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Examining the developmental trade-off between phonology and morphology in Hebrew reading acquisition

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Abstract

The relative importance of phonological versus morphological processes in reading varies depending on the writing system's orthographic consistency and morphological complexity. This study investigated the interplay between phonology and morphology in Hebrew reading acquisition, a language offering a unique opportunity for such examination with its rich, complex Semitic morphological system and dual writing versions differing in orthographic consistency—transparent-pointed and deep-unpointed versions. Ninety-eight second graders and 81 fourth graders participated in pseudoword-reading tasks designed to distinguish between the different processes: pointed morphologically based pseudowords (pointed MPW), reflecting phonological and morphological processing; unpointed morphologically based pseudowords (unpointed MPW), reflecting only morphological processing; and pointed non-words (pointed NW), with no internal morphological structure, reflecting only phonological processing. Real pointed-word reading accuracy and fluency were also assessed. Results showed the highest accuracy in reading unpointed MPW, with a similar accuracy level observed between unpointed MPW and pointed MPW in second grade, while a significant difference emerged in fourth grade. An age-by-processing type interaction revealed decreasing accuracy in pointed MPW and increasing accuracy in unpointed MPW with age. Additionally, morphological processing significantly enhanced the accuracy and fluency of reading pointed words beyond phonological processing, despite the comprehensive phonological information provided by the transparent, pointed script. These findings suggest that the contribution of morphology exceeds that of phonology as early as second grade, with this trend strengthening through fourth grade, emphasizing children's early prioritization of morphological transparency over orthographic consistency in learning to read Hebrew Semitic orthography.

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Introduction

In the process of learning to read, children progress from sublexical phonological processing of decoding words through grapheme–phoneme correspondence to establishing more direct lexical links between orthography and meaning, gradually utilizing larger orthographic units (Ehri, 2005; Nation, 2009). This developmental progression involves an increasing reliance on morphological processing—identifying the smallest meaning units in written words—while simultaneously reducing dependence on phonology (Castles & Nation, 2022; Castles et al., 2018). Although evidence suggests that even skilled readers routinely continue to use phonological processing, the progression toward a reliance on morphological processing is essential for achieving proficiency in word reading (Carlisle & Kearns, 2017; Castles & Nation, 2022; Castles et al., 2018). Over the past decade, reading research has largely focused on understanding this developmental process in different languages (see Borleffs et al., 2019; Perfetti & Verhoeven, 2017). Theoretical models of reading development across orthographies (e.g., Frost, 2012; Seymour, 2006; Share, 2018) suggest that the extent to which developing readers utilize phonological versus morphological processing is influenced by language and writing system characteristics, such as orthographic consistency and morphological complexity. These language-specific features are crucial in shaping cognitive–linguistic formation and determining the prioritization between phonology and morphology in the process of reading and learning to read (see also Perfetti & Verhoeven, 2017).

Hebrew presents a unique opportunity to examine the interplay between orthographic consistency and morphological complexity in a within-language study design. First, Hebrew employs an abjad-consonant writing system with two script versions: a transparent pointed script with vowel diacritics and a deep unpointed script without vowel diacritics. This variability in orthographic consistency provides researchers with a valuable context to explore how the presence or absence of diacritics influences the reading process. Second, Hebrew is characterized by a rich and complex Semitic morphological system, integrating morphemes based on both linear and nonlinear interlaced principles—the root-and-pattern morphology. Despite this complexity, Hebrew orthography maintains a high degree of morphological transparency, as is evident in its prominent morpho-orthographic structure (Frost, 2012; Ravid & Schiff, 2006). Given Hebrew's distinctive orthography and morphology, the present study aimed to investigate the interaction between phonological and morphological processing throughout reading acquisition by examining how vowel diacritics (orthographic consistency) and morpho-orthographic structure (morphological transparency) influence word identification processes among second and fourth graders. This investigation seeks to deepen understanding of the language-specific factors influencing the progression from phonological- to morphological-based word

identification among developing readers (Castles & Nation, 2022; Castles et al., 2018). Although ample evidence suggests that Hebrew readers begin relying on morphological processes as early as second grade, examining the developmental changes in the extent to which children utilize phonological versus morphological processing in their reading acquisition trajectory is essential for a nuanced comprehension of the reading acquisition process within Hebrew's typological properties.

Orthographic consistency, morphological complexity, and word reading processes

Phonological processing is essential in learning to read (Melby-Lervåg et al., 2012). The foundation for reading development lies in phonological decoding, which involves establishing connections between written graphemes and their corresponding phonemes—the smallest abstract linguistic units that distinguish one word from another (Castles et al., 2018; Landerl et al., 2022). However, the degree of consistency in mapping these orthographic and phonological units varies across writing systems, ranging from transparent to deep in orthographic consistency (Seymour et al., 2003). Ziegler and Goswami's (2005) grain size theory postulates that orthographic consistency influences the size of linguistic units utilized by readers. While readers learning in shallow or transparent orthographies (e.g., Greek or German) primarily rely on small sublexical units (e.g., phonemes or syllables), readers in deep or opaque orthographies (e.g., English or Danish) need to utilize larger linguistic units (letter patterns or whole words), as the small sublexical units tend to be less consistent. Crosslinguistic research supports this theory, indicating that orthographic consistency influences both the rate of reading acquisition (Caravolas et al., 2013; Seymour et al., 2003) and the cognitive–linguistic mechanism variation involved in reading words (Georgiou et al., 2008; Ziegler et al., 2010). However, orthographic consistency is only one dimension of complexity that potentially influences reading development (Borleffs et al., 2019; Daniels & Share, 2018). As alphabetic writing systems represent both phonemic and morphemic linguistic units (Frost, 2012), attention has increasingly been paid to a language's morphological complexity and the morphological transparency of its orthography, referring to the extent to which the internal morphological structure of a complex written word facilitates access to its pronunciation and meaning (Elbro & Arnbak, 1996; Verhoeven & Perfetti, 2011).

Morphemes, the smallest units of meaning in words, play a crucial role in word reading (Carlisle & Kearns, 2017). Substantial evidence supports the developmental relationship between children's morphological awareness—the explicit ability to reflect on and manipulate morphemes in spoken language (Carlisle, 2000)—and their reading abilities (see Lee et al., 2023 for a meta-analysis). Recent research emphasizes the multidimensional nature of morphology, suggesting multiple pathways through which it supports reading processes (Deacon et al., 2017; Levesque et al., 2021). A central dimension is morphological decoding, defined as the use of morphemes in word reading

(Levesque et al., 2021). This reading strategy involves decomposing complex written words into their constituent morphemes (Deacon et al., 2017; Verhoeven & Perfetti, 2011), reflecting the implicit use of morphological processing in word reading. Discovering the systematic relationships between orthography and meaning within the writing system, through repeated exposure to words sharing the same morpheme (e.g., the suffix '-less' in 'endless,' 'regardless,' and 'priceless'), facilitates accurate pronunciation and faster access to meaning (Carlisle & Stone, 2005; Verhoeven & Perfetti, 2011), enhancing word reading by shifting from serial grapheme–phoneme decoding to decomposing larger morpho-orthographic units (Castles & Nation, 2022; Castles et al., 2018).

While evidence suggests that skilled readers automatically decompose both familiar and unfamiliar written words into their constituent morphemes (Dawson et al., 2018, 2021), how and when morphological processing becomes integrated into the reading process is less understood (Carlisle & Kearns, 2017; Castles & Nation, 2022; Castles et al., 2018). Seymour (2006) suggests that morphological strategies become integrated into the reading process in the third morphographic stage, only after mastering foundational reading skills that enable the construction of an internal representation of orthographic units (see also Ehri, 2005). Share (2018), on the other hand, proposes a continuous, stage-independent process where morphological representations integrate into the reading process with reading acquisition and continue throughout development by gradually building an orthographic lexicon, one word or morpheme at a time. Nevertheless, both models emphasize that the extent to which readers rely on morphological representations and their effectiveness in the reading process depend not only on the reader's morphological awareness and the establishment of their reading skills but also on environmental factors such as orthographic consistency and morphological complexity. These factors determine the extent to which the writing system fosters sensitivity to the morphological structures of written words and facilitates word recognition through morphological processes (Frost, 2012; Perfetti & Verhoeven, 2017).

The question arises as to what extent the use of morphological processing during reading depends on the writing system's orthographic consistency and morphological complexity. A common hypothesis suggests that morphological processes should be more relevant to reading in deep orthographies due to the ambiguity between graphemes and phonemes (Schiff & Raveh, 2007; Verhoeven & Perfetti, 2011). While recent crosslinguistic research supports this notion (e.g., Desrochers et al., 2018; Mousikou et al., 2020), other findings indicate that the centrality of morphology in reading depends on the morphological richness of the language and the morpho-orthographic structure, rather than the orthographic consistency of the writing system (Casalis et al., 2015). This perception has been reinforced by recent studies in transparent orthographies with rich morpho-orthographic structures, such as German (Fleischhauer et al., 2021) and Greek (Giazitzidou et al., 2023), suggesting that language structure leads to increased reliance on morphological processing during word reading, despite orthographic consistency. With early, extensive, and consistent exposure to a spoken language rich in morphology, children appear to develop a high level

of sensitivity to the internal morphological structure of written words (Bar-On & Ravid, 2011; Ravid & Schiff, 2006). Hebrew offers an opportunity to investigate the interplay between orthographic consistency and morphological complexity in a within-language design.

Hebrew orthography and morphology

Hebrew orthography is an abjad-consonantal writing system which exists in two versions that differ in orthographic consistency. In pointed Hebrew, consonants are represented by letters, while vowels are represented by nikud diacritics placed below, in, or above the letters. This script is used for beginning reading and is considered highly transparent. The unpointed script, the default for native speakers, mainly represents consonants and partially and inconsistently represents vowels using AHWY letters, representing both consonants and vowels, providing incomplete and ambiguous vowel information (Share, 2017; Share & Bar-On, 2017). Children are exposed to the deep, unpointed version around third grade, completing the transition by fourth grade (Share & Bar-On, 2017).

Like other Semitic languages (e.g., Arabic), Hebrew is characterized by high morphological density in both inflectional and derivational word formation (Vaknin-Nusbaum, 2024). The complexity of its morphological system arises from the interplay of both a linear principle and a nonlinear interlaced principle, known as root-and-pattern morphology (Bar-On & Ravid, 2011; Share, 2017). In Hebrew, the formation of all verbs and the majority of nouns and adjectives involves the combination of root and pattern morphemes. The root, which usually contains three consonants, carries the core lexical meaning of the word and connects members of the morphological family. For example, *ktv* is the root of the words *katav* (“he wrote”), *ktiva* (“writing”), *katevet* (“reporter”). The word pattern, consisting of a sequence of vowels or vowels and consonants, determines its vocal, syntactic–semantic properties and the classification of the word in terms of speech part (Ravid & Schiff, 2006). The root and pattern morphemes are represented in written form in a clear, distinct, and coherent manner, even more than in spoken language (Ravid & Schiff, 2006), and are considered the cornerstones of understanding the Hebrew writing system and developing reading skills (Share, 2017). While most reading studies have emphasized the centrality of the root, the morphological pattern also plays a central role, serving as the basis for transition between the writing versions by completing the missing phonological information in the unpointed script (Bar-On & Ravid, 2011; Frost, 2012). The morphological pattern enables the identification of many words based on the same pattern (e.g., hitragshut: “excitement,” hitaamlot: “exercise,” hitpatxut: “development,” and hitarvut: “intervention”) and facilitates the decoding of unfamiliar words, even in their unpointed form (Bar-On & Ravid, 2011).

Hence, the phonologically dual nature of the Hebrew writing system and its morpho-orthographic transparency dictate an early reliance on morphological aspects in reading (Ravid & Schiff, 2006; Vaknin-Nusbaum & Sarid, 2021; Vaknin-Nusbaum et al., 2016). Nevertheless, one might expect that decoding pointed words,

which provide the reader with almost complete phonological information about word pronunciation, should be based on grapheme–phoneme conversion without relying on the word's morphological structure. Unpointed words cannot be accurately pronounced without activating the missing phonological information. The word's morphological structure, particularly its pattern, is a central source of knowledge that helps readers activate the missing phonological information (Bar-On & Ravid, 2011; Frost, 2012). The present study investigated how the presence or absence of vowel diacritics (orthographic consistency) and the morpho-orthographic structure (morphological transparency) influence word identification processes at different points in Hebrew reading acquisition.

Orthographic consistency, morphological complexity, and Hebrew word reading processes

The phonological transparency of Hebrew pointed orthography facilitates word reading in the early stages (Schiff, 2012; Shany et al., 2012). Evidence suggests that even skilled adult readers benefit from this transparency (e.g., Navon & Shimron, 1981; Shimron & Navon, 1982), employing a segmented approach to decode small units when reading pointed words (Weiss et al., 2015a, 2015b). However, comparative studies of pointed and unpointed word reading during the elementary school years reveal that in second grade, children rely on diacritics for faster and more accurate word reading, while by fourth grade, despite mastering pointed script reading, diacritics no longer enhance accuracy and may even hinder reading speed and fluency (Katzir et al., 2012; Schiff, 2012; Schiff et al., 2013).

The morphological transparency inherent in the Hebrew writing system, coupled with early exposure to morphologically complex words, fosters the development of morphological awareness, as demonstrated by studies showing the developmental relationship between children's morphological awareness and their reading skills throughout elementary school (e.g., Cohen-Mimran, 2009; Vaknin-Nusbaum & Sarid, 2021; Vaknin-Nusbaum et al., 2016). Studies examining morphological processing during online reading indicate that Hebrew-speaking children begin to recognize the morphological structures as early as second grade, demonstrating knowledge of roots and morphemic patterns in written words (Haddad et al., 2018; Ravid & Schiff, 2006), a finding supported by fMRI studies as well (Barouch et al., 2022), with this knowledge continuing to develop through fifth grade (Ravid & Schiff, 2006). This is in line with the triplex model of Hebrew reading development (Share & Bar-On, 2017), according to which, in the second lexico-morpho-orthographic path (grades 2–4), readers in second grade gain mastery in pointed script reading and gradually reduce their reliance on phonological processing in favor of lexical morpho-orthographic processing. This progress is crucial for the transition to reading in the unpointed script version in fourth grade, where reliance on morphological processing becomes necessary due to its phonological ambiguity (Bar-On & Ravid, 2011). The present study focused on the evolving nature of reading processes during this critical period, attempting to capture developmental changes in the engagement of phonological versus morphological processing in

word reading from second to fourth grade, in order to better understand how the distinctive features of Hebrew influence the developmental trade-off between phonology and morphology in the process of learning to read.

Two recent studies, employing both behavioral (2nd grade, $N=27$, and 5th grade, $N=29$; Haddad et al., 2018) and fMRI (2nd and 3rd grade, $N=16$, and 5th and 6th grade, $N=9$; Barouch et al., 2022) methods, have delved into the interaction between morphological and phonological processing in Hebrew reading acquisition by examining mono-morphemic and bimorphemic words presented with or without diacritics. Interestingly, the findings indicated that morphological structure was more beneficial for younger second-grade readers compared to older fifth-grade readers (Haddad et al., 2018), enhancing word recognition only in the transparent pointed script in both ages but hindering word recognition for the deep unpointed script for second graders (Barouch et al., 2022; Haddad et al., 2018). These results underscore the early sensitivity of Hebrew readers to morphological structure in written words while challenging the notion of a developmental increase in reliance on morphological processing during elementary school years (Ravid & Schiff, 2006). Moreover, they challenge the idea that morphological information compensates for the absence of phonological information. Instead, the researchers suggested that children rely on the phonological information in pointed words to facilitate morphological processing (Barouch et al., 2022; Haddad et al., 2018). The present study aims to deepen the investigation of developmental changes in children's engagement in phonological and morphological processing by using pseudowords to assess their decoding skills. Pseudowords, being unfamiliar to the reader, enable the capture of the "pure" processing involved in reading, reflecting implicit and direct processes of analyzing the units within written words for accurate pronunciation (Carlisle & Kearns, 2017; Castles et al., 2018). This approach allows for the examination of children's mental processes in reading independently of their lexical knowledge or metalinguistic awareness.

The study builds upon two prominent studies in Hebrew that employed pointed (Shany et al., 2012) and unpointed (Bar-On & Ravid, 2011) pseudoword tasks. Shany et al. (2012) used pointed pseudowords, both with and without real morphemic patterns, among second, fourth, and sixth graders. They observed a downward trend in accuracy with nonmorphological-based pseudowords between second and fourth grades (60% vs. 54%, respectively), while accuracy remained consistent with morphological-based pseudowords (76%, 74%) across these ages. The researchers suggested that this comparable accuracy in reading morphological-based pointed pseudowords may stem from differing reliance on phonological knowledge provided by diacritics (higher in second grade) and morphological knowledge provided by the word structure (higher in fourth grade). Bar-On and Ravid (2011) employed unpointed pseudowords composed of a pseudo-root and a genuine pattern. They revealed that Hebrew-speaking children begin to rely on the morphological pattern at the beginning of second grade (30%), with a dramatic increase in this ability at the end of second grade (55%), which continues to develop with advances in reading in the unpointed writing version.

Building upon these prior works, this study aimed to directly compare phonological, morphological, and phonological-morphological processing within a

single investigation, using the same pseudoword lists within a unified framework. To examine these different processing types, phonological information was directly provided by vowel diacritics, while morphological information was indirectly provided through the root-and-pattern structure, allowing for the separation between phonological and morphological processing (Bar-On et al., 2018). The primary goal was to investigate developmental changes in the utilization of phonological compared to morphological information in word identification processes among second and fourth graders. The second aim was to explore whether morphological processing contributes to pointed word-reading accuracy and fluency beyond phonological processing at these ages, despite the extensive phonological information provided by the transparent pointed script. Based on existing Hebrew literature, it was assumed that both second and fourth graders would demonstrate higher accuracy when reading pseudowords with morphological structure. Only second graders were expected to display higher accuracy when phonological information is provided. Additionally, it was anticipated that morphological processing would contribute to pointed word-reading accuracy and fluency beyond phonological processing at both developmental stages.

While prior research has established the early onset of morphological processing in Hebrew children, this study's design adds value by offering insights into how the interplay between phonological and morphological processing evolves through different points in reading acquisition and whether this development depends more on changes in orthographic consistency or the morphological transparency inherent in the Hebrew writing system. These insights may hold implications for designing more effective literacy programs tailored to the specific orthographic and morphological features of the Semitic Hebrew language.

Methods

Participants

The study employed a cross-sectional design, collecting data from a sample of 179 children (86 girls and 93 boys), including 98 s graders (aged 6.8–8.5 years) and 81 fourth graders (aged 9–10.3 years). These participants were selected from two randomly chosen elementary schools in Haifa, Israel, and no special education children were included. Two second-grade participants were excluded from the original dataset due to being identified as outliers in the reading tasks (scoring 2 *SD* below the mean). All participants were native Hebrew speakers from families of high socioeconomic status, falling within the second and third deciles according to the Ministry of Education's school index (This index is calculated based on the socioeconomic characteristics of the school neighborhood, i.e., the educational and income levels of the parents). Their verbal IQ scores ranged from 8 to 14, falling within the average range and above. None of the participants were reported to have vision or hearing problems or attention deficit disorders by their teachers.

Measures

Building upon prominent studies in Hebrew, the same pseudoword lists from Shany et al. (2012) and Bar-On and Ravid (2011) were utilized to examine phonological–morphological, morphological, and phonological processing, enabling the separation between the different processing types. Specifically, phonological–morphological processing was evaluated through pointed morphologically based pseudowords (pointed MPW), morphological processing was assessed using unpointed morphologically based pseudowords (unpointed MPW), and phonological processing was examined using pointed pseudowords without an existing morphological pattern, defined as pointed nonwords (pointed NW). Pointed word–reading accuracy and fluency were also assessed. All these measures were validated for the same age groups as those in the present study.

Phonological processing and *phonological–morphological processing* were assessed using a pointed pseudowords reading test (Shany et al., 2006). Participants were instructed to read aloud 33 pointed pseudowords from two categories. The first category included pointed *morphologically based pseudowords* (pointed MPW)—letter strings with phonemic diacritics representing existing Hebrew morpho-orthographic structures, for example, "nirpag" (pseudoword) corresponds to "nivhal" (real word meaning "was scared"). The second category included letter strings with phonemic diacritics that do not correspond to any real Hebrew morpho-orthographic structure, such as "tutsted" and "taasta," and are thus defined as pointed *nonwords* (pointed NW). Both types of stimuli were presented within a single list, with pointed MPW preceding pointed NW (Cronbach's α was 0.88 for pointed MPW and 0.81 for pointed NW in second grade and was 0.75 for pointed MPW and 0.73 pointed NW in fourth grade). Percentage accuracy was calculated separately.

Morphological processing was assessed using an unpointed pseudowords reading test (morphological decoding; Bar-On & Ravid, 2011). Participants were instructed to read aloud 20 unpointed *morphologically based pseudowords* (unpointed MPW)—letter strings without phonemic diacritics constructed of a pseudo-root incorporated in a genuine pattern. For example, decoding the words הִזרתָה, תמולקת as "hitrazef," "tiklómet" reflects morpho-orthographic identification—that is, mapping the morphological pattern of the sequence of letters (in this case, the pattern *tiCCoCet, hitCaCeC*). The score obtained was calculated as the number of words read correctly according to an existing Hebrew pattern (Cronbach's α was 0.81 for second grade and 0.77 for fourth grade).

Reading accuracy of pointed words was assessed using two single-word tests, in which all the words presented were nouns varying in frequency, length, and morphological structure. In the first test (Shany et al., 2006), participants were instructed to read aloud 38 single-pointed words (the reported Cronbach's α was 0.90 for second grade and 0.85 for fourth grade). In the second test (Shany et al., 2001), participants were instructed to read aloud 50 single-pointed words (Cronbach's α was 0.92 for second grade and 0.83 for fourth grade). Percentage accuracy was calculated separately.

Reading fluency of pointed words was assessed using the Hebrew version (Schiff et al., 2006) of the Test of Word Reading Efficiency (TOWRE) (Wagner et al., 2001). Participants were instructed to read aloud as many words as possible within 45 s. The word list contained 104 pointed words arranged in four columns organized by increasing level of difficulty in the number of syllables, phonological structure, length, frequency, and morphological complexity, providing a range of difficulty. The words included all the vowels and consonants of the Hebrew language. The score ranged from 0 to 104, reflecting the number of correct words read, with a higher score indicating higher reading fluency (the reported Cronbach's α was 0.95).

Procedure

The study received approval from the Ministry of Education and the ethics committee of the Faculty of Education at the University of Haifa. Written consent, ensuring anonymity and confidentiality, was obtained from parents. Data collection took place from January to May, initially involving second graders and then fourth graders, within the school setting. Each participant underwent individual test sessions lasting approximately 30 min, conducted in a quiet school room. To maintain consistency, the first author administered all tests in the same manner for every participant, ensuring uniformity across the study.

Results

Table 1 presents the mean (*M*) and standard deviation (*SD*) for all study variables at each age. Before running all analyses, a combined score was calculated for two word-reading accuracy tasks. The correlations between the two tasks were $r = 0.87^{**}$ ($p < 0.01$) in second grade and $r = 0.65^{**}$ ($p < 0.01$) in fourth grade.

Table 1 Means and *SD* of word-reading measures and three types of processing in each grade

Variable	2nd Grade ($N = 96$)			4th Grade ($N = 81$)		
	Range	*M*	*SD*	Range	*M*	*SD*
Pointed word–reading accuracy	37.45–96.7	75.95	14.8	51.63–100	85.2	8.07
Pointed word–reading fluency	24–78.6	46.01	11.8	28–102.66	58.42	13.88
Pointed NW	0–100	30.67	28.6	0–88.88	30.45	26.74
Pointed MPW	8.33–95.83	58.5	23.42	12.5–87.5	51.9	17.28
Unpointed MPW	24–100	62.25	16.63	14.8–100	78.02	15.47

Pointed NW: pointed nonwords, without morphological pattern; Pointed MPW: pointed morphologically based pseudowords; Unpointed MPW: unpointed morphologically based pseudowords

Developmental changes in phonological and morphological processing in word identification

A two-way ANOVA of repeated measures was employed to assess accuracy as the dependent variable. The within-subject variable was the type of processing (pointed NW, pointed MPW, unpointed MPW), and the between-subject factor was grade (second vs. fourth). A significant effect was observed for processing type, $F(2,173) = 193.87$, $p < 0.001$. Pairwise comparisons revealed significant differences in accuracy between the three processing types ($p < 0.001$) across the grades, with the lowest accuracy for pointed NW ($M = 30.72$, $SD = 2.09$), followed by pointed MPW ($M = 55.44$, $SD = 1.55$) and the highest accuracy for unpointed MPW ($M = 70.07$, $SD = 1.22$). Additionally, a significant interaction was found between grade and processing type, $F(2,173) = 25.43$, $p < 0.001$. The interaction is presented in Fig. 1.

Comparison between grades

Figure 1 shows that the accuracy of pointed NW remains consistent across grades, while the accuracy of reading pointed MPW decreases with age, and accuracy in unpointed MPW increases. Post hoc analyses were conducted to examine the differences between the groups within each type of processing. Results revealed significant differences in accuracy levels between second and fourth grades for unpointed MPW ($t(175) = -6.48$, $p < 0.001$) and pointed MPW ($t(174) = 2.27$, $p < 0.05$), but no difference for pointed NW.

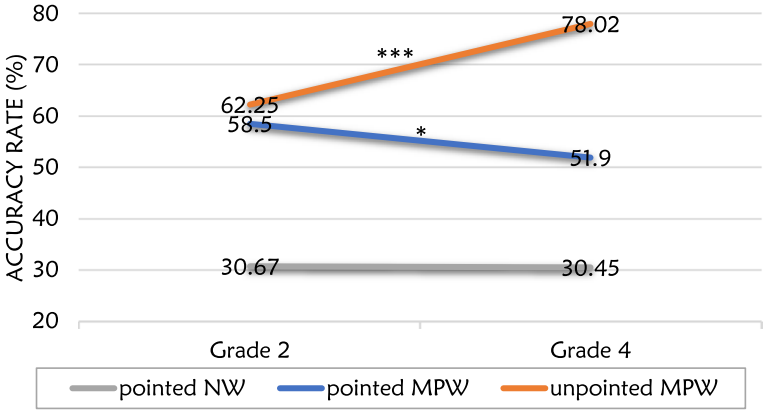

Fig. 1 Grade × processing type interaction. *Note.* Significant differences between grades within each type of processing ***$p < .001$, *$p < .05$. Pointed NW: pointed nonwords, without morphological pattern; Pointed MPW: pointed morphologically based pseudowords; Unpointed MPW: unpointed morphologically based pseudowords

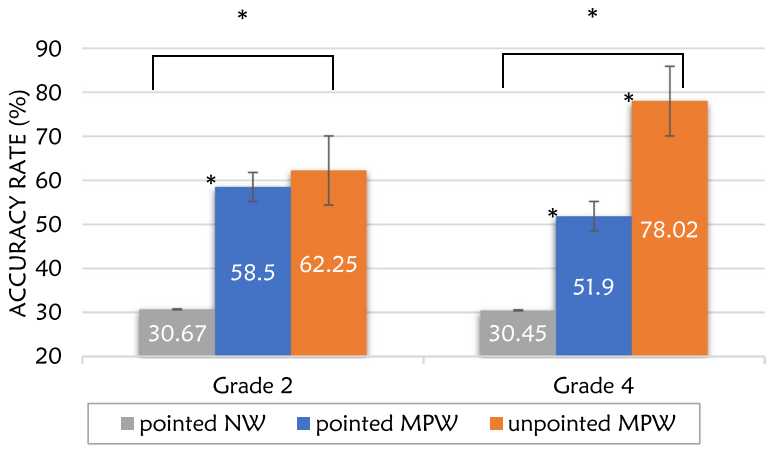

Fig. 2 Significant differences between the types of processing within each grade. *Note.* Error bars indicate standard errors. Asterisks represent significant differences at $p < .001$. Pointed NW: pointed nonwords, without morphological pattern; Pointed MPW: pointed morphologically based pseudowords; Unpointed MPW: unpointed morphologically based pseudowords

Comparison within grades

Figure 1 also illustrates similar accuracy levels between pointed MPW and unpointed MPW in second grade, contrasting with the wider gap observed in fourth grade, favoring unpointed MPW. Post hoc analyses of repeated measures were conducted to examine the differences in accuracy levels between the types of processing within each age group. Results showed significant differences ($p < 0.001$) between pointed NW and pointed MPW and between pointed NW and unpointed MPW in second grade. In fourth grade, significant differences ($p < 0.001$) were observed in accuracy levels among all three types of processing, including between pointed MPW and unpointed MPW (Fig. 2).

Table 2 Correlations between the variables in second (below, $N = 96$) and fourth (above, $N = 81$) grades

Variable	1	2	3	4	5
1. Pointed word–reading accuracy	1	.64**	.49**	.63**	.69**
2. Pointed word–reading fluency	.73**	1	.13	.41**	.51**
3. Pointed NW	.58**	.28**	1	.60**	.35**
4. Pointed MPW	.67**	.32**	.79**	1	.42**
5. Unpointed MPW	.58**	.59**	.20*	.24*	1

Pointed NW: pointed nonwords, without morphological pattern; Pointed MPW: pointed morphologically based pseudowords; Unpointed MPW: unpointed morphologically based pseudowords

*$p < .05$; **$p < .01$

Pearson correlations

Significant correlations were found between all measures. In second grade, the three types of processing (pointed NW, pointed MPW, unpointed MPW) had similar correlations with word-reading accuracy, while unpointed MPW had a stronger correlation with word-reading fluency. In fourth grade, unpointed MPW and pointed MPW had a stronger correlation with word-reading accuracy and fluency compared to pointed NW. The three types of processing were generally correlated, indicating an overlap between the variables. No two independent variables were too highly correlated to be included in the multiple regressions (<0.70; Tabachnick & Fidell, 2007), except for pointed NW and pointed MPW in second grade. Therefore, pointed NW was included in the regression only in the fourth grade. The correlations are presented in Table 2.

The contribution of phonological and morphological processes to pointed word reading

The study employed hierarchical regression analyses using the enter approach to examine the contribution of phonological and morphological processes to pointed word–reading accuracy and fluency in second and fourth grades. In second grade, only pointed MPW and unpointed MPW were included, with pointed MPW entering the equation first and unpointed MPW entering the second step. In fourth grade, all types of processing were included, with pointed NW entering the equation first, followed by pointed MPW, and then unpointed MPW. This order allowed for an examination of whether morphological processing contributed beyond phonological processing to pointed word reading, despite the phonological information provided by the transparent writing system.

In second grade, results for word-reading accuracy indicated that pointed MPW accounted for 45% of the variance, which was statistically significant. The inclusion of unpointed MPW in the second step added a further 21% of variance, also statistically significant. For word-reading fluency, pointed MPW accounted for 11% of the variance in the first step, and the addition of unpointed MPW in the second step contributed another statistically significant 30% of variance over and above the contributions of pointed MPW.

In fourth grade, results for word-reading accuracy showed that pointed NW accounted for 24% of the variance, but this contribution became nonsignificant after including pointed MPW in the equation, which added another statistically significant 17% of variance. At step 3, unpointed MPW added a further statistically significant 21% of variance over and above the contributions of Pointed MPW. Regarding word-reading fluency, pointed NW accounted for 2% of the variance, which was statistically significant, while the addition of pointed MPW in the next step contributed another statistically significant 18% of variance. At step 3, unpointed MPW added a further statistically significant 15% of variance over and above the contributions of pointed NW and pointed MPW.

Table 3 Hierarchical regression analyses using the enter approach for pointed word–reading accuracy and fluency in each grade

	Variable	Word-reading accuracy			R^2	Word-reading fluency			R^2
		B	*SE*	β		*B*	*SE*	β	
2nd Grade ($N=96$)	Pointed MPW	.36	.04	.56***	.45	.09	.04	.18*	.11
	Unpointed MPW	.42	.06	.47***	.21	.4	.06	.57***	.30
	Total variance	66%				41%			
	Model significance	$F(2,94)=88.3$, $p<.001$				$F(2,94)=31.86$, $p<.001$			
4th Grade ($N=81$)	Pointed NW	.03	.03	.09	.24	-.13	.06	-.25*	.02
	Pointed MPW	.16	.04	.36***	.17	.31	.09	.39**	.18
	Unpointed MPW	.26	.04	.51***	.21	.39	.09	.43***	.15
	Total variance	62%				35%			
	Model significance	$F(3,80)=42.02$, $p<.001$				$F(3,80)=13.74$, $p<.001$			

Pointed NW: pointed nonwords, without morphological pattern; Pointed MPW: pointed morphologically based pseudowords; Unpointed MPW: unpointed morphologically based pseudowords

*$p<.05$; **$p<.01$; ***$p<.001$

These results underscore the substantial "pure" contribution of morphological processing above and beyond that of phonological processing to the accuracy and fluency of word recognition in a transparent writing system in both grades (Table 3).

Discussion

This study investigated how language-specific features, such as orthographic consistency and morphological complexity, influence the extent to which developing readers utilize phonological versus morphological processing, as proposed by theoretical models of reading development across orthographies (Frost, 2012; Seymour, 2006; Share, 2018). Focusing on the distinctive features of Hebrew's orthography and morphology, the research aimed to (a) investigate developmental changes in the utilization of phonological information (provided directly by vowel diacritics) compared to morphological information (provided indirectly by morpho-orthographic structures) in word identification among second and fourth graders; and (b) assess whether morphological processing contributes beyond phonological processing to word-reading accuracy and fluency in the transparent, pointed writing version. . Building on previous research (Bar-On & Ravid, 2011; Shany et al., 2012), the study employed three types of pseudowords allowing the separation between phonological and morphological information (Bar-On et al., 2018). While previous evidence suggests that Hebrew readers incorporate morphological processing as early as second grade (e.g., Barouch et al., 2022; Haddad et al., 2018), this study demonstrates that morphology plays a greater role than phonology in word identification processes even at this early stage, with this trend continuing to strengthen through fourth grade. Regression analysis further showed morphological

processing significantly contributes to pointed word reading skills beyond phonological processing at both grades, despite the comprehensive phonological information provided by the pointed writing system. Overall, the findings underscore the early prioritization of morphological transparency over orthographic consistency in learning to read Hebrew Semitic orthography, highlighting the crucial role of morphological processing beyond phonological processing from second grade onward, even in reading a transparent system.

Developmental trade-off between phonology and morphology in Hebrew reading acquisition

The findings revealed a significant advantage for morphological information over phonological information. Children demonstrated higher accuracy in reading unpointed MPW compared to pointed MPW, with pointed NW being the least accurately read. Previous studies in Hebrew (Shany et al., 2012) and Arabic as well (Bar-On et al., 2018) have also shown a higher level of accuracy in reading pointed MPW (phonological–morphological information) compared to pointed NW (phonological information) among children of similar ages. These findings underscore the distinct contribution of morphological information in written words beyond that of phonological information, highlighting the superiority of morphological structure in the reading process within Semitic-abjad writing systems as early as second grade (Share & Bar-on, 2017).

From a developmental perspective, distinct patterns emerged across the three types of processing: while the accuracy of reading pointed NW remained stable from second to fourth grade, the accuracy of pointed MPW significantly decreased with age, whereas the accuracy of unpointed MPW significantly increased from second to fourth grade. These three developmental trends between the types of processing constitute empirical evidence of the developmental changes in word identification process from second to fourth grade. First, consistent with the study's findings, Shany et al. (2012) did not observe a significant difference in reading accuracy of pointed NW between second and fourth grade, despite a downward trend between these ages in their study. It should be noted that a similar level of accuracy in this measure was found in second, fourth, and sixth grades in Arabic as well (Bar-On et al., 2018). These findings consistently indicate that specific knowledge about diacritics remains stable between these ages in Semitic-abjad writing systems, despite the transition stage to reading in the unpointed script version (fourth grade in Hebrew and fifth-sixth grade in Arabic; Bar-On et al., 2018). Second, the significant decrease in the accuracy level of pointed MPW versus the significant increase in unpointed MPW between second and fourth grade suggests that while the morphological structure exists in both types of pseudowords (pointed and unpointed), the presence of diacritics is the factor that influences the accuracy decreasing with development. These two arguments, although they may seem contradictory, lead to the conclusion that the developmental changes in reading processes between second and fourth grade are driven by an increasing reliance on morphological processing with age rather than a decline in knowledge about

diacritics (see Share, 2017 for this argument). In other words, although phonological strategies remain equally available for readers at both ages, with reading experience and the acquisition of morpho-orthographic representations, there is a growing reliance on morphological processing at the expense of the phonological one (Castles & Nation, 2022). That is, the findings illustrate a developmental process wherein knowledge about diacritics does not disappear but is rather influenced by a more efficient skill level (Shany et al., 2012), manifesting in gradual morpho-orthographic learning (Bar-On & Ravid, 2011).

Further reinforcement of these gradual changes can be found by examining each age separately. Although at both ages, children more accurately read unpointed MPW than pointed MPW, the accuracy level was similar between these two measures in second grade, while a significant difference was found between them in fourth grade. These findings suggest that although children in second grade already considerably rely on the morphological structure in written words, at this early stage, they are accustomed to the presence of vowel diacritics and utilize phonological information. With reading experience and increased morpho-orthographic learning (Bar-On & Ravid, 2011), the morphological strategy gradually becomes more dominant in the reading process. Thus, by fourth grade, phonological information becomes superfluous (Ravid, 1996) and may even interfere with word identification accuracy due to the extensive reliance on morphological processing. These findings support the increasing reliance on morphological processing and morpho-orthographic representations in Hebrew reading acquisition (Bar-On & Ravid, 2011; Ravid & Schiff, 2006). They also provide empirical support for Shany et al.'s (2012) hypothesis that, in fourth grade, the accuracy of reading pointed MPW is not due to the more efficient use of phonological information provided by diacritics but rather to the morphological information provided by the word structure. The findings, which demonstrate significant differences in accuracy among the three types of processing in fourth grade, with the highest level observed for unpointed MPW, empirically support the superiority of morphology over phonology in word identification processes at this advanced developmental stage.

While there is extensive recognition regarding fourth graders' reliance on morphological over phonological processing, unexpected findings emerged in second grade, revealing the highest accuracy for unpointed MPW, which was similar to that for pointed MPW, with a significant gap between these measures and the lowest accuracy in pointed NW. These findings are surprising not because second graders rely on morphological processing—a well-established finding in Hebrew literature (Barouch et al., 2022; Haddad et al., 2018; Ravid & Schiff, 2006)—but rather due to the extent of reliance on morphological processing compared to phonological processing at this early developmental stage. In second grade, young readers, who have just gained mastery in pointed script reading and are exclusively exposed to the pointed writing version (Share & Bar-On, 2017), are expected to rely extensively on diacritics and phonological processing for more accurate word reading (Katzir et al., 2012; Schiff, 2012; Shany et al., 2012). And although according to Bar-On and Ravid (2011), by second grade, the morphological pattern is expected to play an important role in word identification, the findings of the

current study, which demonstrate a similar level of accuracy in reading pointed MPW and unpointed MPW, indicate that children at this early stage identify pointed and unpointed words with the same level of accuracy as long as there is a morpho-orthographic root-and-pattern structure. In other words, it is evident that already at this stage, morphological processing plays a prominent role in identifying written words, regardless of the orthographic transparency of the writing system. These findings challenge Shany et al.'s (2012) hypothesis that second-grade children primarily rely on diacritics and phonological processing in word identification when both phonological and morphological information is provided. Instead, the study's results align with recent literature suggesting that even at this early stage, children rely on morphological processing in reading pointed words (Barouch et al., 2022; Haddad et al., 2018). The current findings may further suggest that diacritics do not constitute the main source of information for young readers of Hebrew as long as they can obtain information from the morpho-orthographic structure of written words. These findings emphasize the importance of morphological transparency over orthographic consistency in the early prioritization between phonology and morphology in the process of learning to read Hebrew, a crucial aspect in understanding the reading acquisition process within the typological properties of Semitic languages.

Shany et al. (2012) compared phonological to phonological–morphological processing using pointed NW and MPW, while Bar-On and Ravid (2011) examined morphological processing using unpointed MPW. By simultaneously investigating all three types of processing within one study, this research contributes to a more comprehensive understanding of the developmental trade-off between phonological and morphological processing in word identification during reading acquisition, shedding light on how children adapt their reading strategies to Hebrew's distinctive orthography and morphology features (Frost, 2012). The study findings strongly support the results of Bar-On and Ravid (2011), which emphasize the central role of the morphological pattern in Hebrew reading development. They are also consistent with the second lexico-morpho-orthographic path of the triplex model (Share & Bar-On, 2017), suggesting that from second grade, Hebrew readers gradually rely less on sublexical phonological processing in favor of lexical processes and morpho-orthographic knowledge. The present study's findings validate and extend this model, indicating that while both phonological and morphological processes are involved in Hebrew reading acquisition (Haddad et al., 2018), the contribution of morphology exceeds that of phonology as early as second grade and continues to increase with age until fourth grade, at the expense of phonology.

Contribution of phonological and morphological processes to pointed word reading

Regarding the second research question, regression analyses revealed that at both ages, morphological processing significantly contributes to pointed word–reading skills beyond phonological processing, despite the availability of vowel diacritics in pointed words that provide comprehensive phonological information. In second

grade, a higher contribution was found for pointed MPW (45%) than for unpointed MPW (21%) in the accuracy measure, while a prominent contribution was found for unpointed MPW (38%) compared to pointed MPW (3%) in the fluency measure. These findings support the previous claim that, despite the centrality of morphological processing among second-grade readers, children at this early stage still rely on or refer to diacritics for more accurate word reading. However, when required for more fluent reading, they primarily rely on the morphological structure in written words at the expense of diacritics' phonological information. This underscores the importance of transitioning from phonological processing to greater reliance on morphological processing in the progression toward more fluent and proficient word reading (Castles & Nation, 2022; Castles et al., 2018). It suggests that children modify their linguistic resources according to the reading-task demands (Saiegh-Haddad & Geva, 2008), possibly because diacritics are attention-demanding (Bar-On et al., 2018), forcing the reader to obey the signs during the more direct lexical orthography-to-meaning process, which may interfere with fluent word reading.

In fourth grade, the accuracy measure results showed the contribution of diacritics' phonological information (24% in the first step), which was no longer statistically significant after including pointed MPW in the second step. Nevertheless, this finding might strengthen the notion that both phonological and morphological strategies are available for fourth-grade readers. An unexpected predictive pattern for the fluency measure showed a small advantage for pointed MPW over unpointed MPW (18% and 15% respectively). In continuity with previous findings of this study regarding the superiority of morphological over phonological processing at this developmental stage, given that both pointed MPW and unpointed MPW include morphological structure, it is possible that in the fourth grade, both tasks tap into the reader's morphological processing. In terms of connectionist models (Plaut et al., 1996; Seidenberg & McClelland, 1989), these overlapping contributions can be interpreted as the increasing simultaneous activation of phonological and morphological processing. That is, in second grade, these two types of processing constitute separable components; however, with reading development, in fourth grade, the system is meant to be simultaneously activated.

Nevertheless, regression analyses at both grades confirm the crucial role of morphological processing in enhancing the accuracy and fluency of reading pointed words, aligning with recent research indicating that children begin utilizing morphological decoding in pointed word reading as early as second grade (Barouch et al., 2022; Haddad et al., 2018). The current findings further underscore the significant and extensive contribution of morphological processing beyond phonological processing in reading pointed words, which provide comprehensive phonological information and seemingly do not necessitate higher level processing. This insight, combined with the previous findings of the study, suggests that the use of morphological processing in reading is deeply rooted in the morpho-orthographic nature inherent in the Hebrew writing system and the robust morphological foundation of Hebrew speakers (Frost, 2012; Ravid & Schiff, 2006; Share, 2017), and not only serves as cues for completing missing phonological information due to changes in orthographic consistency. This underscores the pivotal role of

morphology in very early stages of Hebrew reading acquisition, shedding light on the prioritization of morphological transparency over orthographic consistency in the process of learning to read Hebrew.

These findings align with the assertion that the extent to which developing readers engage in morphological processing is primarily influenced by the language's morphological richness and the morpho-orthographic structure, rather than the orthographic consistency of the writing system (Casalis et al., 2015). This highlights how language-specific features profoundly shape the processing system of readers and determine the prioritization between phonology and morphology in the process of learning to read (Frost, 2012; Seymour, 2006; Share, 2018). The findings also contradict the central theory proposed by Ziegler and Goswami (2005), which assumes that readers learning in transparent orthographies, which provide more consistent phonological information, will primarily rely on small sublexical units and phonological processing and less on larger linguistic units and morphological processing. Share (2021) recently argued that this theory presents a one-dimensional view of the mapping consistency between spelling and sound (see also Frost, 2012), where orthographic consistency is only one of many factors influencing the variation between writing systems and their impact on reading process development (Borleffs et al., 2019; Daniels & Share, 2018). The findings of this study validate this claim, indicating that the morphological complexity of a language and the morphological transparency of its writing system foster sensitivity to the morphological structures of written words and the early reliance on morphological processing in word reading (Bar-On & Ravid, 2011; Frost, 2012; Ravid & Schiff, 2006), regardless of the orthographic consistency of the writing system.

The findings of this study hold significant implications for reading instruction and intervention strategies in Hebrew literacy acquisition. First, this study demonstrates that developing readers utilize morphological processing in reading unfamiliar (new) and familiar words even if the words are pointed (providing phonological information). Recognizing the importance of morphological over phonological processes as early as second grade underscores the necessity for instructional approaches that integrate explicit teaching of morpho-orthographic structures alongside phonological strategies from the initial stages of Hebrew reading instruction. Teachers and intervention specialists can design tailored activities that emphasize morphological units within spoken and written words, aiding in understanding Hebrew word structure and meaning. Provided with early, explicit instruction in recognizing and analyzing morphemes in written words, children can establish a stronger morphological foundation and enhance their reading abilities. Furthermore, the study's findings challenge conventional assessment practices that prioritize phonological decoding of pointed pseudowords. Instead, assessments incorporating unpointed pseudowords with morphological structures may provide a more accurate measure of reading proficiency in Hebrew. Educators can use these assessments to identify students who may benefit from targeted intervention in morphological processing skills. Tailored interventions focusing on morphology can be developed to address the difficulties of struggling readers, offering more effective support to help them overcome reading challenges in Hebrew.

Future research should address several limitations of the current study. First, the cross-sectional design and relatively small sample size might limit the generalizability of the findings to a broader population. Additionally, the high socioeconomic status of the participants may have influenced the study's results, potentially restricting their applicability to broader demographics. Children from lower socioeconomic status backgrounds may have lower linguistic abilities due to the home literacy environment as well as less exposure to different linguistic stimuli, which may influence reading acquisition at school. Future studies should include populations that are more diverse and consider additional factors such as teacher quality, classroom environment, and teaching methods, which may significantly influence reading development. Second, the pseudowords used in the study were not adapted in terms of length, frequency, difficulty, or number of items, and reading rate was not measured. Conducting longitudinal studies with larger and more diverse samples, while considering these factors, would lead to a more accurate assessment and provide a deeper understanding of the nuances of the Hebrew reading acquisition process. Future research could also explore the effectiveness of instructional interventions targeting specific aspects of morphological processing compared to phonological processing on reading outcomes in Hebrew-speaking children. Investigating different instructional approaches could offer valuable insights into effective reading instruction strategies for Hebrew learners. Furthermore, examining the relationship between morphological and phonological awareness and that between morphological and phonological decoding would contribute to a more comprehensive understanding of the factors influencing reading development and the enhancement of reading instruction and intervention programs for Hebrew-speaking children.

In summary, there has been a growing recognition that writing systems reflect the features of the spoken language, influencing the interplay between phonology and morphology in the process of reading and learning to read (Frost, 2012; Perfetti & Verhoeven, 2017). While many alphabetic systems prioritize orthographic consistency over morphological transparency (Landerl et al., 2022), the Hebrew abjad-consonantal writing system, representing the Semitic Hebrew language's rich synthetic morphology, emphasizes the superiority of morphemes over phonemes (Verhoeven & Perfetti, 2022). The present study sheds light on how children learning to read Hebrew gradually shift towards greater reliance on morphological processing at the expense of phonological processing from second to fourth grade. While the findings confirm fourth graders' preference for morphological processing, they also reveal that even in the early stages of second grade, children prioritize morphological processing over phonological processing for identifying unfamiliar (new) words accurately or recognizing familiar words fluently, regardless of the phonological information within the words. This underscores the superior influence of morphological transparency over orthographic consistency, suggesting that children learning to read in such a rich morphological system develop sensitivity to written morphology alongside phonology simultaneously from the early stages, emphasizing the importance of early acquisition of morpho-orthographic root-and-pattern representations in mastering Hebrew orthography. Understanding the influence of the Hebrew language and writing system's distinctive characteristics on

the interplay between phonology and morphology among developing readers is vital for designing effective reading programs and interventions, as well as for diagnosing and addressing reading challenges among Hebrew-speaking learners.

Appendix

Phonological and phonological–morphological processing; Shany et al., 2006. In reading pointed pseudowords, the items were selected based on the following syllabic structures: (1) items made up of phonological units of more than one syllable, representing existing morpho-orthographic structures in the language, while the root is a pseudo-morpheme. Familiarity with the morphological pattern serves as a clue for deciphering the item (for example, "titpandi" for the weight "titkadmi"); (2) items made up of phonological units of two or more syllables that have no representation in the language. Without morphological cues, readers are compelled to rely on encoding concatenation operations tseruf (e.g., "wachelak").

Morphological decoding; Bar-On & Ravid, 2011. Root selection: Pseudo-roots were chosen to periodize morphological rather than lexical processes in reading unpointed words. This selection was intended to reduce resemblance to words with genuine roots by ensuring that target items differed by at least two root radicals. Special attention was paid to ensure that the first two root radicals do not share the same place of articulation. Pattern selection: Given that most Hebrew content words are based on nonlinear morphological patterns, task items encompassed the three main lexical categories: nouns, verbs, and adjectives. Emphasis was placed on the fundamental root-and-pattern structure, avoiding inflections usually expressed by linear affixation to a stem. Patterns were chosen based on their productivity, meaning their ability to relate to extensive morphological families.

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