shimron & Sivan, 1994), and that the facilitating effect of vowel letters on word recognition develops over time with increasing exposure to unpointed words (Harel-koren, 2007; Schiff, 2003; Shany et al. 2011). For skilled readers, different studies show mixed results: Diacritics either facilitate (Koriat, 1984, 1985; Navon & Shimron, 1981; Shimron & Navon, 1982) or had no effect (Bentin & Frost, 1987; Harel-koren, 2007; Schiff & Ravid, 2004; Shimron & Sivan, 1994) on word recognition. Vowel letters were found to improve word recognition for skilled Hebrew readers, only in unpointed words (Frost, 1995; Ravid & Schiff, 2004; Schiff & Ravid, 2004).

Dyslexia in Hebrew and the role of orthographic transparency

Many dyslexic Hebrew readers, like dyslexics in other orthographies, show deficient phonological processing that is characterized by poor phoneme awareness and low decoding skills as compared to typical readers (Friedmann & Castles, 2013; Miller-Shaul, 2005; Shany & Share, 2010; Shany & Ben-Dror, 2011; Shany & Breznitz, 2011). These differences increase during development, while differences in orthographic processing decrease, suggesting that dyslexic readers develop a compensatory orthographic strategy over the years (Miller-Shaul, 2005).

The current literature about the role of diacritics and vowel letters for Hebrew-speaking children and adults with dyslexia is scarce and shows contradicting findings. Several studies demonstrate low accuracy and speed in Hebrew-reading dyslexic children and adults as compared to controls for both pointed and unpointed words (Breznitz & Meyler, 2003; Breznitz, 2002; Breznitz & Misra, 2003). However, a study with dyslexic fourth-graders found that they performed worse than typically developing second graders in reading accuracy of pointed words but not in reading unpointed words (Schiff, Katzir, & Shoshan, 2012). In addition, dyslexic sixth graders who demonstrated poor phonemic awareness, did not benefit from reading more transparent pointed as compared to unpointed text (Shany & Ben-Dror, 2011), and adult dyslexics performed poorly on a lexical decision task even in the presence of diacritics, and unlike typical readers, they did not benefit from the presentation of vowel letters (Schiff & Ravid, 2004).

The current study

In the current study, we aim to shed light on the role of phonology in typical and impaired reading. For this purpose, we used the two versions of the Hebrew script to examine the effects of orthographic transparency and familiarity, and their compound effect on typical and dyslexic adult readers. The effect of orthographic transparency was examined by comparing word recognition latency and accuracy of pointed and unpointed words and by comparing words with and without vowel letters. To examine whether additional phonological information increases the reliance on assembled reading, we manipulated the number of consonants, because a slowing effect of word length is a sensitive indicator of assembled reading (De Luca et al. 2008; Ellis & Hooper, 2001; Ellis et al. 2004).

The effect of familiarity with the orthographic representations is evident in the comparison of pointed words (less familiar for adult readers) and unpointed words (more familiar). Because both diacritics and vowel letters increase orthographic transparency, but only diacritics reduce familiarity for adult readers, if we find different effects of diacritics and vowel letters, this would indicate that the familiarity modulates effects of orthographic transparency. In addition, the effect of familiarity was examined post hoc by testing the correlation between word recognition latency and word frequency.

We asked two overarching research questions:

1. *How are typical adult Hebrew readers influenced by orthographic transparency and familiarity?* We predicted that for typical adult Hebrew readers, increased orthographic transparency will result in greater reliance on decoding of orthography to phonology, as would be evident in a slowing length effect for pointed words. Furthermore, we expected that the increase in transparency would facilitate and improve word recognition only when the graphemic representations are familiar. Thus, only vowel letters, and not diacritics, may facilitate word recognition, due to easier access to phonology and meaning.
2. *Do adult Hebrew readers with dyslexia characterized by a phonological processing deficit benefit from increased orthographic transparency? And does it depend on their familiarity with the orthographic representations?* We predicted that adult dyslexic Hebrew readers would be slower and less accurate as compared to typical readers. In addition, we expected them to be more sensitive to decreased orthographic familiarity, due to lower lexical quality and less stable orthographic representation. Consequently, we expected that the familiarity with the orthographic representation would modulate the effect of orthographic transparency. That is, pointed words which are less familiar may force them to slow and effortful assembled reading, and therefore, they are expected to demonstrate slower word

recognition of pointed compared to unpointed words. In contrast, dyslexic readers may benefit from the transparent and familiar vowel letters, due to easier access to phonology and meaning.

Materials and methods

Participants

The current research was approved by The Ethic Committee—Institutional Review Board (IRB). Approval number 043/11.

A group of 26 dyslexic readers was recruited through the student support services at universities and colleges in Israel. All were diagnosed as dyslexics in childhood and were currently diagnosed as dyslexics by the university student support services as well. Ages range from 22:07 to 38 years (M=27:09, SD=4:01). This group matches the definition of "compensated" dyslexics (Miller-Shaul, 2005), whose reading achievements are good enough for them to continue on to academic studies. The control group includes 25 age-matched typical readers, 23–34:09 years old (M=27:01, SD=3.1), and students in academic institutes. All participants were native Hebrew speakers, right-handed, and display normal (or corrected to normal) vision in both eyes. None of them had a history of neurological, attention, or psychiatric disorders.

Because we were specifically interested in the effect of phonological transparency and familiarity on dyslexics with a deficit in phonological processing, in addition to being diagnosed by the university student services, our inclusion criteria included measures of phonological decoding and phonological awareness. Because there are no standardized reading tests for adults in Hebrew, these selection criteria were based on local norms collected in our lab from an independent sample of 191 typical readers (reported in Appendix 1), as done in previous studies (Ben-Yehudah & Ahissar, 2004; Katzir et al. 2004; Miller-Shaul, 2005). Dyslexic participants had a score of at least one standard deviation below the average of the local norms in at least one of the two phonological tests: decoding and awareness. One standard deviation was chosen following a standard practice in the Hebrew literature (Breznitz, 2003; Cohen-Mimran, 2006; Shany & Share, 2010; Shany et al. 2011). Typical readers were recruited from spouses and friends of the dyslexic participants, who were never diagnosed with reading impairments.

Eleven participants were excluded from the study because they did not meet the inclusion criteria for dyslexics (two from dyslexics), due to very low accuracy which limited the statistical power of response time analysis (two from dyslexics) or due to technical recording problems (one from dyslexics and six from typical readers groups). Finally, the analysis was done on data from 21 dyslexics (8 males) and 19 typical readers (9 males).

Selection tests

Phonological decoding: one minute pseudoword test (Shatil 1997a) In this test, participants read lists of pointed nonwords as quickly and accurately as possible within one minute. Number of correct words read within one minute was counted. Hence it is a combined measure of accuracy and fluency.

Phonological awareness: Phoneme Deletion (Recognition) Test for Pseudowords (Ben Dror & Shani, 1996) In this test, participants were instructed to listen to pseudowords and omit a specified phoneme located at the beginning or middle of a given pseudoword. Number of accurate answers (out of 25) and total time were scored. Eventually, we used only total time score as a selection criterion because of a ceiling effect in accuracy.

Additional measures

Word reading: One Minute Word Test (Shatil, 1997b) In this test, participants read lists of real unpointed words as quickly and accurately as possible within 1 min. Hence, it is a combined measure of accuracy and fluency.

Letter naming: RAN letters (Breznitz, 2001; Denckla & Rudel, 1974) In this test, participants were instructed to name aloud as quickly and accurately as possible a list of 50 printed letters. The list consists of five (nonfinal) Hebrew letters: (s), (a), (d), (g), and (l), each repeated randomly ten times. A total time (in seconds) was scored.

Means and standard deviation of all measures for the two groups are presented in Table 1. Dyslexic readers' performed significantly worse than typical readers in all fluency or combined accuracy-fluency measures but not in accuracy measure. This is in line with former studies with adult dyslexics in Hebrew (Ben-Dror et al. 1991; Breznitz, 1997a; Breznitz & Misra, 2003; Miller-Shaul, 2005). In addition, adult compensated dyslexics in all orthographies mainly show deficient reading fluency and intact accuracy (Bruck, 1990; Callens et al. 2012; Shaywitz et al. 2003).

Stimuli

The stimuli consist of 192 concrete Hebrew nouns. Three factors (each with two levels) were manipulated in a factorial design: The presence of diacritic marks (half of the word were presented with diacritic marks and half without them), Word length (words with three vs. four consonant), and the presence of vowel letters (half of the words contain one vowel letter and half do not) (all words were presented in their typical written form and vowel letters were not removed or inserted into these forms). This resulted in eight lists of 24 words each. All words were bi-syllabic and mono-morphemic and were matched for frequency across conditions, both in means and distribution. As there is no available consensus corpus for written Hebrew frequency, our frequency ranking was based on subjective rating of ten elementary school teachers on a 1–5 Likert scale that represent a range of average to high frequency in adult texts (see Table 2).

Table 1 Means and standard deviation of selection tests and other measures

	Units of measure	Dyslexic readers (N=21)	Typical readers (N=19)	Sig.
Phoneme Deletion Test	Total time (s)	212.67 (49.54)	100.31 (12.37)	p<.001
	Number of correct answers	20.15 (5.75)	22.47 (2.98)	N.S.
One-Minute Pseudoword Tests	Number of correct pseudowords per minute	30.63 (10.44)	61.47 (13.49)	p<.001
One-Minute Word Tests	Number of correct words per minute	70.75 (19.90)	102.78 (19.75)	p<.001
RAN Letters	Total time (s)	28.47 (7.03)	22.68 (3.31)	p<.01

Standard deviations are given in parenthesis

Table 2 Examples of words for each word list

	Long words with vowel letter	Long words without vowel letter	Short words with vowel letter	Short words without vowel letter
With diacritics	גַּרְעִין GRAIN /gara'in/ (nucleus)	אַרְנָב ARNV /a'rnav/ (rabbit)	תִּירָס TIRS /tiras/ (corn)	דֶּלֶת DLT /delet/ (door)
Word frequency Mean and range	3.221 (1.333–4.75)	3.409 (1.25–4.875)	3.399 (1.417–4.917)	3.269 (1.125–5)
Without diacritics	סנפיר SNPIR /snapir/ (fin)	קלסר KLSR /klaser/ (folder)	אגוז AGOZ /a'egoz/ (nut)	חדק XDK /xedek/ (proboscis)
Word frequency Mean and range	3.169 (1.333–4.7)	3.305 (1.375–5)	3.422 (1.5–4.917)	3.415 (1.5–4.333)

Experimental procedure

We employed an oral naming task because it has a high ecological validity for testing reliance on phonological representations during word recognition (Burani et al. 2008; Koriat, 1984, 1985).

Stimuli from the current experiment were presented together with 56 words from another experiment (Author, in process) which were similar in length and frequency and appeared in both the pointed and unpointed versions. Hence, the total number of trials for both experiments together was 248. Pointed and unpointed words were presented in separate blocks of 124 words each, to minimize interference from frequent switching between strategies associated with reading pointed and unpointed words. Block order was counter balanced across individuals, while the other conditions (number of consonants and vowel letters) were randomly intermixed.

Stimuli were presented on a computer monitor, and participants were required to read them aloud, while oral responses and reaction times were recorded using a voice-activated key (E-prime, Serial Response Box, PST). The words disappeared 1200 ms after the onset of the vocal response and were replaced by a fixation cross. Reaction times were collected from the stimulus presentation to the onset of vocalization. The presentation of the subsequent word was triggered by the participants when they were ready in order to make sure they were attentive.

Analysis of data

Response times shorter than 154 ms (−2 SD) and longer than 1570 ms (+3 SD) (i.e., 1.55 % of total responses) were excluded from the analysis. Participants mean response time of correct responses and percentage of pronunciation errors for the different factors were calculated.

To test our research questions regarding the effects of orthographic transparency and familiarity in typical and dyslexic adult Hebrew readers, we examined both different patterns within each group and the differences between groups. A repeated measures ANOVA was conducted with group (impaired vs. typical readers) as a between-subject variable and three within-subject factors: 2 levels of diacritics (pointed vs. unpointed)×2 lengths (three vs. four consonants)×2 vowel letter conditions (with or without a vowel letter). Planned separate analyses within each group and within pointed and unpointed words were conducted to test our specific hypotheses, even if there were no significant interactions of experimental factors and group. In order to look at the effect of word frequency and orthographic neighborhood on reading, we also conducted item analyses on response time as dependent variables, with group, diacritics vowel letters, and length as independent variables, and word frequency or orthographic neighborhood as covariates.

Results

Subject analysis

To compare between the dyslexic and typical readers we conducted a repeated measures ANOVA for both groups together (group as a between subject factor), separately with accuracy and reaction time as dependent measures. Performance of dyslexics was significantly slower ($F(1,38)=20.974$, $p<.001$, eta squared=.356) (see Fig. 1). Although dyslexics readers were less accurate than typical readers ($F(1,38)=12.926$, $p<.001$, eta squared=.254), they showed high levels of reading accuracy in all conditions (see Appendix 2). In addition, the analysis of response time shows significantly slower responses for pointed compared to unpointed words ($F(1,38)=4.37$, $p<.05$, eta squared=.103) and a significant three-way interaction between diacritics, vowel letters, and word length ($F(1,38)=4.37$, $p<.05$, eta squared=.103). Furthermore, the analysis of accuracy shows significantly more accurate responses for words with a vowel letter ($F(1,38)=17.135$, $p<.001$, eta squared=.311), and significant two-way interactions between diacritics and vowel letters ($F(1,38)=4.172$, $p<.05$, eta squared=.099) and between diacritics and word length ($F(1,38)=24.641$, $p<.001$, eta squared=.393). Despite of the nonsignificant interaction between group and experimental conditions, further analysis of response time was conducted separately for each group, to test our predictions on the role of orthographic transparency and familiarity in reading within each group. The main results are presented in Figs. 1–3. Accuracy was not further analyzed for each group due to the high levels of accuracy demonstrated by both groups.

Effect of diacritic marks

Diacritic marks increase transparency by providing unambiguous phonological information of vowel but decrease familiarity for adult Hebrew readers. Thus, both transparency and familiarity effects are evident in the comparison between pointed and unpointed words in each group. A significant slowing effect of diacritics was found for dyslexics ($F(1,20)=8.139$, $p<.01$, eta squared=.289) but not for typical readers (see Fig. 1).

Interactions between diacritics and word length

Word length effect served as an indication for assembled reading in pointed as compared to unpointed words. Significant two-way interactions of diacritics and word length were found for both dyslexic ($F(1,20)=5.942$, $p<.05$, eta squared=.229) and typical readers ($F(1,18)=15.706$, $p<.001$, eta squared=.466). For unpointed words, the presence of an additional consonant letter decreased latencies in typical readers ($F(1,18)=5.662$, $p<.05$, eta squared=.239) but not in dyslexics. For pointed words, the presence of an additional consonant letter increased latencies for both typical readers ($F(1,18)=7.032$, $p<.05$, eta squared=.281) and dyslexics ($F(1,20)=7.151$, $p>.05$, eta squared=.263) (see Fig. 2).

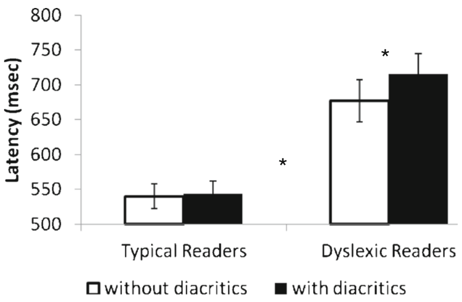

Fig. 1 Effects of diacritics. Latencies of oral naming of single words for typical readers (N=19) and dyslexics readers (N=21) without diacritics and with diacritics. *Error bars* represent standard error. *Asterisks* represent significant differences between conditions at p<.05

Interactions between diacritics and vowel letters

Vowel letters increase transparency without compromising familiarity. Thus, the effect of transparency is evident in the comparison between words with and without vowel letters, and the compound effect of transparency and familiarity is evident in the differential effect of vowel letters in pointed vs. unpointed words. Significant two-way interactions of diacritics and vowel letters were found for both dyslexic (F(1,20)=22.52, p<.001, eta squared=.53) and typical readers (F(1,18)=6.737, p<.05, eta squared=.272). For unpointed words, the presence of a vowel letter accelerated the response in both dyslexics (F(1,20)=8.679, p<.01, eta squared=.303) and typical readers (F(1,18)=12.173, p<.01, eta squared=.403). However, for pointed words, the presence of a vowel letter increased latencies for dyslexic readers (F(1,20)=12.637, p<.01, eta squared=.387) but not for typical readers (see Fig. 3).

Item analysis

In order to examine group differences in the effects of word frequency on reaction time, an additional post hoc ANOVA was conducted across groups, with all experimental factors and with word frequency as a covariate. This analysis showed a significant main effect of word frequency (F(1,38)=46.742, p<.001, eta squared=.21), indicating that more frequent words were read faster than less frequent words. It also showed a significant interaction of group and

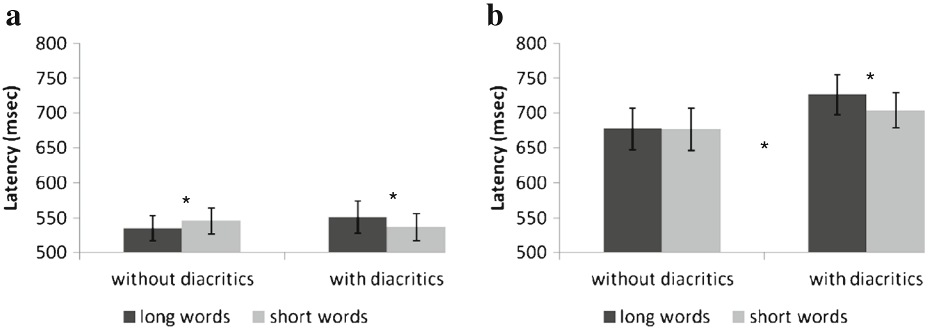

Fig. 2 Effects of diacritics and word length. Latencies of oral naming of single words for typical readers (**a**) (N=19) and dyslexics readers (**b**) (N=21) without diacritics and with diacritics, for long and short words. *Error bars* represent standard error. *Asterisks* represent significant differences between conditions at p<.05

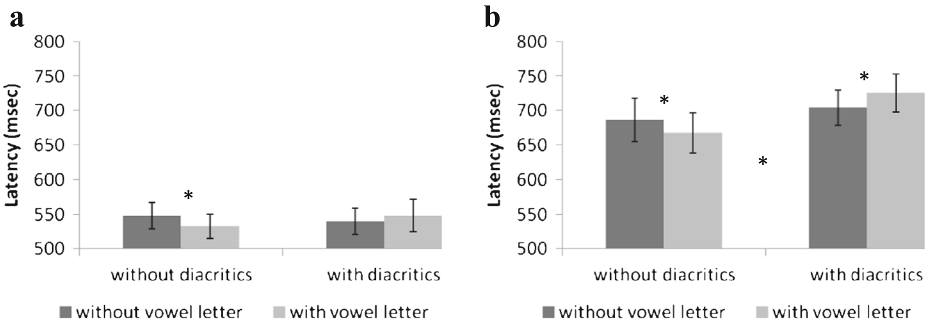

Fig. 3 Effects of diacritics and vowel letters. Latencies of oral naming of single words for typical readers (**a**) (N=19) and dyslexics readers (**b**) (N=21) without diacritics and with diacritics, for words without and with vowel letters. *Error bars* represent standard error. *Asterisks* represent significant differences between conditions

word frequency ($F(1,38)=30.152$, $p<.001$, eta squared=.146). Simple Pearson correlation of reaction time and word frequency was negative and stronger in dyslexics ($r=(-0.449)$, $p<.001$) compared to typical readers ($r=(-.280)$, $p<.001$).

In order to account for the possibility that the "reversed" effects of word length on reaction time were due to the density of the orthographic neighborhood, a post hoc measure of orthographic neighborhood size was extracted for all experimental words from the Language Resources for Hebrew Corpus (Itai & Wintner, 2008). The size of the orthographic neighborhood of a given word is defined as the number of words of the same length created by replacing a single letter in the target word (Coltheart et al. 1977). Two sample t tests showed that long words had a smaller orthographic neighborhood (mean=7.86, SD=7.30) compared to short words (mean=21.81, SD=9.16) ($T(1,190)=11.658$, $p<.001$), and words with vowel letters had a smaller orthographic neighborhood (mean=12.11, SD=11.70) than words without a vowel letter (mean=17.56, SD=9.14) ($T(1,190)=3.593$, $p<.001$). It should be noted that these differences are inherent to the manipulation, since the additional letter restricts the number of potentially similar words. This is in line with former findings that in most alphabetic languages, three-letter words have more neighboring words than four-letter words (Baayen et al. 1993; Norris & Kinoshita, 2012). An item ANOVA for both groups with orthographic neighborhood as a covariate showed no significant effect of orthographic neighborhood on reaction time. The reversed length effect on reaction time found in the subject analysis for typical readers in unpointed words was no longer significant when orthographic neighborhood was added to the model.

Discussion

To summarize our results, the current study shows that adult dyslexic readers were both slower and less accurate than typical readers in reading single Hebrew words. Nevertheless, they did show relatively high levels of reading accuracy in all conditions. Despite insignificant interactions of group with experimental conditions, analysis within each group showed that the presence of diacritic marks slowed reading in dyslexic individuals. In contrast, typical readers did not show a main effect of diacritics on reading latency, but they showed an interaction of diacritics and word length on reading latency suggesting reliance on mapping of different size units in pointed vs. unpointed words. Finally, vowel letters decreased latency only in unpointed words for both dyslexic and typical readers.

The current study replicates and extends previous studies on Hebrew-speaking dyslexics. First, we replicated the findings that Hebrew-speaking adults with dyslexia, who are compensated and attend higher education, still show ongoing difficulties with word recognition (Ben-Dror et al. 1991; Breznitz, 1997a; Breznitz & Misra, 2003; Miller-Shaul, 2005; Shany & Breznitz, 2011). They were systematically slower than controls, suggesting that they lack automaticity at processing all levels of written material. Second, we extend previous studies to suggest that both dyslexics and controls are sensitive to both familiarity and transparency of the orthographic representation to some extent. Thus, it is not just transparency that affects word recognition. Nevertheless, while dyslexic readers showed larger effects of increasing task demands, typical adult Hebrew readers were less sensitive to these factors and showed effective word recognition in all conditions. Finally, our findings suggest that orthographic depth hypothesis is too simplistic to describe the compound effect of orthographic transparency and familiarity, and the differences between dyslexic and typical adult Hebrew readers, and that a more connectionist point of view would be more suitable to describe these phenomena.

The effect of orthographic transparency

As predicted, dyslexic readers were significantly slower on reading pointed as compared to unpointed words. This finding suggests that despite the opacity of the unpointed Hebrew script, dyslexic readers with a phonological deficit do not benefit from the additional phonological information provided by diacritic marks. In contrast to dyslexic readers and consistent with our predictions, the results for typical readers do not show a significant main effect for diacritics. However, the presence of the diacritics did have an effect on the reading mechanism of typical readers as evident by the interaction between diacritics and word length. In pointed words, typical readers demonstrated a classic length effect (longer words were read slower than short words), while in unpointed words, they demonstrated a reversed length effect (longer words were read faster).

The slowing effect of word length, found only for reading pointed words, is consistent with previous studies showing a greater effect of word length in transparent orthographies (Cuetos & Suárez-Coalla, 2009; De Luca et al. 2008; Ellis & Hooper, 2001; Hawelka et al. 2010; Marinus & de Jong, 2010). This effect may indicate that reading pointed words involves a serial assembly of smaller grain-size phonological units (Ziegler et al. 2003). These results are in line with former studies in Hebrew, showing that adult Hebrew readers do not ignore diacritics even if they are not necessary for word recognition (Frost, 1994; Koriat, 1984, 1985; Navon & Shimron, 1981; Ravid, 1996; Shimron & Navon, 1982). Nevertheless, despite the serial approach to reading pointed words, they do not halt typical readers, who can ultimately read them as efficiently as the more familiar unpointed words. This finding is consistent with previous studies showing no effect of diacritics on word recognition for skilled Hebrew readers (Bentin & Frost, 1987; Harel-koren, 2007; Schiff & Ravid, 2004; Shimron & Sivan, 1994).

We suggest two possible explanations for the slowing effect of diacritics in individuals with dyslexia: First, for these individuals with a phonological decoding deficit, assembly of small size units of pointed words may be slower and more effortful than reading unpointed words. Second, it is possible that they do not at all engage with assembly of small size units when they encounter pointed words and must rely on other compensatory mechanisms. The finding that dyslexic readers did demonstrate a length effect for pointed words supports the first explanation. However, the reason for why the presence of diacritics increases the need to rely on phonological decoding for both typical dyslexic readers and other compensatory mechanisms in dyslexic individuals may be related not only to orthographic transparency but also to the reduced familiarity of pointed words, as will be discussed in the next section.

In contrast to diacritics and consistent with our predictions, the presence of vowel letters reduced response time only for unpointed words for both dyslexic and typical readers. This finding is in line with a previous study (Frost, 1995), which showed that vowel letters facilitate reading in unpointed (but not in pointed) words among typical adult Hebrew readers. Harel-Koren (2007), on the other hand, did not find any effect of vowel letters among adults, but only in second and fourth grades. However, the latter study presented the same words with and without vowel letters, resulting in many cases of unfamiliar orthographic patterns. The facilitative effect of vowel letters on reading latency may be due to its transparency, or alternatively due to reduced number of orthographic competitors, as we found that words with more letters (either a consonant or a vowel letter) have smaller orthographic neighborhoods.

The effect of familiarity with the orthographic representations

The first parameter that reflects the effect of familiarity is the difference between pointed and unpointed words. The slowing effect of diacritics, specific for dyslexic readers, suggests that dyslexic readers are more vulnerable to reduced familiarity of orthographic representation of pointed words, while typical readers have more stable orthographic representations.

In contrast to the slowing effect of length on reading pointed words, we found a surprising facilitating effect of length on reading rate of unpointed words, only for typical readers. The absence of a slowing effect of word length has been suggested to imply a larger grain-size units reading routine, as found for less transparent orthographies (Coltheart et al. 2001). Moreover, the more efficient reading of longer words, uniquely found in our study, may suggest that their statistical properties make longer words more easily recognized as whole-word units, as compared to short words. One statistical parameter that can account for this advantage of long words is orthographic neighborhood size (Coltheart et al. 1977).

The post hoc comparison of the orthographic neighborhood size between long and short words showed that longer words indeed have a smaller orthographic neighborhood. This finding corroborates our interpretation of the facilitating effect of length evident in unpointed words as resulting from the fewer orthographic competitors in long words. Yet, only typical readers show a facilitating effect of word length on reaction time in unpointed words. In line with the Lexical Quality Hypothesis (Perfetti, 2007), this may indicate that dyslexics, as compared to typical readers, have difficulties in whole-word recognition and retrieval due to low lexical quality and less stable orthographic representations.

The second parameter we tested to examine the effect of familiarity was word frequency. We found that frequent words were read faster than less frequent words for both dyslexic and typical readers, but this effect was stronger for dyslexics. These results are in line with studies from transparent orthographies, showing that the effects of word frequency on reading latencies in dyslexics are equal or larger than in controls (Davies, Cuetos, & Glez-Seijas, 2007; De Luca et al. 2008; Dürrwächter et al. 2010; Rello et al. 2013). In addition, these results support the suggestion that dyslexics are more vulnerable to reduced familiarity and frequency of the word patterns, due to low lexical quality of low frequency words.

Familiarity overrides the effect of transparency

The facilitative effect we found for words with vowel letters but not for words with diacritics on reading latency suggests that vowel letters and diacritics play very different roles in word recognition although both provide phonological information about vowels. Thus, although vowel letters are phonologically more ambiguous than diacritics, they have an advantage for word recognition, presumably because they do not reduce familiarity. Furthermore, the effect of an additional vowel letter is similar to that of an additional consonant in unpointed words in typical readers. In both cases, words with more letters (and thus, less orthographic competitors) result in faster recognition. Hence, the facilitating effect of vowel letters may be due to enhancing the phonological or the orthographic representations, or both.

Interestingly, while the effect of diacritic marks was different for dyslexic and typical readers, the two groups were similarly affected by the presence of vowel letters in unpointed words. In terms of the Lexical Quality Hypothesis (Perfetti, 2007), these results suggest that when increasing the orthographic transparency using a familiar graphemic representation, it improves lexical quality for both dyslexic and typical readers and thus improves word recognition. On the other hand, when the graphemic representation is less familiar, it decreases lexical quality, mainly for dyslexics, even though it increases orthographic transparency, and thus, it results in slower word recognition.

Conclusions

Results from the current study lead to several conclusions: First, dyslexic readers are more vulnerable than typical readers to reduced familiarity of the orthographic representation, and they benefit less from reduced competition from orthographic neighbors, due to their less stable orthographic representations. This interpretation is in line with Perfetti's Lexical Quality Hypothesis (2007), and Share's idea of "functional familiarity" (2008a), that arise from the connectionist approach to the phonological deficit in dyslexia (Manis et al. 1996). The idea of the "functional familiarity" of written word is that the familiarity of words is not only a between-items contrast differentiating real words vs. nonwords or high vs. low-frequency words but also a within-item developmental transition from unfamiliar to familiar. Therefore, each word is functionally unfamiliar when encountered for the first time (Share, 2008b). Hence, according to both the Perfetti's Lexical Quality Hypothesis (2007), and Share's idea of "functional familiarity" (2008a), a primary deficit in phonological processing hinders the ability to create stable whole-word orthographic representations during reading acquisition and thus causes a secondary deficiency in larger grain-size reading (in addition to deficient assembly reading of small grain-size units). Supporting the ideas raised by Perfetti (2007, 2011) and Share (2008b, 1995), we extend previous studies to suggest that phonological deficit in adult dyslexic Hebrew readers leads to deficient processing in different grain-size units. Nevertheless, our second conclusion is that, for both dyslexic and typical Hebrew readers, orthographic familiarity overrides transparency, and as found for more transparent orthographies, dyslexic Hebrew readers with phonological deficit actually may benefit from increased orthographic transparency when the representation is frequent and familiar, as evident in the effect of vowel letters in unpointed words.

The current study raises several questions that should be further investigated. First, this study only examined adult Hebrew readers. The reading instruction process in Hebrew progresses from transparent to opaque orthography, and different demands and resources are relevant for word recognition in each phase (Bar-On, 2010). Hence, a developmental study among typical and dyslexic readers will shed light on the specific role of graphemic representations in these different phases. Second, the participant sample in our study included compensated dyslexics. Future research should explore the role of graphemic representation in more profound reading impairment and in different subtypes of dyslexia (Shany & Breznitz, 2011; Zoccolotti & Friedmann, 2010).

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Appendix 1

Table 3 Local norms for typical readers

	Units of measure	Number	Mean (SD)	Criteria of 1 SD below average
Phoneme deletion test	Reaction time (s)	168	109.89 (31.11)	>141 s
One-minute pseudoword Tests	Number of correct pseudowords per minute	191	61.04 (14.146)	<46.89 correct pseudowords

Appendix 2

Table 4 Means and standard deviation of accuracy and latency

	Dyslexic readers (N=21)		Typical readers (N=19)	
	Latency (ms)	Accuracy %	Latency (ms)	Accuracy %
Pointed words Three consonants without vowel letter	701.55 (111.57)	97.91 (3.00)	537.88 (76.13)	100 (0)
Three consonants with vowel letter	705.89 (117.52)	98.72 (3.16)	535.38 (98.68)	99.78 (0.95)
Four consonants without vowel letter	707.72 (126.18)	97.15 (4.44)	541.40 (93.10)	98.87 (1.93)
Four consonants with vowel letter	745.39 (139.42)	97.05 (4.53)	561.26 (108.46)	99.55 (1.34)
Unpointed words Three consonants without vowel letter	685.31 (141.06)	95.66 (3.63)	552.44 (82.30)	97.34 (3.5)
Three consonants with vowel letter	668.23 (138.83)	97.46 (3.26)	538.69 (80.60)	99.78 (0.95)
Four consonants without vowel letter	688.12 (148.14)	96.93 (3.57)	543.09 (89.97)	99.10 (1.78)
Four consonants with vowel letter	666.15 (129.86)	98.30 (2.60)	526.20 (71.31)	100 (0)

Standard deviations are given in parenthesis

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