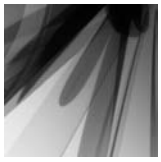

FIRST LANGUAGE

ARTICLE

www.sagepublications.com Vol 24(2): xxx-xxx (200406)
DO1: 10.1177/0142723704044127

Learning to represent vowels in written Hebrew: different factors across development

Dorit Ravid, *Tel Aviv University*
Rachel Schiff, *Bar Ilan University*

ABSTRACT
The study investigates novice and veteran Hebrew readers' perception of words containing a vowel letter in different orthographic and morphological contexts. In the first experiment, children and adults 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. Accuracy scores improved with age and schooling, and at the same time lexical decision times dropped. Only expert adult readers found it easier to correctly identify words with consistent W than words with inconsistent W. Participants generally found it easier to reach decision if the word contained a W, but in the pointed experiment adults alone were able to judge words correctly even when W was absent. Morphological structure affected all readers in the same way. The study supports a root-based view of Hebrew spelling. It also supports 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.

KEYWORDS
Gradeschool; Hebrew; morphology; reading; spelling; vowels

BACKGROUND: VOWELS IN WRITTEN LANGUAGE

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, and particularly for poor readers, than consonants are (Frost & Bentin, 1992; Landerl, Wimmer & Frith, 1997; Purushothama, 1990). Vowel errors constitute a large part of children's spelling errors in English (Treiman, 1993), and are motivated by phonological considerations (Ehri, Wilce & Taylor, 1987). Varnhagen, Boechler & Steffler (1999) found that English-speaking children progress from using phonological 'best-guess' strategies to relying gradually on analogical orthographic information in spelling ambiguous vowel phonemes. Studies on the emergence and consolidation of Hebrew spelling also indicate that vowel spelling is acquired later and with more difficulty than consonant spelling (Ravid & Kubi, in press; Share & Levin, 1999). The current study aims to examine the interface of phonological, orthographic and morphological factors in learning to overcome ambiguity in spelling the vowels *o* and *u* by the Hebrew letter VAV spelled W (ו).

The problem of vowel spelling in the written word has broader implications for general processing theories beyond the psycholinguistics of Hebrew spelling. 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. Our study will show how young Hebrew spellers learn to overcome the poor internal orthographic representation of the grapheme W (ו) due to the multiplicity and ambiguity of cues necessary for its occurrence in the word. This Hebrew study will provide the unique opportunity of teasing apart phonological from orthographic representation. Specifically, our study addresses the interface of spelling development with the role phonology plays in determining which orthographic information fails to be stored.

VOWELS IN WRITTEN HEBREW

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 diacritic marks termed *nikud* 'pointing'. This full, transparent and orthographically shallow version provides precise, in many cases redundant, phonological information about the written Hebrew

Table 1 Vowel pointing in Hebrew, with corresponding graphemic values in diacritics, using the letters G ג and A א to demonstrate diacritic values

Modern Hebrew vowel	*Hebrew diacritic sign*	*Hebrew diacritic name*
a	גָ	*qamats*
a	גַ	*pattah*
a	אָ	*hataf-pattah*
e	גֶ	*serey*
e	גֶ	*segol*
e	אֱ	hataf-segol
i	גִ גִי	*hiriq*
o	גוֹ גֹ	*holam*
o	גָ	*qamats qatan*
u	גֻ	*qubuts*
u	גּוּגּוּגּוּ	*shuruq*
e /0	גְ	*schwa*

word. The main information is vocalic: in addition to the full representation of all consonants by 22 letters, the five Modern Hebrew vowels are represented by 9 diacritic *nikud* marks, combining to form 13 marks (Table 1). Thus each vowel has at least two, in some cases three, corresponding written signs. For example, the vowel *e* is represented by the marks *serey, segol* and *hataf-segol* appearing under the letters, as in examples *séfer* 'book' spelled סֵפֶר, and *emet* 'truth' spelled אֱמֶת. This pointed version is used in reading and writing school instruction, in children's books, in texts for new immigrants, and in Biblical and poetic texts (Ravid, in press).

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,[1] 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 (Hebrew י) in the written string YLDWTY 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, although there are a number of homophonous graphemes. Vowels are relatively less stable in representation; the normally used non-pointed version over-represents consonants at the expense of 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,

Table 2 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*	no constraints

the non-pointed written string WKŠBMKTBYYK pronounced *uxšebemixtaváyix* 'and-when-in-your,Fm,Pl-letter-s' (Hebrew וכשבמכתביייך): all the consonants are represented in this written string, including the root morpheme K-T-B 'write' and affixal function elements – two conjunctions, a preposition, a pattern prefix and a genitive suffix; but only two of the vowels (*u* and *i*) are represented in writing. 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 2. This table summarizes the multiple functions of and constraints on AHWY as consonant and vowel designators in Modern Hebrew.

AHWY and diacritic pointing interact with orthographic conventions in representing vowels. In general, vowel representation by AHWY at word final position in both pointed and non-pointed script is consistent, while representation of word-internal vowels is inconsistent or not permitted. The vowels e, a are usually marked by zero in word-internal position, and by A and H at word final position, e.g., *yafe* 'pretty', spelled YPH, Hebrew יפה. The vowels *i, u, o* are represented by W and Y at any position in the word (and thus more often), e.g., *uvetoxo* 'and-in-it', spelled WBTWKW, Hebrew ובתוכו.

Two morphological devices common in Hebrew are relevant here. One is the Semitic root-and-pattern structure, which combines root radicals (usually consonants) with a mainly vocalic pattern to produce a word. For example, root *g-d-l* takes adjectival pattern *CaCoC*[2] 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 to the noun base *enoš* 'human' to produce *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).

AHWY and pointing marks carry more than phonological information: their occurrence is closely linked to the morphological information expressed in the word.

There are three morphological roles that AHWY can fulfill as *matres lectionis*, that is, 'mothers of reading' – AHWY used in their vowel role as reading facilitators (Ravid, 2001):

1. *Root letters*. While root letters are generally consonantal (Ravid, 2002), in some cases they represent vowel values. For example, one of the few cases when A appears in word-internal position is as a root letter, e.g., A in *karati* '(I) read', spelled QRATY (Hebrew קראתי), root Q-R-A. All four matres lectionis may function as vocalic root letters, and they may not be deleted when the word is pointed.

2. *Function letters*. Vowels often participate in expressing function (i.e., non-root) morphological roles, especially in word-final position. For example, Y in *kosi* 'my glass', spelled KWSY (Hebrew כוסי) expresses genitive case, 1st person singular. Again, all four *matres lectionis* may function as vocalic function letters, and they may not be deleted when the word is pointed.

3. *Internal vowel letters*. W and Y alone may also have an additional, in a sense less meaning-bearing, role in representing word-internal *o, u, i*,[3] as part of the (mainly) vocalic pattern of the word (e.g., *o* in *gadol* 'big', spelled GDWL, Hebrew גדול, adjectival pattern *CaCoC*; or in *gódel* 'size', spelled GWDL in non-pointed script, Hebrew גודל, adjectival pattern *CóCeC*). In such cases, pointing marks may sometimes substitute for Y and W, and in others they may not. This is the domain of our enquiry.

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.

Spelling without pointing diacritics (*plene spelling*) is the default in Modern Hebrew texts intended for experienced readers, and thus requires the addition of *matres lectionis* AHWY to dispel possible ambiguity (Schwarzwald, 2001). Mature, experienced writers/readers of Hebrew usually have a firm grasp of spelling patterns of the AHWY graphemes when they constitute root or function letters, since they appear in both pointed and non-pointed spelling. However, there is much confusion regarding the status of W and Y signifying internal vowels in the normally used non-pointed Hebrew orthography (Schiff & Ravid, in press). In such cases, W and Y do not convey any morphological information (in the sense of being root or function letters), and their occurrence in the word depends on whether it is pointed or not.

In three separate studies, Hebrew vowel spelling was found to be the most difficult category for both children and adolescents (Gillis & Ravid, 2000; Ravid & Kubi, in press): vowel letters were exchanged, deleted and inserted by spellers more frequently than consonant letters. Most prone to spelling errors were words with non-morphological word-internal W and Y, which have two alternative spellings in Hebrew: *plene* (or non-pointed), with the vowel letter marked, and pointed, without the vowel letter.

In a series of studies, Levin and her colleagues consistently found that consonants emerge in the writing of Hebrew-speaking children earlier than vowels (Levin,

Amsterdamer & Korat, 1997). Levin, Share & Shatil (1996) report, for example, that of preschoolers who were able to spell the five required consonants, fewer than 25% were able to spell the two required vowels; but those who were successful with vowels were always successful with consonants. Levin, Ravid & Rapaport (1999) also report more advanced consonant writing than vowels in kindergarten and in first grade.

The current study investigates the changing psycholinguistic perception of the Hebrew grapheme W, standing for the vowels *o* and *u*. Specifically, we are interested in how children compared with adults perceive the status of the letter W as a consistent and an inconsistent element in the written word, and in its interaction with linear and non-linear morphological structure. This investigation was conducted in two different contexts: pointed and non-pointed words. The grapheme W was selected for investigation 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 as a function letter and in representing internal vowels, and, relatedly, it participates in a variety of morphological structures.

We predict shorter decision times and more accuracy in adults than in children. Beyond these simple predictions, a number of interrelated psycholinguistic questions arise in this context.

- *W status*. How stable is the status of W across development in written Hebrew? It is *consistent* as a function letter participating in the expression of function suffixes in both pointed and non-pointed writing: the feminine plural suffix *-ot* (e.g., *ban-ot* 'girl-s' spelled BNWT, Hebrew בנות) or the abstract suffix *-ut* (e.g., *reš-ut* 'permiss-ion', spelled RŠWT, Hebrew רשות). But it is less stable when representing a word-internal vowel, depending on the morphophonological structure of the word (Schiff & Ravid, in press). Note, for example, the *o* in *bóker* 'morning', which is spelled BWQR (Hebrew בוקר) but often occurs in writing as BQR (Hebrew בקר). We predict shorter decision times for items with consistent W and more accuracy than items with inconsistent status for both children and adults.
- *W presence or absence*. What happens when the grapheme W is removed? Will the resulting written string be judged as correctly or incorrectly written by literate adults? The Hebrew Language Academy (1996) stipulates where W may be removed and where it must be retained, but how psychologically real are these stipulations, especially in developmental terms? How do they interact with W status? Despite the official language establishment, inconsistent W is often deleted in non-pointed script and retained in pointed script. These cases are not considered strict 'spelling errors' by literate Hebrew speakers (Ravid & Kubi, in press; Schiff & Ravid, in press), who are often confused about the occurrence of W and Y in written Hebrew (Gillis & Ravid, 2000). Although not similar, English words such as *neighbor, color* or *endeavor* (US spelling), spelled *neighbour, colour* and *endeavour* in British English, might be considered as an analogy. We predict easier and more efficient reading of words with W in both children and adults.
- *Morphological structure*. Is W perceived differently in words with linear and non-linear structure? In our study, the target letter W designated the vowel *o* or

u in one of the syllables of the CVCVC string (*CaCoC /CaCuC, CóCeC /CuCaC*). In linear structure, W was consistent as a function letter in the -WT suffix (e.g., *banot* 'girls', spelled BNWT, Hebrew בנות). In non-linear root and pattern structure, W designated an internal vowel *o* or *u*, and its status was either consistent or inconsistent, as explained above. We held constant the same syllable structure CVCVC across the two morphological structures to see if they affect Hebrew readers' judgement of W status. We predict the interference of morphological factors in reading Hebrew words with W for both children and adults.

EXPERIMENT I: POINTED

Our study was designed to find out the answers to the questions outlined above by measuring children's and adult 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

The participants consisted of monolingual Hebrew-speaking children and adults from middle-high SES background with no diagnosed language or learning disabilities. The children were 29 2nd graders (14 boys and 15 girls, aged 7–8, mean age 7;8), 39 4th graders (18 boys and 21 girls, aged 9–10, mean age 9;5), and 29 8th graders (13 boys and 16 girls, aged 13–14, mean age 13;7). The oldest group consisted of 38 third-year undergraduate education adults, all literate, monolingual Hebrew-speaking women without any formal university-level knowledge in Hebrew linguistics.

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 (university students of education), who were asked to rank them on a scale of 1 to 5, from most to least frequent in the written language. 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, all ranked 1 and 2, were selected for the purposes of this study (e.g., *banot* 'girls', *sulam* 'ladder'). Words were judged in their written form. In order to check whether the written words were matched in frequency, a mean rating of frequency was constructed for the 12 consistent words (see structure of research instrument below). 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.

Research instrument and procedure

The research instrument constructed for the purposes of this study consisted of 24 written bi-syllablic Hebrew 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 BQR בקר), 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 גֹּדֶל) and in an illegal non-pointed string (e.g. *GDL for *gódel* 'size', Hebrew גדל). The study paradigm is presented in Table 3.

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. 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 their original Hebrew 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 3 shows that when items are presented with W, they are always legal, and when items are presented without W, they are always illegal (marked by a star), except in the case of pointed inconsistent W.

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.

Table 3 Task structure and structure of the test categories, with examples

W present			*W absent*		
12 items with consistent W		*12 items with inconsistent W*	*12 items with *consistent W*		*12 items with inconsistent W*
6 non-linear structure	*6 linear structure*	*all non-linear structure*	*6 non-linear structure*	*6 linear structure*	*All non-linear structure*
karov KRWB 'near' root *k-r-v*, pattern *CaCoC* *katuv* KTWB 'written' root *k-t-b*, pattern *CaCuC*	*yaf-ot* YPWT 'pretty-Fm,Pl' *reˇs-ut* RSˇWT 'permiss-ion'	*bóker* 'morning' BWQR root *b-k-r*, pattern *CóCeC* *sˇutaf* 'partner' SˇWTP root *sˇ-t-f*, pattern *CuCaC*	*karov* *KRB 'near' root *k-r-v*, pattern *CaCoC* *katuv* *KTB 'written' root *k-t-b*, pattern *CaCuC*	*yaf-ot* *YPT 'pretty-,Fm,Pl' *reˇs-ut* *RSˇT 'permiss-ion'	*bóker* 'winter' BQR root *b-k-r*, pattern *CóCeC* *sˇutaf* 'partner' SˇTP root *sˇ-t-f*, pattern *CuCaC*

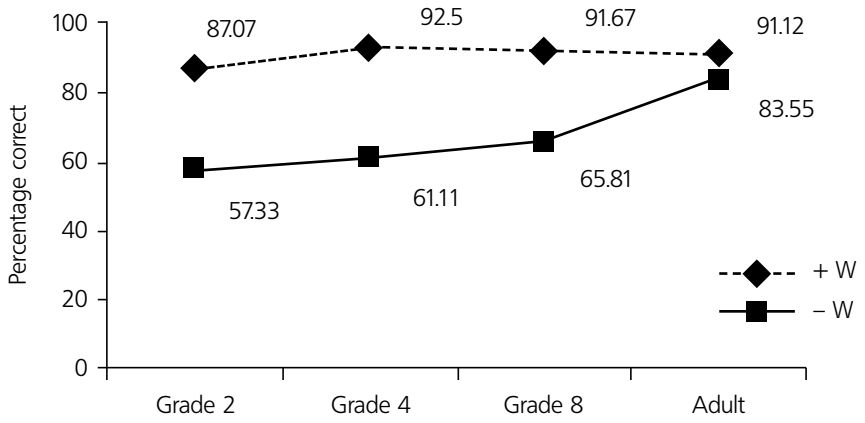

Figure 1 Experiment 1, accuracy scores (pointed items): interaction of Grade (2nd grade, 4th grade, 8th grade, and adults) × W presence (+W/–W)

Results

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

Accuracy

A three-way ANOVA with repeated measures of Grade: 4 [Grade 2, Grade 4, Grade 8, adults] × W presence: 2 [W present/W absent] × W status: 2 [consistent/inconsistent W] was carried out on the correct percentage scores of the study participants. Three main effects emerged. First, there was an effect for Grade ($F(3,131) = 20.4$, $p < 0.001$): accuracy scores improve with age (Grade 2 $M = 72.2$, $SD = 10.86$; Grade 4 $M = 76.82$, $SD = 7.14$; Grade 8 $M = 78.74$, $SD = 7.33$; adults $M = 87.34$, $SD = 7.66$). A *post-hoc* Bonferroni analysis shows a significant difference at the 0.05 level between the adults and each of the age groups. A second effect emerged for W presence ($F(1,131) = 230.12$, $p < 0.001$): items with W scored higher ($M = 90.59$, $SD = 12.58$) than items without W ($M = 66.95$, $SD = 15.62$). Another effect emerged for W status ($F(1,131) = 22.0$, $p < 0.001$): items with consistent W scored higher ($M = 83.67$, $SD = 16.24$) than items with inconsistent W ($M = 73.87$, $SD = 15.21$).

These findings were qualified by two interactions. One was an interaction of Grade × W presence ($F(3,131) = 13.86$, $p < 0.001$), as shown in Fig. 1. This figure and a *post-hoc* Bonferroni analysis show that all young groups score higher on pointed words with W, but adults do as well on both types of words (presented with and without W). Moreover, young groups score lower than adults on words without W, but, within the three child groups, this does not differ significantly with age.

The Grade × W status interaction (Fig. 2) was also significant, $F(3,131) = 2.69$, $p < 0.05$. According to Fig. 2 and a post-hoc Bonferroni analysis, 2nd graders differ from 8th graders and from adults on words with consistent W. In the 2nd graders there is

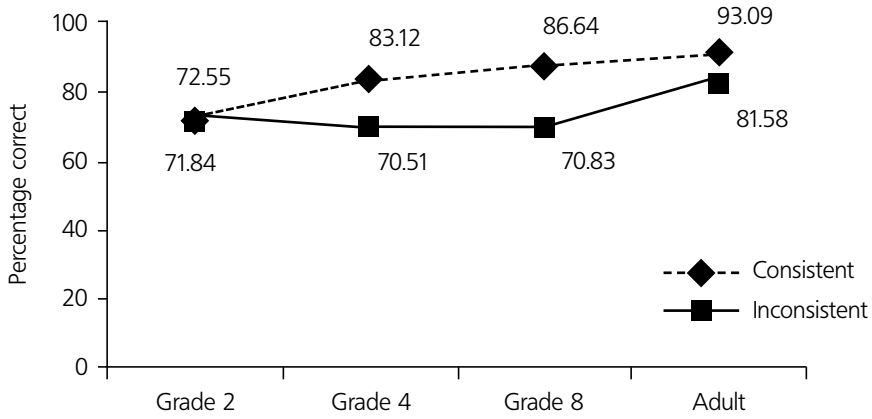

Figure 2 Experiment 1, accuracy scores (pointed items): interaction of Grade (2nd grade, 4th grade, 8th grade, and adults) × W status (consistent/inconsistent)

no difference between consistent and inconsistent items, whereas in older age groups consistent items score higher.

The effect of W-status may be confounded by the fact that all 12 inconsistent items were non-linear whereas only half of the consistent items (6) were non-linear. In order to neutralize this problem, we conducted a three-way analysis (Grade × W status × W presence) on the non-linear items alone. All three effects emerged again: an effect of Grade ($F(3,131) = 13.77$, $p < 0.001$); W presence ($F(1,131) = 241.49$, $p < 0.001$); and an effect of W status ($F(1,131) = 13.18$, $p < 0.001$). There were no interactions, but exactly the same pattern of development was revealed here as in Fig. 2: in the 2nd graders there is no difference between consistent and inconsistent items, whereas in older age groups consistent items score higher. This further validates our findings.

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 CVCWC syllabic structure with either *o* or *u* in the second syllable. We carried out a three-way ANOVA with repeated measures Grade: 4 [Grade 2, Grade 4, Grade 8, adults] × W presence: 2 [W present/W absent] × morphological structure: 2 [linear/non-linear]. In addition to the two main effects of Grade ($F(3,131) = 12.07$, $p < 0.001$) and W presence ($F(1,131) = 102.31$, $p < 0.001$) which emerged as before, there was a third main effect for morphological structure ($F(1,131 = 12.01$, $p < 0.002$): linear items scored higher ($M = 85.33$, $SD = 16.24$) than

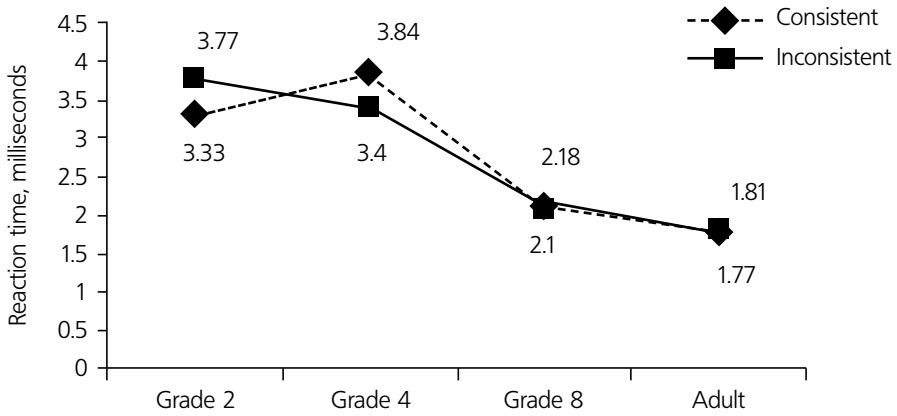

Figure 3 Experiment 1, reaction time (pointed): interaction of Grade (2nd grade, 4th grade, 8th grade, and adults) × W status (consistent/inconsistent)

non-linear items ($M = 82.02$, $SD = 18.04$). There was no interaction of Grade and morphological structure.

Reaction times

A three-way ANOVA with repeated measures of Grade: 4 [Grade 2, Grade 4, Grade 8, adults] × W presence: 2 [W present/W absent] × W status: 2 [consistent/inconsistent W] was carried out on the accurate RT scores of the participants. There was only an effect of Grade ($F(3,123) = 16.56$, $p < 0.001$): RT declines with Grade (Grade 2 $M = 3.55$, $SD = 1.59$; Grade 4 $M = 3.62$, $SD = 1.81$; Grade 8 $M = 2.14$, $SD = 0.90$, adults $M = 1.79$, $SD = 0.76$). The *post-hoc* analysis showed that the 2nd and 4th graders differed significantly from the 6th graders and the adults. No other main effect emerged, but there was an interaction of Grade and W status ($F(3,123) = 6.81$, $p < 0.001$), as depicted in Fig. 3. According to this figure and a post-hoc Bonferroni analysis, the main reason for the interaction is the difference between 2nd and 4th grade on consistent items: a U-shape is formed with its peak in 4th grade. This finding is discussed below. We conducted a further analysis within the non-linear items alone (see accuracy results above). As before, there was only an effect for Grade.

We then focused on a further analysis within the consistent W category, which had two types of morphological structures: linear (e.g., *ban-ot* 'girl-s') and non-linear (e.g., *gadol*, root *g-d-l*, pattern *CaCoC*). We carried out a three-way ANOVA of Grade × W presence × morphological structure. No relevant effects or interactions emerged.

Discussion

The task required children and adults to judge whether written strings containing the

grapheme W in different contexts were spelled correctly, and measured both accuracy of decision and time to decision. In this first experiment, where task words were presented with pointing, accuracy scores improved with age and schooling. The children and adolescents were more successful in items presented with W than in items presented without W, showing that they are not adequately familiar with the system that permits the omission of W when the word is pointed, as we predicted. The most dramatic change in vowel perception occurs very late, in high-school; aAdults do as well on words presented with and without W. Words with consistent W were easier than words with inconsistent W for all groups except for the 2nd graders. This means again that important changes in how children perceive vowel representation occur towards the high-school years.

In items with consistent W, linear items with stem and suffix structure scored higher than non-linear items with root and pattern structure, showing that W in the morphological role of function letter is more stable than W in the role of internal vowel letter. This finding was stable across all study groups, showing that Hebrew-speaking children, adolescents and adults are affected in the same way by Hebrew morphology.

The first experiment also showed a drop in time of lexical decision with age and schooling. We found, however, rather surprisingly, that 4th graders spend the most time on lexical decision in words with consistent W. We interpret this finding to mean that 4th graders pay more attention to word structure due to the major changes in internal linguistic representations occurring at this time: 2nd graders identify words with consistent structure (e.g. *karov* 'close') more rapidly than they do words with inconsistent structure (e.g., *gódel* 'size') even with pointing added, but in 4th grade they start re-analysing well-established representations (Karmiloff-Smith, 1979), which creates the U-shape. Lexical decision of inconsistent items, which are interpreted as almost 'bare roots', constantly decreases with age and schooling.

EXPERIMENT II: NON-POINTED

No feedback about correctness or about any aspect of the responses was given to the participants. This enabled us to conduct the second experiment 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. Pointing provides readers with full phonological information about the word, including all vowels as well as consonantal distinctions such as stop and spirant versions of the letters P, K, B ב,כ,פ. Pointing necessitates assembled reading, since it directs the reader to each and every phonematic distinction, and is typical of the initial stages of learning to read. Non-pointed Hebrew words provide readers with partial and inconsistent information about the phonological form of the word; therefore reading without pointing is typically addressed, and necessitates knowledge of the array of morphological options available in the language as well as an adequate vocabulary. Thus, the non-pointed material presented in the second experiment is inherently different in nature from the pointed version, and requires different processing procedures. Nevertheless, we do not compare the two experiments or the pointing issue in this paper.

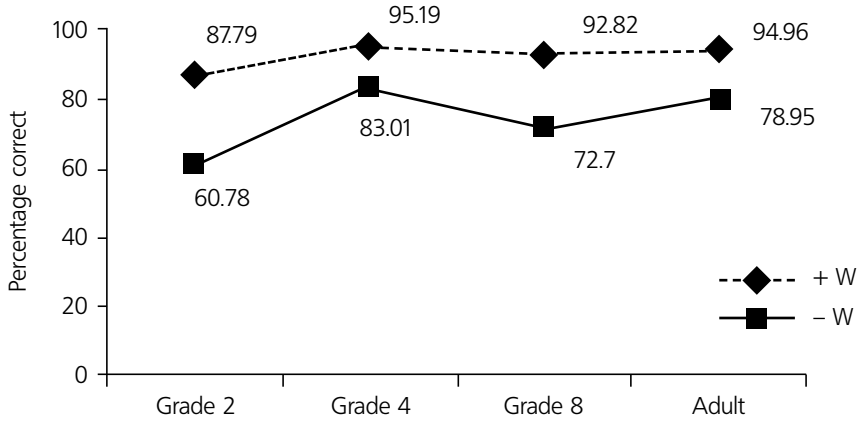

Figure 4 Experiment 2, accuracy scores (non-pointed items): interaction of Grade (2nd grade, 4th grade, 8th grade, and adults) × W presence (+W/–W)

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 to 4: 1, most probably a legal string; 2, a possible legal string; 3, just possibly a legal string; 4, impossible as a legal string. 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

Accuracy

A three-way ANOVA with repeated measures of Grade: 4 [Grade 2, Grade 4, Grade 8, adults] × W presence: 2 [W present/W absent] × W status: 2 [consistent/inconsistent W] was carried out on the correct percentage scores of the study participants. Three main effects emerged. First, there was an effect for Grade ($F(3,131) = 6.93$, $p < 0.001$): accuracy scores improve with Grade (Grade 2 $M = 74.28$, $SD = 20.68$; Grade 4 $M = 89.1$,

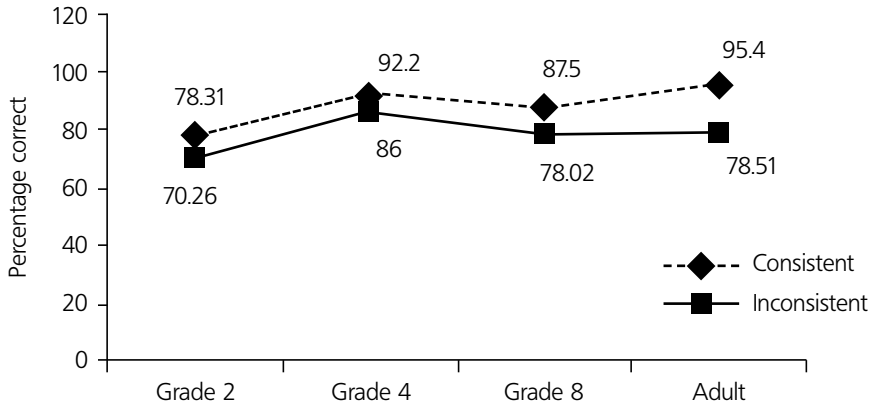

Figure 5 Experiment 2, accuracy scores (non-pointed items): interaction of Grade (2nd grade, 4th grade, 8th grade, and adults) × W status (consistent/inconsistent)

SD = 9.34; Grade 8 *M* = 82.76, *SD* = 14.18; adults *M* = 86.95, *SD* = 11.73). The *post-hoc* analysis revealed a significant difference between 2nd and 4th graders. A second effect emerged for W presence ($F(1,131) = 151.83$, $p < 0.001$): items with W scored higher (*M* = 92.68, *SD* = 11.99) than items without W (*M* = 73.86, *SD* = 21.72). Another effect emerged for W status ($F(1,131) = 58.5$, $p < 0.001$): items with consistent W scored higher (*M* = 88.35, *SD* = 13.92) than items with inconsistent W (*M* = 78.2, *SD* = 19.47).

These findings were qualified by two interactions. One was an interaction of Grade × W presence ($F(3,131) = 4.27$, $p < 0.008$), as shown in Fig. 4. According to this figure and a *post-hoc* Bonferroni analysis, the main reason for this interaction is the fact that the scores of 2nd graders on words presented without W differ from all other groups and the fact that 4th graders have peak scores in words presented without W. Moreover, the scores of all groups (including adults) are higher in words presented with W, except in the 4th graders where no such difference is found.

Another interaction was found of Grade × W status ($F(3,131) = 3.53$, $p < 0.02$); see Fig. 5. According to this figure and a post-hoc Bonferroni analysis, this interaction derives from the fact that only the adults do better on the words with consistent W.

As described in Experiment I above, the effect of W-status may be confounded by the fact that all 12 inconsistent items were non-linear whereas only half of the consistent items (6) were non-linear. To neutralize this problem, we conducted a separate analysis (Grade × W status × W presence) on the non-linear items alone. All three effects emerged again: an effect of Grade ($F(3,131) = 6.43$, $p < 0.001$); an effect of W presence ($F(1,131) = 119.05$, $p < 0.001$); and an effect of W status ($F(1,131) = 58.39$, $p < 0.001$). The same interactions emerged again: Grade × W presence ($F(3,131) = 4.14$, $p < 0.009$) and Grade × W status ($F(3,131) = 2.72$, $p < 0.05$). This points to the robustness of our findings.

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 CVCWC syllabic structure with either *o* or *u* in the second syllable. We carried out a three-way ANOVA with repeated measures Grade: 4 [Grade 2, Grade 4, Grade 8, adults] × W presence: 2 [W present/W absent] × morphological structure: 2 [linear/non-linear]. No effect or interaction relating to morphological structure emerged here.

Reaction time

A three-way ANOVA with repeated measures of Grade: 4 [Grade 2, Grade 4, Grade 8, adults] × W presence: 2 [W present/W absent] × W status: 2 [consistent/inconsistent W] was carried out on the RT scores of the participants. There was only an effect of Grade ($F(3,123) = 15.43$, $p < 0.001$): RT declines with Grade (Grade 2 $M = 3.08$, $SD = 1.56$; Grade 4 $M = 2.92$, $SD = 1.23$; Grade 8 $M = 1.69$, $SD = 0.61$; adults $M = 1.78$, $SD = 0.59$). The *post-hoc* analysis showed the differences to reside between the 2nd graders and the 6th graders and adults, on the one hand; and between the 4th graders and the 6th graders.

We then focused on a further analysis within the consistent W category, which had two types of morphological structures: linear (e.g., *ban-ot* 'girl-s') and non-linear (e.g., *gadol*, root *g-d-l*, pattern *CaCoC*). We carried out a three-way ANOVA of Grade × W presence × morphological structure. In addition to an effect for age $F(3,129) = 14.33$, $p < 0.001$, there was an interaction of Grade × morphological structure ($F(3,129) = 4.99$, $p < 0.004$), shown in Fig. 6. This figure and a *post-hoc* Bonferroni analysis show that this interaction derives from the fact that scores on linear structure decline from 2nd to 4th grade, but this does not happen in the non-linear items, where the decline starts only in 4th grade onwards.

Discussion

In the second experiment, the same task items were presented in non-pointed form. As in the previous experiment, accuracy scores generally improve with grade. Adults, but not other groups, did better on consistent items. This shows that knowledge of vowel representation in non-pointed words consolidates very late. Items presented with W generally had higher accuracy scores, but this difference is not significant in the 4th graders, who do well even on words presented without W; it may be the case that 4th graders attribute word-like status to written strings without W which have root-like forms. RT on non-pointed words again grows faster with grade, but 2nd graders take more time on decision in words with linear structure than on words with non-linear structure. We interpret this result as indicating an early perception of root-like structures and with more time taken over words with W, a non-stable orthographic entity.

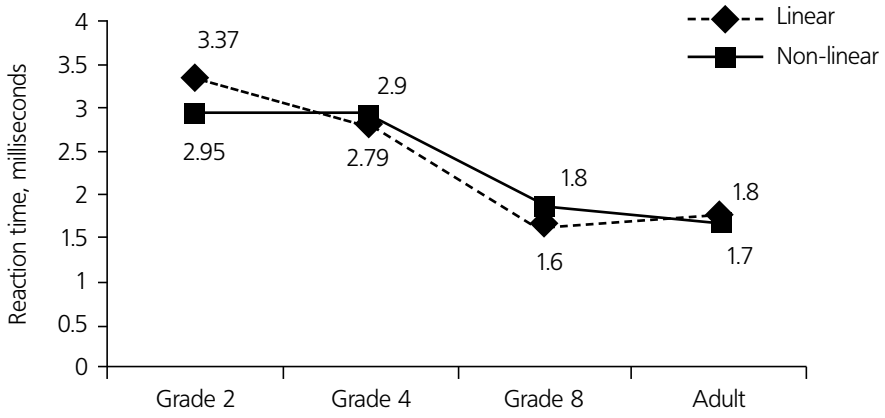

Figure 6 Experiment 2, reaction time (non-pointed): interaction of Grade (2nd grade, 4th grade, 8th grade, and adults) × morphological structure (linear/non-linear items)

GENERAL DISCUSSION

The study examined the developing perception of the grapheme W standing for the vowels *o* and *u* in children, adolescents and adults, given the complex morpho-phonological and morphological contexts for its occurrence in the word. Our findings lead us to a number of conclusions.

W status in development

We hypothesized that W might not be perceived uniformly in written Hebrew. The variable *W* status had two alternatives: consistent and inconsistent status. Consistent W items consisted of two types of items: non-linear words where W marks the internal vowels of the pattern (e.g., GDWL *gadol* 'big', Hebrew גדול, pattern *CaCoC*; KTWB *katuv* 'written', Hebrew כתוב, pattern *CaCuC*); and linear words, where the W is part of the feminine plural suffix *-ot* or abstract suffix *-ut*, both spelled -WT (e.g., BNWT *banot* 'girls', Hebrew; בנות RSWT *reš̆ut*. 'permission', Hebrew תשור). In both cases, W is consistent across the board. Inconsistent W items were all non-linear words with *o* or *u*, with inconsistent W deleted in pointed script and retained in non-pointed script (e.g., G(W)DL *gódel* 'size', Hebrew גדל(ו), pattern *CóCeC*; S(W)TP *š̆utaf* 'partner', Hebrew שתף(ו), pattern *CuCaC*).

Our results provide evidence that W status is non-uniform in *adult* written Hebrew: adult readers find it easier to correctly identify words with consistent W than words with inconsistent W. This effect in adults is robust and does not change with pointing. Note that this finding covers the correct identification of both correctly and incorrectly

written strings. Consistent words are always written with W – and in half of them, W is a function letter carrying important morphological information. The inconsistent words, in contrast, sometimes show up with W and sometimes, when pointed, show up without W. Therefore, it is easy to identify a consistent W word as either correctly written with the W or incorrectly written without the W; however, making the same decision about inconsistent words is not as clear-cut, and requires paying additional attention to whether the word is also pointed (and then correct) or non-pointed (and then incorrect). Inconsistent W placement thus does not have a stable representation in mature, literate Hebrew readers. For adult readers, the omission of inconsistent W (e.g., GDL for *gódel* 'size', Hebrew גדל) results in a *less acceptable* but not a misspelled string.

But the differing orthographic status of W is not established early on and it interfaces with the differing presentation of phonological information in the written word. 2nd graders alone do not succeed better on determining when pointed consistent words are spelled correctly with the mandatory W and incorrectly without it, than on pointed inconsistent words, where the omission of W does not result in a misspelled string. Our explanation is that 2nd graders, novice reader/writers who are not yet familiar with the conventions of the orthography (Ravid & Tolchinsky, 2002), focus intensely on deciphering phonological information of any kind in the word. Once they detect vowel marking of any kind in the word, even pointing instead of W insertion – which is illegal in consistent-W words – they accept the word as correct. This finding supports findings in previous studies which indicate that in early gradeschool, children still pay attention to and rely on pointing cues for word deciphering, while later on they abandon pointing completely (Ravid, 1996; Ravid & Shlesinger, 2001; Shimron, 1999). We regard the fact that 4th graders take more time than any other group on reaching lexical decision as a window on consolidating orthographic perception, since this is the age and schooling bracket where pointed reading is abandoned (Share & Levin, 1999).

W status differentiates sharply between young and expert readers in the non-pointed experiment. Without the interference of pointing diacritics, the only knowledge Hebrew readers can rely on is on the patterning of graphemes in the word. Here we turn to 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*, and W specifically, have a more ambiguous relation to speech than graphemes which code consonants, for example, and are thus coded less effectively (see also the neuro-linguistic functional magnetic resonance imaging study discussed in Pugh *et al*., 2000). In adult Hebrew readers, these ambiguous letters are orthographically represented last and the weakest. 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. By adulthood, words with consistent W are more deeply entrenched in spelling memory than words with inconsistent W. But in younger readers there is strong competition from the fact that most of our incorrectly spelled words are nevertheless 'legal' in the

sense that they are homographic with some other written strings in the language. It is only the adults who are able to take the context provided into consideration and note that it is incompatible with the incorrect W-less strings. Even in 8th grade, this capacity to embed the written string in its context and use contextual cues to identify word appropriateness is not yet in place.

W presence in development

On the whole, Hebrew readers find it easier to determine whether a word is written correctly or not if the word contains a W than if it does not in both pointed and non-pointed contexts. However, in the pointed experiment the adults alone were able to judge words correctly even when W was absent. We believe this finding highlights expert Hebrew readers' ability to shift successfully between the two vowelling systems – graphemic AHWY and pointing. Moreover, in order to determine whether pointed words are spelled correctly without W, one needs to have deep memory traces of spelling patterns of both consistent and inconsistent W marking – which seems to be restricted to a very late stage of development. In contrast, in the second experiment it was the 4th graders who did as well on accurately judging words with and without W. This is another indication of the interim stage where pointed reading is abandoned. As a result, 4th graders judge skeletal three-letter strings which are homographic with legal words as correct, overriding the mismatch with the context. Their results closely resemble those of the adults, but in the case of the adults, as we have seen, success stems from familiarity with the written system, while in gradeschool it derives from the fact that no such memory traces are as yet present.

Morphological distinctions in literacy development

Hebrew is a language with rich morphological, in addition to phonological and orthographic, information conveyed in the spelling system. Recall that our items were classified into two structural types: linear (stem and suffix) and nonlinear (interdigitated root and pattern). If morphology were not an issue, we would get the same results for both structure types. The actual results indicate that it is easier to identify a linear than a non-linear written string with or without W. This is because, as we saw above, W constitutes an essential part of the suffix -WT as a function letter with a clear morphological role (*-ot* for plural feminine or *-ut* for abstract nominal), and together WT form a separate morphemic unit which is easily identified by Hebrew speakers (Ravid, 2001). W presence is therefore critical in linear structure and its removal breaks apart the meaningful morpheme. It might be argued that, since this is the consistent W category, W presence should be crucial in non-linear structure as well. But, as explained above, W does not carry a typical morphological role in representing an internal vowel: the larger unit it forms part of is the pattern, an abstract discontinuous unit which is hard to identify, isolate and represent by Hebrew speakers (Ravid & Malenky, 2001). Moreover, other vowels in this pattern (*a, e*) are marked by zero as a rule. The removal of W – the only overt written symbol of the pattern – in consistent structure is thus still perceived as incorrect, but identification lags behind linear structure. This finding was stable across all study groups, showing that Hebrew-

speaking children, adolescents and adults are affected in the same way by Hebrew morphology. Similar findings on the robust nature of Hebrew morphology and its stable perception across age groups are found in Ravid & Kubi (in press). Note, however, that the very youngest group takes longer on lexical decision in non-pointed words with linear structure than on words with non-linear structure. We interpret this result as indicating an early perception of root-like structures and with more time taken over words with W, a non-stable orthographic entity.

CONCLUSIONS

This study presents initial results on how children and adolescents compared with adults are able to process pointed and non-pointed Hebrew words with different morphological structures containing the grapheme W. The analysis of the status of this vowel letter in Hebrew provides a window on two issues. One is the relationship between orthographic and phonological representation while making spelling decisions: our study was able to pinpoint the development of orthographic representations of words with internal *o, u* from its phonological representation and to show that they are not linked in a straightforward manner.

A second issue is the general question of how spelling patterns are learned. Our results provide some support 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 phonologically 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, and that it takes a long time for stable representations to appear in Hebrew readers.

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 Cs.
3. A may also appear word-internally in words of foreign origin, e.g., bar 'bar' spelled BAR, Hebrew באר (compare with bar 'wheat' spelled BR, Hebrew בר).

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Appendix I

Task words presented in Hebrew

Experiment I (pointed)		*Experiment II (non- pointed)*	
W present	*W absent*	*W present*	*W absent*
בָּנוֹת	בָּנ֫ת	בנות	בנת
טוֹבוֹת	טוֹב֫ת	טובות	טובת
חַלּוֹת	חַלּ֫ת	חלות	חלת
טָעוּת	טָעֻת	טעות	טעת
שְׁטוּת	שְׁטֻת	שטות	שטת
רְשׁוּת	רְשֻׁת	רשות	רשת
קָרוֹב	קָר֫ב	קרוב	קרב
רָחוֹק	רָח֫ק	רחוק	רחק
גָּדוֹל	גָּד֫ל	גדול	גדל
עָסוֹק	עָסֹק	עסוק	עסק
כָּתוּב	כָּתֻב	כתוב	כתב
סָגוּר	סָגֻר	סגור	סגר
אוֹכֶל	א֫כֶל	אוכל	אכל
אוֹרֵךְ	א֫רֵךְ	אורך	ארך
חוֹרֵף	ח֫רֵף	חורף	חרף
בּוֹקֵר	ב֫קֵר	בוקר	בקר
גּוֹבַה	ג֫בַה	גובה	גבה
רוֹחַב	ר֫חַב	רוחב	רחב
קוּפָּה	קֻפָּה	קופה	קפה
סוּכָּה	סֻכָּה	סוכה	סכה
סוּכָּר	סֻכָּר	סוכר	סכר
מוּכָּר	מֻכָּר	מוכר	מכר
סוּלָּם	סֻלָּם	סולם	סלם
שׁוּתָּף	שֻׁתָּף	שותף	שתף

Appendix II

Analysis of homography in non-pointed test items

Non-pointed task words presented without ו	Possible legal word	Score as legal word*
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

* 1 – most probably; 2 – possible; 3 – just possible; 4 – impossible

Legality criteria: 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 5 judges who reached 92% agreement. This was followed by a discussion between the judges until agreement was reached.

ADDRESS FOR CORRESPONDENCE

School of Education, Tel Aviv University,
Tel Aviv 69978, Israel
E: doritr@ccsgpost.tau.ac.il