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ABSTRACT

The study investigates dyslexic and normal Hebrew readers' perception of words containing a vowel letter in different orthographic and morphological contexts. In the first experiment, 72 undergraduate education students (half diagnosed with reading disabilities and half normal readers) were asked to judge pointed words with different morphological structures with and without the grapheme W. Half of the words had consistent (obligatory) W and half had inconsistent (optional) W. In the second experiment, the same procedure was repeated using the same words without pointing marks. Response latencies and accuracy were measured. In both experiments, dyslexic readers did less well than normal readers, they had lower scores on accurate lexical decisions, and they took more time over these decisions. They also exhibited some deviant patterns indicating that they cannot make use of orthographic and morphological cues which are available to normal readers, especially in the pointed experiment. Processing pointed words placed a heavier cognitive burden on the dyslexic readers. These findings are in line with other studies of adult dyslexic reader/writers, and support a reading / spelling processing model, which claims that internal orthographic representations of words are increasingly strengthened with each exposure during reading, but not all graphemes are strengthened equally. The general implication is that the ambiguities that exist in the relationships between orthography, phonology and morphology underlie spelling knowledge and are particularly difficult for dyslexic readers.

Representing written vowels in university students with dyslexia compared with normal Hebrew readers

INTRODUCTION

Recent research on the development and processing of written language indicates that consonants and vowels are represented and processed differently: Vowels are more problematic for readers than consonants in many languages (Adams, 1990; Frost & Bentin, 1992; Goswami, 1993; Landerl, Wimmer & Frith, 1997; Purushothama, 1990). For example, Shankweiler and Liberman (1972) found that vowel reading errors were twice as frequent than as initial and final consonant reading errors combined. Reading and spelling vowels is particularly challenging for people with reading disabilities (Bryson & Werker, 1989). This paper describes two experiments in which dyslexic students were asked to read and judge the spelling of words where the Hebrew letter W ו (standing for the vowels *u* and *o*) was manipulated.

Dyslexia typically includes severe and persistent problems in both reading and spelling (e.g., Lennox & Siegal, 1993; Manis, Custodio & Szeszulski, 1993; Moates, 1983; Nelson, 1980). Spelling is seemingly a harder task than reading because there are more ways to graphically represent / spell a given sound than ways to pronounce any given phoneme (Bruck & Waters, 1988; Curtin, Manis & Seidenberg, 2001; Frith, 1980; Waters, Bruck & Seidenberg, 1985). Many sound-grapheme representations, especially those involving vowels, are variable, which makes spelling comparatively more difficult, especially for dyslexics. Furthermore, accurate spelling, especially of relatively or entirely unfamiliar words, requires both phonemic analysis and phoneme-grapheme mapping of the target word. In contrast, for pronouncing an unfamiliar word, partial decoding and context clues may suffice. Thus, as Lennox and Siegal (1993) contend, if a child lacks the necessary phonological skills for reading, the child will certainly be lacking the necessary skills for correct spelling. This would explain their findings that reading disabled children performed more poorly on spelling than children with other learning disabilities. This is also in line with the research position that dyslexics rely far more heavily on phonological-graphical processes than normal readers do (e.g., Boder, 1973). Alternatively, spelling requires a higher degree of orthographic knowledge than reading: Partial word-specific knowledge and context may suffice for recall, yet, accurate spelling requires more specificity.

Although dyslexia is a term characteristically used to describe beginning and novice readers, follow-up studies have shown that dyslexia often persists into adulthood, although the prevalence and severity of reading difficulties change with age (Bruck, 1985, 1993; Finucci, Gottfredson & Childs, 1986; Rawson, 1968).

Studies on the emergence and consolidation of Hebrew spelling indicate that vowel spelling is also acquired later and with more difficulty than consonant spelling (Levin, Ravid & Rapaport, 2001; Levin, Share & Shatil, 1996; Ravid & Kubi, 2003; Seidman, 2001; Share & Levin, 1999). The focus of the current study is the domain of written vowels in Hebrew dyslexic readers, and it aims to examine the effect of phonological, morphological and orthographic factors on how they perceive words containing the letter W.

Modern Hebrew employs two versions of the same orthography. One version, pointed orthography, represents both consonants and vowels. All consonants are represented by letters, while the five vowels a,e,i,o,u are represented by 13 diacritic marks termed nikud ‘pointing’ (and often also by the letters AHWY). This pointed version provides precise, in some cases redundant, phonological information about the written Hebrew word. It is used in reading and writing school instruction, in children’s books, in texts for new immigrants, and in Biblical and poetic texts. A second orthographic version of Hebrew, the non-pointed orthography, represents all consonants by all letters, while vowels are partially and ambiguously represented by the letters AHWY, which serve a double function as designators of consonants and vowels (Hebrew אהוי). For example, both initial consonantal (or rather, semi-vowel) y and final vowel i in the word yalduti ‘childish’ are represented by the letter Y (Yod) in the written string YLDWTY (Hebrew ילדותי). Non-pointed orthography is the default version of written Hebrew, used across the board for most purposes, including school instruction from 4th grade onwards.

In spite of the fact that Modern Hebrew has two options of representing vowels, consonants are the more stable part of the written Hebrew word: Each and every consonant is represented in writing, though there are a number of homophonous graphemes. Vowels are relatively less stable in representation: The normally used non-pointed version under-represents vowels. Observation shows that Hebrew speakers, including teachers, often claim that they do not “hear vowels” when asked to segment words, and relate only to consonants. Note, for example, the non-pointed written string KTB pronounced *ktav* ‘writing’ or *katav* ‘wrote’ (Hebrew כתב): Only the consonants are represented in this written string, but no vowel. Moreover, vowel representation is not consistent and systematic, depending on the vowel, on the grapheme representing it, on its morphological function, and on orthographic conventions, as shown in Table 1.

Table 1 summarizes the multiple functions of and constraints on AHWY as consonant and vowel designators in Modern Hebrew.

PLEASE INSERT TABLE 1 ABOUT HERE

THE CONTRIBUTION OF MORPHOLOGY

Studies on reading pointed and non-pointed Hebrew words indicate that single pointed words are read faster than non-pointed words, but when words are presented in context, the effect of pointing diminishes (Koriat, 1985; Navon & Shimron, 1985). Abu-Rabia's work on reading Arabic, another mainly consonantal Semitic language which uses diacritics to disambiguate homophonous strings, also indicates a facilitating effect of pointing on readers, mediated by context (Abu-Rabia, 2001). In a recent study, Shimron (1999) found that pointing did not have a powerful effect on gradeschoolers' memory, and interacted with task conditions and reader skills. Shimron puts forth the idea that knowledge of Hebrew orthography is supplemented with important contributions from Semitic morphology, and that reading Hebrew leans heavily on syntactic and discourse cues in addition to phonological information. This idea is supported by a wide range of studies that point at the centrality of morphological structure and meaning in reading and writing Hebrew (Ben-Dror, Bentin & Frost, 1995; Frost, 1995; Frost, Forster & Deutsch, 1997; Ravid, 2001, in press). These studies indicate that Hebrew readers/writers represent and analyze morphological structures in processing written words and texts, and that they employ morphological strategies in different ways than speakers of languages with less rich morphologies (Gillis & Ravid, 2000; Ravid & Bar-On, 2001).

Two morphological devices common in Hebrew are relevant here. One is the Semitic root-and-pattern structure, which combines root radicals (usually consonants, marked by C's) with a mainly vocalic pattern to produce a word. For example, root *g-d-l* takes adjectival pattern *CaCoC* to create adjective *gadol* 'big', causative verb pattern *hiCCiC* to make verb *higdil* 'magnify', and abstract pattern *CóCeC* to create the abstract nominal *gódel* 'size'. Root and pattern affixation is considered non-linear since neither of the two morphological components appears in continuous form; rather, they are interdigitated within each other. A second word-formation device is the stem-and-suffix structure, which attaches a suffix to a base, usually a word. For example, the abstract suffix *–ut* may be attached to the adjective base *kal* ‘easy’ to produce *kal-ut* ‘ease’; and the denominal suffix *-i* is attached to the noun base *enoš* ‘human’ to produce adjective *enoš-i* ‘humane’. This morphological device is linear in nature, since the two morphemes are distinct and follow each other in the word (Ravid, 1990).

W STATUS AND W PRESENCE

The current study investigates how dyslexic readers perceive the role of the Hebrew grapheme W, standing for the vowels *o* and *u* in interaction with phonological, orthographic and morphological factors. Specifically, we are interested in their perception of W as a *consistent* and an *inconsistent* element in the written word (henceforth: W *status*), and in interaction with linear and non-linear morphological structure. This investigation was conducted in two different contexts: pointed and non-pointed words. Studies indicate that adult Hebrew readers are adept at reading non-pointed texts, employing “top-down” morphological, syntactic and discourse cues in retrieving vocalic patterns and assigning meaning to graphemic strings in their contexts (Frost & Bentin, 1992; Shimron, 1999). Frost (1995) showed that when reading non-pointed Hebrew words, the more missing vowels in the word, the higher the amount of ambiguity in the process of filling in the missing vowels and the slower the process of word recognition.

The spelling of word-internal W interacts with the morpho-phonological structure of the word. In some contexts, W is marked obligatorily in both pointed and non-pointed script. We term this status *consistent.* Thus *gadól* ‘big’ and *loméd* ‘studies’ are always spelled GDWL (Hebrew גדול) and LWMD (Hebrew לומד) respectively. In other contexts, W is marked only in non-pointed script and is termed by us *inconsistent*. Thus *gódel* ‘size’ will be spelled GWDL in non-pointed script (Hebrew גודל) and GDL (Hebrew גֹּדֶל) in pointed script. This means Hebrew readers encounter different written representations of the same words, governed by complex morpho-phonological criteria accessible only to linguistically tutored individuals (see Ravid, in press, and Schiff & Ravid, 2004 for detailed explanations).

The problem of vowel status in the written word has broader implications for general processing theories beyond the psycholinguistics of Hebrew spelling. In a recent paper, Katz & Frost (2001) adopt the view that reading and spelling interface in their dependence on *both* graphemic and phonological information rather than on one to the exclusion of the other. They propose that spelling knowledge is thus to a certain extent a function of readers' ability to recognize spelling patterns following multiple exposures to these patterns. Consequently, readers' acceptance of certain misspellings indicates that the mental orthographic representation of specific letters, which are not critical for the reader's knowledge of the word's phonology, is initially ill- or weakly formed. According to this view, the stability of a single letter is a function of the simplicity of the grapheme-phoneme relation: A stable memory trace of a spelling pattern is the result of a simpler link between phonology and orthography, which requires less processing before a decision is made about the phonemic value of the letter. As we have shown above, the internal letter W may have a poor internal orthographic representation in Hebrew readers due to the multiplicity and ambiguity of cues necessary for its occurrence in the word. Thus Hebrew provides us with the unique opportunity of teasing apart phonological from orthographic representation. Specifically, our study addresses the issue of whether a single letter may have less stable orthographic encoding, which means that phonology plays a role in determining which orthographic information fails to be stored.

PREDICTIONS

The grapheme W was selected for investigation in dyslexic students since on the one hand it designates only two vowels (*o* and *u*) and thus represents a limited and well-defined domain; but on the other hand it may have either consistent or inconsistent status, and it participates in a variety of morphological structures.

Our predictions for both experiments were as follows:

- Dyslexic students will score lower and take more time to reach lexical decision than normal readers.
- Items with consistent W will be more accurate and have shorter decision times than items with inconsistent status in both study groups, since consistent W creates a more stable memory trace (Katz & Frost, 2001).
- When the grapheme W is removed, accuracy will decline and decision times will increase in both groups since word form may be impaired.
- Words with linear structure will score higher on accuracy and will take less time for lexical decision in both groups, since linear suffixes are easier to detach from the written word: They are clearly visible and divisible at word end, unlike roots and patterns, which are interdigitated.

METHODS

EXPERIMENT I (POINTED PRESENTATION)

Our study was designed to find out the answers to the study questions by measuring adult dyslexic readers' reaction to the presence or absence of the grapheme W with consistent or inconsistent status in written Hebrew words with the same syllabic but different morphological structures. In the first experiment, all target words were presented with pointing marks (*nikud*).

PARTICIPANTS

38 undergraduate education students, all with a long history of reading difficulties and diagnosed with reading disabilities within three years prior to attending university or while attending university, were randomly selected from a group of students involved in a learning disabilities support group. A comparison group consisted of 38 volunteer participants, all undergraduates who were accepted into the control group if they perceived themselves as average readers, with no history of learning or reading problems, were not taking medication, and had not repeated a grade. All participants were monolingual native Hebrew speakers. There was an equal number of males and females in both groups, and the age range of participants was 20-26 (Israeli students are typically older than their American and European peers, since they only start University after a military service of 2-3 years). Mean age is 23;5, SD=1.83.

ITEM SELECTION

In order to neutralize frequency effects, and in the absence of Hebrew frequency lists, the following procedure was undertaken to select test items: 35 items were presented to 30 judges (students of education), who were asked to rank them on a scale of 1-5, from most to least frequent. Estimated frequency was calculated for each word by averaging the ratings across all 30 judges, with 95% agreement among judges. On the basis of these ratings, 24 most frequent words ranked 1 and 2 were selected for the purposes of this study (e.g., *banot* ‘girls’, *sulam* ‘ladder’). Words were presented in their written form and were thus judged by our raters. In order to check whether the written words were matched in frequency a mean rating of frequency was built for the 12 consistent words (see structure of research instrument below) , and the same was done for the 12 inconsistent words for all 30 raters. We conducted a t-test to find out whether there is a difference in the frequency of the categories. No significant differences were found (t(28)=1.3, n.s. This analysis was also conducted separately on the items with differing morphological structure (see below), and again no differences were found t(10)=1.0, n.s.

DESIGN AND PROCEDURE

The research instrument constructed for the purposes of this study consisted of 24 written Hebrew bi-syllablic nouns and adjectives, all with the same syllable structure CVCVC. The 24 target vowels (*o* and *u*) were spelled by the grapheme W pertaining to two categories. One category contained 12 words with *consistent* W representing the vowels *o* and *u* (structured *CaCoC* / *CaCuC*), further subdivided into two types of morphological structure: (i) 6 words with the same *linear* (stem and suffix) structure (e.g., *yaf-ot* ‘pretty-Fm,Pl’ spelled YPWT, Hebrew יפות; *resh-ut* ‘permit-ing’ spelled RŠWT, Hebrew רשות); (ii) 6 words with *non-linear* (root-and-pattern) structure (e.g., *karov* ‘near’, root *k-r-v*, adjectival pattern *CaCoC*, spelled QRWB, Hebrew קרוב). A second category contained 12 words with *inconsistent* W (structured *CóCeC* /*CuCaC*, e.g., *bóker* ‘morning’, spelled either BWQR בוקר or BQRבקר), all with *non-linear* structure.

Each of the 24 test items appeared twice in random order in two conditions - with or without W (e.g., *karov* ‘near’, spelled either QRWB קרוב or *QRB קרב). Pointed words without W were presented using the alternative diacritics *xolam xaser* and *kubuc* for W. In the case of consistent W, absence of W always resulted in an illegal string (e.g., *QRB). In the case of inconsistent W, absence of W resulted in a legal pointed string (e.g., G_oD_eL for *gódel* ‘size’, Hebrew גֹדֶל) and in an illegal non-pointed string (e.g. *GDL for *gódel* ‘size’, Hebrew גדל). The study paradigm is presented in Table 2.

INSERT TABLE 2 ABOUT HERE

Each of the test words first appeared on a computer screen in a sentential context to ensure clear and unambiguous comprehension. First the sentence appeared on the screen with an empty slot standing for the test word. Then the actual test item appeared on the screen in larger font below its sentential context. Study participants were asked to judge whether the written string appearing on the screen was a correctly written (i.e., legal) word in Hebrew. For a legal written string they were supposed to press Enter, clearly marked “correct”; for an illegal written string they were supposed to press the space bar, clearly marked “incorrect”. Each testing session was preceded by a practice session consisting of four items representing the test categories (with / without W; consistent / inconsistent W), which ensured that participants understood the instructions and knew what they were supposed to do. All test items are presented in Hebrew their original form in Appendix I.

SCORING

Three independent variables were tested in this experiment: W status (consistent / inconsistent W), W presence (word presented with / without W), and morphological structure (linear / non-linear structure). Table 2 shows that when test items are presented with W, they are always legal, and when items are presented without W, they are legal on half the items, and illegal on the other half (the 12 inconsistent items, marked by a star).

Participants’ responses were measured by reaction time to string identification and by accuracy, i.e., number of correct responses. Reaction time was measured in milliseconds. Correct responses (i.e., responses correctly identifying a test item as either a legal or an illegal string in that context) were assigned a score of 1; incorrect responses were assigned a score of 0.

RESULTS

Below we present the results on accuracy and reaction time in the pointed experiment.

ACCURACY

Since all 12 inconsistent items were non-linear whereas only half of the consistent items (6) were non-linear, we conducted a three-way ANOVA with repeated measures Group: 2 [dyslexia / normal readers] x W presence: 2 [W present / W absent] x W status: 2 [consistent / inconsistent W] was carried out on the correct percentage scores of the non-linear items alone. No simple effects emerged, however there were two interactions. One, an interaction of Group x W presence ($F(1,54)=8.56$, $p<.006$), is shown in Figure 1.

PLEASE INSERT FIGURE 1 ABOUT HERE

Figure 1 and a Bonferroni analysis (at the .05 level) show that normal readers read pointed words with W more accurately than words without W, while in readers with dyslexia both types of words do not differ; and that within words with W, normal readers are more successful than readers with dyslexia. A second interaction emerged between Group and W status ($F(1,54)=6.25$, $p<.02$), shown in Figure 2.

PLEASE INSERT FIGURE 2 ABOUT HERE

Figure 2 and a Bonferroni analysis show that readers with dyslexia do more poorly on pointed words with consistent W than do normal readers.

THE EFFECT OF MORPHOLOGICAL STRUCTURE

A further analysis was conducted on the consistent W category taking into account items' morphological structure – linearly structured items with W in the suffix (e.g., *ban-ot* 'girl-s') versus items with non-linear root-and-pattern structure (e.g., *gadol*, root *g-d-l*, pattern *CaCoC*). All items had the same CVC<u>W</u>C syllabic structure with either *o* or *u* in the second syllable. We carried out a three-way ANOVA with repeated measures Group: 2 [dyslexia / normal readers] x W presence: 2 [W present / W absent] x morphological structure: 2 [linear / non-linear]. There was an effect for Group ($F(1,54)=12.84$, $p<.002$) – normal readers scored higher (M=93.3, SD=8.13) than readers with dyslexia (M=79.76, SD=18.28) on reading pointed words. There was also an effect for morphological structure – pointed linear items scored higher (M=89.73, SD=15.57) than non-linear items (M=83.33, SD=19). There was a three-way interaction of Group x W presence x morphological structure, shown in Figure 3.

PLEASE INSERT FIGURE 3 ABOUT HERE

Figure 3 and a Bonferroni analysis indicate that dyslexic readers do more poorly than normal readers on all structures presented with pointing, except for non-linear words presented without W. Readers with dyslexia perform similarly on all structures, while normal readers' scores decline only in non-linear words presented without W.

REACTION TIMES

A three-way ANOVA with repeated measures Group: 2 [dyslexia / normal readers] x W presence: 2 [W present / W absent] x W status: 2 [consistent / inconsistent W] was carried out on the RT scores of the participants. There was a main effect for Group ($F(1,50)=9.45$, $p<.004$) – normal readers were faster (M=1.77, SD=0.81) on making lexical decisions on pointed words than dyslexics (M=2.59, SD=1.07), and a main effect for W presence ($F(1,50)=38.48$, $p<.001$) – pointed words with W were generally read faster (M=1.83, SD=0.73) than words without W (M=2.53, SD=1.41). There emerged a two-way interaction Group x W presence ($F(1,50)=22.05$, $p<.001$), presented in Figure 4.

PLEASE INSERT FIGURE 4 ABOUT HERE

Figure 3 and a Bonferroni analysis indicate that dyslexic and normal readers do not differ on pointed words presented with W, however dyslexics take more time on deciding on words without W than on words with W, and also more time than do normal readers on words without W.

We also conducted a three-way ANOVA with repeated measures Group: 2 [dyslexia / normal readers] x W presence: 2 [W present / W absent] x morphological structure: 2 [linear / non-linear] on the RT scores of the participants. Apart from the a main effect of Group ($F(1,51)=7.48$, $p<.01$), there were no relevant interactions.

DISCUSSION

The study task required participants to judge whether written strings containing the grapheme W in different contexts were spelled correctly, and measured both accuracy of decision and time to lexical decision. Our predictions were largely confirmed, though the dyslexic group not only fared less well than the normal group but also presented different behavior. In this experiment, where task words were presented with pointing, dyslexics performed not only less well than normal readers, as predicted, but also deviated in their ability to process pointed words. While normal readers benefited from W presence in the pointed word, dyslexic readers did not. Readers with dyslexia also did less well on words with consistent W than normal readers, and were not able to process them better than words with inconsistent W as did normal readers. Dyslexic readers were not sensitive to differing morphological structures, while normal readers did better on all linear items and all non-linear items presented with W. Normal readers made generally faster lexical decisions than dyslexics, and dyslexics were hindered by words without W while normal readers were not. More factors affected normal readers and not dyslexic readers when measured by accuracy. Accuracy is thus particularly relevant when testing reading in a pointed orthography, which involves attention to both letters and diacritics in different linguistic contexts. It is able to highlight more fine-grained problems in dyslexic readers than lexical decision.

EXPERIMENT II (NON-POINTED PRESENTATION)

The second experiment was conducted on the same population 2 weeks after the first one, using exactly the same design with the same target words. This time all target words were presented without pointing marks.

THE PROBLEM OF HOMOGRAPHY

Due to the under-representation of vowels in Hebrew script, many written strings are homographic with other written strings, so that test items without W may be legal strings even when the obligatory W is omitted. Therefore we have conducted an analysis of homography in our test items (see list in Appendix II). Note, first, that

23 out of 24 non-pointed words presented without W are homographic with some other written string in Hebrew, so are in fact, in a sense, 'legal' words. In Appendix II we scored the 24 words for a likelihood of being 'legal' or homographic without W on a scale of 1-4: 1- most probably a legal string; 2- a possible legal string; 3- just possibly a legal string; 4 – impossible as a legal string. Legality criteria and inter-judge reliability appear at the end of Appendix I. The words are presented in Hebrew. Out of the 24 non-pointed strings without W, 13 are most probably legal words, 5 are possible, 4 are just possible, and one (שטת) cannot be interpreted as a possible legal string. A one-way analysis by homography type (1,2,3) showed no significant effect of homography (F(2,74)=1.51, n.s): Type 1 M=0.90, SD=0.12; Type 2: M=0.89, SD=0.18; Type 3: M=0.93, SD=0.14.

RESULTS

We conducted a three-way ANOVA with repeated measures Group: 2 [dyslexia / normal readers] x W presence: 2 [W present / W absent] x W status: 2 [consistent / inconsistent W] on the correct percentage scores of the non-linear items alone. There was a main effect for Group (F(1,54)=32.42, p<.001) – normal readers scored higher on non-pointed words (M=88.24, SD=12.67) than did dyslexic readers (M=72.32, SD=7.65). When we examined differing morphological structures in the non-pointed words, again only this effect emerged ($F(1,54)=221.23$, $p<.001$): Normal readers ($M=97.02$, $SD=4.22$), dyslexic readers ($M=76.19$, $SD=6.09$). A three-way analysis was also carried out on reaction times of participants, with the result of a main effect of Group ($F(1,54)=18.45$, $p<.001$), showing that normal readers make faster decisions ($M=1.86$, $SD=0.63$) than do dyslexics ($M=2.88$, $SD=1.09$). There emerged an interaction of Group x W presence ($F(1,54)=15.53$, $p<.001$), presented in Figure 5.

PLEASE INSERT FIGURE 5 ABOUT HERE

Figure 5 and a Bonferroni analysis indicate that dyslexics take more time on both types of non-pointed words, but they are even slower on words without W, while normal readers take the same time on both types.

We also conducted a three-way ANOVA with repeated measures Group: 2 [dyslexia / normal readers] x W presence: 2 [W present / W absent] x morphological structure: 2 [linear / non-linear] on the RT scores of the participants. The was a main effect of Group ($F(1,54)=22.05$, $p<.01$), and an interaction of Group x W presence x morphological structure ($F(1,54)=5.39$, $p<.03$), presented in Figure 6.

PLEASE INSERT FIGURE 6 ABOUT HERE

Figure 6 and a Bonferroni analysis show that for normal readers, performance is not affected in the non-pointed presentation by either morphological category (linear vs. non-linear) or by W presence or absence; however for dyslexic readers morphological category is significant: They reach lexical decision faster when the word is non-linear and presented with W, but they lag especially over non-linear words presented without W.

DISUCSSION

The non-pointed experiment showed clearly the advantage of normal readers over dyslexics on both reading accuracy and lexical decision times. However, the only deviations on the part on the dyslexics were in lexical decision times: They take more time on non-pointed words without W, and especially on non-linear words without W.

GENERAL DISCUSSION

The study compared adult Hebrew reader / writers' perception of the status of the vowel letter W in two populations: Dyslexic and normal readers, who were required to judge whether written strings containing W in different contexts were spelled correctly. In the first experiment, words were presented with pointing, that is, vowel diacritics carrying the full vocalic information in the word; and without pointing, i.e., with partial and ambiguous vowel marking by letters. The presence or absence and the orthographic functions of the grapheme W, standing for vowels *o* and *u*, were the focus of this study.

In both experiments, dyslexic readers did less well than normal readers: They had lower scores on accurate lexical decisions, and they took more time over these decisions. However, not only were their results in both experiments lower than those of the normal population, they also exhibited some deviant patterns indicating that they cannot make use of orthographic and morphological cues which are available to normal readers, especially in the pointed experiment. Regarding accuracy in the pointed experiment, normal readers benefited from W presence in the word (e.g., spelling *gadól* 'big' GDWL, Hebrew גדול, incorrectly as GDL גדל), but dyslexics did not. Normal readers also did better on words with consistent W (e.g., *gadól* 'big' GDWL, Hebrew גדול) than on words with inconsistent W (e.g., *gódel* 'size' GWDL, Hebrew גודל), but dyslexics did not. Finally, normal readers benefited from linear morphological structure (e.g., linear *ban-ot* 'girl-s' spelled BNWT בנות vs. non-linear *gadól* 'big' spelled GDWL גדול, root *g-d-l*) – but dyslexic readers did not. Regarding lexical decision time, dyslexics were slower on words without W in both experiments, and in the non-pointed experiments they took the longest time over non-linear words presented without W, e.g., GDL גדל for *gadol* 'big' or *gódel* 'size'.

In general, normal readers showed that they were aware of stable and consistent spelling patterns in Hebrew and were able to make use of their knowledge in deciding whether the stimuli they were administered were spelled correctly. They succeeded more on words with consistent W where the appearance of W is obligatory and creates more stable written representations. Normal readers did better on words where W was present, since when it was removed, the written word almost always consisted of three letters which could be interpreted as the Semitic consonantal root which may be assigned various legal readings: For example the incorrect stimulus GDL גדל for *gadol* 'big' may be read as *gadal* 'grew' or as *gidel* 'raised'. Though these options were not viable in the given context, normal readers' ability to read Hebrew efficiently by assigning the written string a vocalic value confused them enough to lower their scores. For the same reason, normal readers did better on linear strings where the grapheme W had a morphological value as part of the suffix *–ot* (denoting feminine plural) or *–ut* (abstract noun) rather than on the non-linear words where the W has a mere phonological value and does not participate in meaningful construction. But dyslexic readers make less use of all of these cues available to normal experienced readers, showing that that their ability to process written information and relate it to lexical and grammatical knowledge was impaired.

Moreover, our results indicate that processing pointed words placed a heavier cognitive burden on the dyslexic readers. There were more deviations from the normal pattern in the pointed experiment, where dyslexics had to process both graphemes and diacritic signs, than in the non-pointed experiment. However even dyslexic readers are impacted by the Semitic character of Hebrew script: They find non-pointed non-linear root-like words presented without W (see above) particularly confusing since they can be interpreted in various ways.

To understand the depth of difference between normal and dyslexic readers, consider Figure 7, which presents accuracy scores on pointed consistent versus inconsistent words (experiment 1) in normally developing 2nd and 4th graders (data taken from Ravid & Schiff, in press). Normal adult readers scored significantly higher on consistent words, where W has a stable representation, than on inconsistent words where W is unstable and often deleted. Against the backdrop of this norm, normally developing 4th graders performed similarly to normal adult readers, though they had higher results on inconsistent W, since their spelling patterns have not consolidated yet. Second graders were qualitatively different: They performed exactly the same on both W categories, showing that they cannot yet make use of W as a vowel letter. The dyslexics perform very similarly to the 2nd graders. But whereas normally developing 2nd graders eventually reach the pattern depicted by normal adult readers, adult dyslexics' predicament is consistent and constant, showing their representation of spelling patterns to be qualitatively deviant from that of normal readers.

These results support and reinforce findings in other languages and orthographic systems regarding adult dyslexics' ability to extract information from the printed word and to be able to consciously manipulate it and its structure (Wilson & Lesaux, 2001). For example, Bruck (1993) found that despite having high educational achievements, dyslexic adults performed more poorly than age-matched normal spellers and also more poorly than normally developing 6th graders. Moreover, their patterns of spelling deficits were similar to those of dyslexic children. Also relevant to our study are the findings of Post, Swank, Hiscock & Fowler (1999), showing that oral vowel discrimination and identification were less stable in less skilled readers in gradeschool, and that vowel spelling was linked to identification accuracy.

Taken more broadly, these results provide independent evidence for the *resonance model* (Stone & Van Orden, 1994), a general theory for learning the relations between spelling and speech. According to this model, the covariance of orthographic and phonological events while recognizing spelling patterns is the main mechanism for strengthening the connections between those representations (Katz & Frost, 2001). The Hebrew-specific case shows that inconsistent words misspelled without W are phonological acceptable, and thus the connection between W-absent spelling and its phonological representation is strengthened, with the result that such spelling becomes more acceptable. The general implication is that the ambiguities that exist in the relationships between orthography, phonology and morphology underlie spelling knowledge. However, dyslexic readers find the storage and manipulation of these relationships particularly difficult, as evidenced by our findings.

Our work also support s the reading / spelling processing model proposed in Katz & Frost (2001), which claims that internal orthographic representations of words are increasingly strengthened with each exposure during reading, but not all graphemes are strengthened equally. Results of their four experiments indicate that subjects have poor internal orthographic representations for letters which have multivalent relationships with the spoken form. Like English geminates and schwas, Hebrew *matres lectionis* have a more ambiguous relation to speech than graphemes which code consonants, for example, and are thus coded less effectively. Overall evidence from Hebrew shows indeed that these ambiguous letters are orthographically represented last and the weakest. In line with the neuro-linguistic functional magnetic resonance imaging study discussed in Pugh et al. (2000), we show that while making a decision on the correct spelling of the vowels *u* and *o*, both spellings are activated and compete with each other, and therefore fail to strengthen the correct spelling and create a deep memory trace of its pattern. Our study shows that W processing is particularly problematic for dyslexic readers who suffer from inadequate exposure to written texts and from a reduced ability to process and store phonological-orthographic patters.

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Table 1. AHWY (Hebrew אהוי) in their dual function as consonant and vowel designators

Grapheme	**Hebrew form**	**Consonant**	**Vowel**	**Constraints on occurrence as vowel designator**
A *Alef*	א	*?*	*a,e*	Word final (unless root letter)
H *He*	ה	*h*	*a,e*	Word final
W *Vav*	ו	*v* (historically, *w*)	*o,u*	No constraints
Y *Yod*	י	*y*	*i*	Morpho-phonemic constraints

Table 2. Task structure and structure of the test categories, with examples

	12 items with Consistent W		12 item W
W present (24 items)	6 <u>Non-linear structure</u> • *karov* KRWB ‘near’ Root *k-r-v*, Pattern *CaCoC* • *katuv* KTWB ‘written’ Root *k-t-b*, Pattern *CaCuC*	6 <u>Linear structure</u> • *yaf-ot* YPWT ‘pretty-,Fm,Pl’ • *reš-ut* RŠWT ‘permiss-ion’	<u>All non-</u> • *b* ‘ E Root *b-k* • *š* ‘ Š Root *š-t-*
	12 items with *Consistent W		12 item W
W absent (24 items)	6 <u>Non-linear structure</u> • *karov* *KRB ‘near’ Root *k-r-v*, Pattern *CaCoC* • *katuv* *KTB ‘written’ Root *k-t-b*, Pattern *CaCuC*	6 <u>Linear structure</u> • *yaf-ot* *YPT ‘pretty-,Fm,Pl’ • *reš-ut* *RŠT ‘permiss-ion’	<u>All non-</u> • *b* ‘ Root *b-k* • *š* ‘ Root *š-t-*

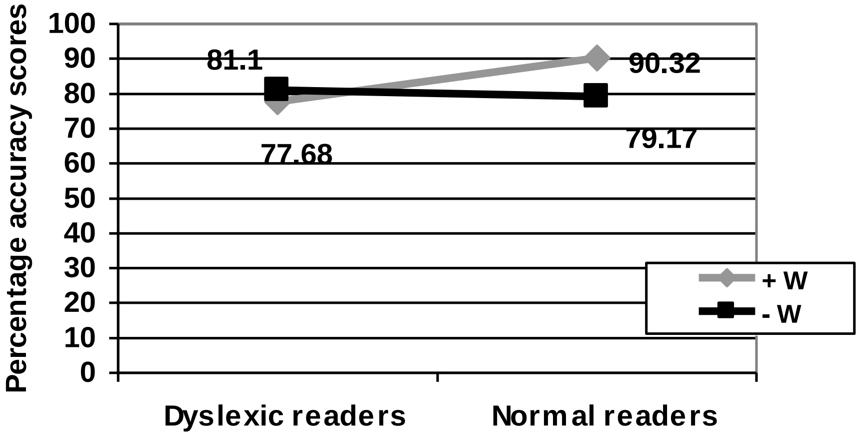

Figure 1. Experiment 1, (pointed items). Accuracy scores: Interaction of group (dyslexic readers, normal readers) x W presence (+ W / - W)

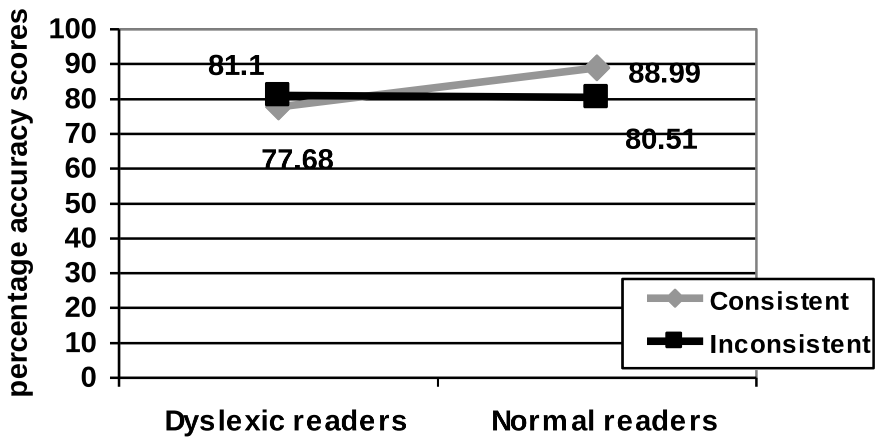

Figure 2. Experiment 1, (pointed items). Accuracy scores: Interaction of group (dyslexic readers, normal readers) x W status (consistent / inconsistent)

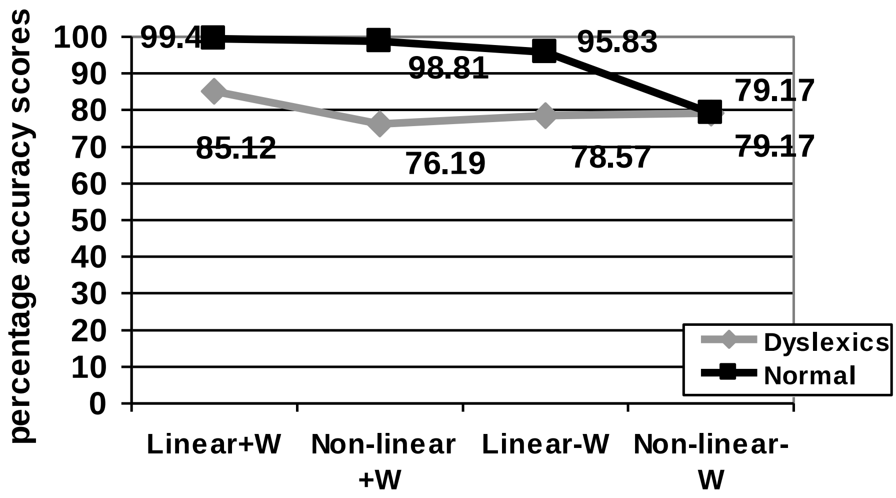

Figure 3. Experiment 1, Accuracy scores (pointed items): Interaction of group (dyslexic readers, normal readers) x morphological structure (Linear, non-linear items) x W presence (+ W / - W)

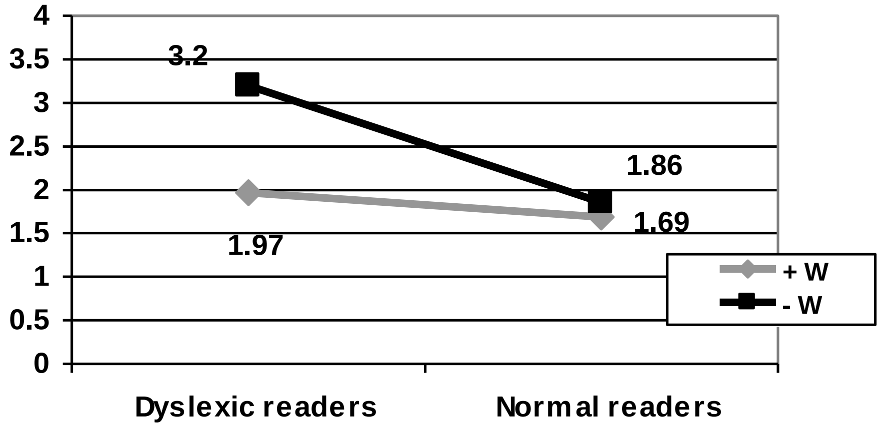

Figure 4. Experiment 1 (pointed). Reaction time: Interaction of group (dyslexic readers, normal readers) x W presence (+ W / - W)

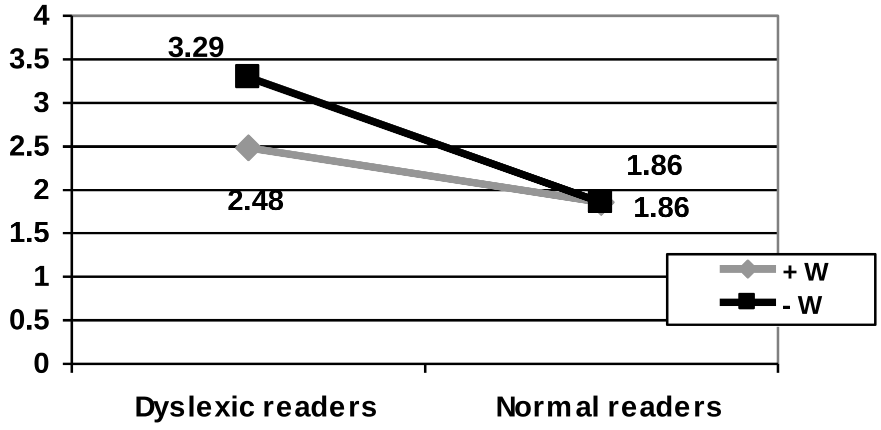

Figure 5. Experiment 2, (non-pointed): Reaction time. Interaction of group (dyslexic readers, normal readers) x W presence (+ W / - W)

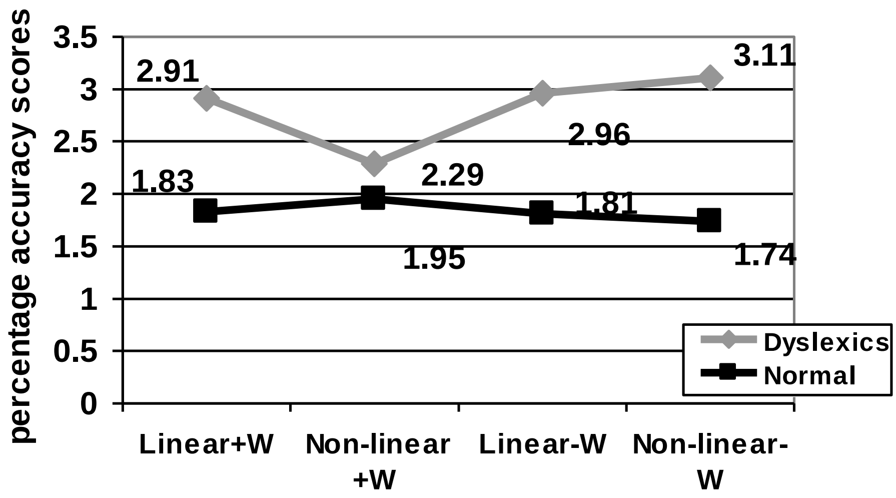

Figure 6. Experiment 2, (non-pointed): Reaction time. Interaction of group (dyslexic readers, normal readers) x morphological structure (Linear, non-linear items) x W presence (+ W / -W)

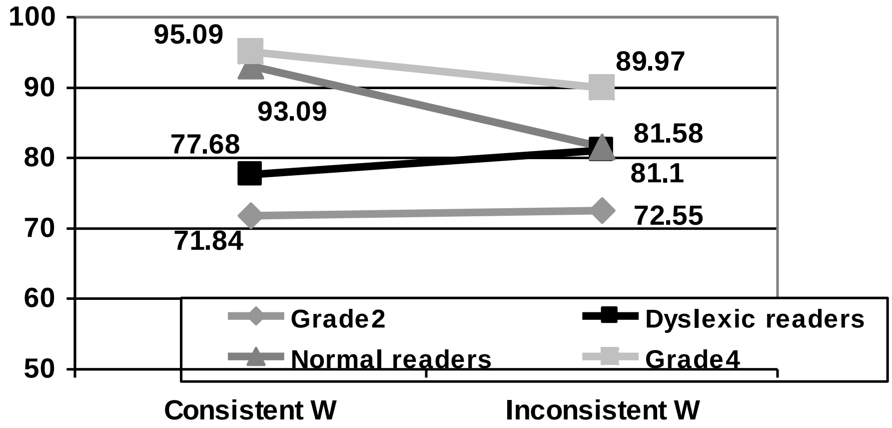

Figure 7. A comparison of accuracy scores in experiment 1 (pointed words): Normally-developing 2nd and 4th graders, normal adult readers and the adult dyslexic readers.

Appendix I

List of all task words as presented in Hebrew in Experiment (pointed)		**List of all task words as presented in Hebrew in Experiment (non- pointed)**	
(i) W presence	(ii) W absence	(ii) W presence	W absence
בָּנוֹת	בָּנֹת	בנות	בנת
טוֹבוֹת	טוֹבֹת	טובות	טובת
חֲלוֹת	חֲלֹת	חלות	חלת
טָעוּת	טָעֻת	טעות	טעת
שְׁטוּת	שְׁטֻת	שטות	שטת
רְשׁוּת	רְשֻׁת	רשות	רשת
קָרוֹב	קָרֹב	קרוב	קרב
רָחוֹק	רָחֹק	רחוק	רחק
גָדוֹל	גָדֹל	גדול	גדל
עָסוּק	עָסֻק	עסוק	עסק
כָּתוּב	כָּתֻב	כתוב	כתב
סָגוּר	סָגֻר	סגור	סגר
אוֹכֶל	אֹכֶל	אוכל	אכל
אוֹרֶךְ	אֹרֶךְ	אורך	ארך
חוֹרֶף	חֹרֶף	חורף	חרף
בּוֹקֶר	בֹּקֶר	בוקר	בקר
גוֹבַה	גֹבַה	גובה	גבה
רוֹחַב	רֹחַב	רוחב	רחב
קוּפָּה	קֻפָּה	קופה	קפה

סכה	סוכה	סֻכָּה	סוּכָּה
סכר	סוכר	סֻכָּר	סוּכָּר
מכר	מוכר	מֻכָּר	מוּכָּר
סלם	סולם	סֻלָּם	סוּלָּם
שתף	שותף	שֻתָּף	שוּתָּף

Appendix II**. Analysis of homography in non-pointed test items**

Non-pointed task words presented without ו	**Possible legal word**	**Score as legal word** 1-most probably 2-possible 3- just possible 4- impossible
Consistent - linear		
בנת	*bant* ‘you, Fm. Understood’	3
טובת	*tovat* ‘welfare, bound compound form’	2
חלת	*xalat* ‘sweet bread, bound compound form’	2
טעת	*ta'at* ‘planting, non-finite form’ (*la*- ‘to’ missing)	3
שטת	impossible	4
רשת	*réšet* ‘net’	1
Consistent - nonlinear		
קרב	*karav* ‘come closer’	1
רחק	*raxak* ‘go further away’	1
גדל	*gadal* ‘grow up’	1
עסק	*asak* ‘be occupied’	1
כתב	*katav* ‘write’	1
סגר	*sagar* ‘shut’	1
Inconsistent - linear		
אכל	*axal* ‘eat’	1
ארך	*arax* ‘last, V’	1
גבה	*gava* ‘become tall’ / collect money’	1
רחב	*raxav* ‘wide’	1
חרף	*xaraf* ‘spend the winter’	2
בקר	*bakar* ‘cattle’	2
קפה	*kafe* ‘coffee’	1
סכה	*sika* ‘pin’	2
מכר	*makar* ‘acquaintance’	1
סלם	*salam* ‘their basket’	3
סכר	*saxar* ‘dam, V’	2
שתף	*šitef* ‘share’	3

<u>Legality criteria</u>: 1 – if string occurs in Hebrew as a free morpheme (non-bound word); 2 – if string occurs only as a bound form or as a member of a large paradigm; 3 – if string constitutes part of a possibly separable sequence; 4 – impossible string.

Inter-judge reliability: Test items were assessed separately by 2 judges who reached 92% agreement. This was followed by a discussion between the judges till agreement was reached.

Notes

[1] We have chosen to represent Hebrew letters by their capital Latin counterparts, and pointing marks by subscript Latin vowel letters.
[2] Root radicals are marked by C's.
[3] A may also appear word-internally in words of foreign origin, e.g., *bar* ,RAB delleps 'rab' באר Hebrew (compare with *bar* 'wheat' spelled BR, Hebrew בר).