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Semantic and syntactic constraints in resolving homography: a developmental study in Hebrew

Amalia Bar-On[1] · **Tal Oron**[1] · **Orna Peleg**[2]

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Abstract

Effects of semantic versus syntactic constraints on resolution of Hebrew heterophonic-homographic words were examined at three reading skill levels. Fourth-and sixth-grade students and a group of adults read aloud sentences containing two types of heterophonic-homographs: noun–noun (e.g., BYCH ביצה is read as *beitsa 'egg'* and *bitsa 'swamp'*) and noun–verb (e.g., GZR גזר is read as *gezer 'carrot'* and *gazar '(he) cut'*). Dominant and less-dominant alternatives were identified for each homograph and the alternatives were embedded in two sentences biased semantically towards noun–noun homographs and syntactically towards noun–verb homograph. The reading accuracy and correction results clearly showed a greater effect for syntactic context than for semantic context. For noun–noun words, the dominance effect appeared among the three study groups, though accuracy of reading the less-dominant meaning increased with age, indicating greater reliance on context. For noun–verb words, a small difference between the two meanings was found in the younger group only. We concluded that in resolving Hebrew heterophonic-homographic words, syntactic constraints are sufficient for accurate reading while semantic information is less efficient. The results are discussed in the context of other languages and the unique typology of the Hebrew orthography.

Keywords Hebrew orthography · Heterophonic-homographic words · Lexical ambiguity · Semantic context · Syntactic context

✉ Amalia Bar-On
amaliaba@zahav.net.il

[1] Department of Communication Disorders, The Stanley Steyer School of Health Professions, Sackler Faculty of Medicine, Tel-Aviv University, Tel-Aviv, Israel

[2] The Program of Cognitive Studies of Language and Its Uses, Sagol School of Neuroscience, Tel-Aviv University, Tel-Aviv, Israel

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Introduction

Lexical ambiguity is universal. In English, for example, over 80% of common words have more than one dictionary entry. About 7% are classified as "true homonyms," where alternative meanings are not semantically related to one another (e.g., the word *organ* refers to a musical instrument or to a part of the body). More prevalent are polysemous words, which have a large number of related dictionary definitions (e.g., *date*, *run*, *post*; Rodd, Gaskell, & Marslen-Wilson, 2002). Our language comprehension system is highly skilled at dealing with lexical ambiguity, such that both readers and listeners are usually able to identify a single meaningful interpretation for each sentence without being overtly distracted by the many possible meanings of its constituent words (Leinengera & Rayner, 2013; Tabossi & Sbisà, 2001). The appropriate interpretation of a word is achieved via a variety of contextual constraints, including lexical associations among co-occurring words, restrictions set by the syntactic structure, message-level semantic information built as context unfolds, pragmatic factors, and world knowledge, among others (Lee & Federmeier, 2009). Yet, one of the most robust findings in the literature is that lexical ambiguity often creates processing burdens, as evidenced by increased reading time for ambiguous words relative to matched control words (e.g., Duffy, Morris, & Rayner, 1988; Rayner & Frazier, 1989).

A large body of work based on multiple measures has accumulated over the past 40 years, revealing how lexical ambiguity affects processing. In particular, studies have explored whether one or multiple meanings are activated when an ambiguous word is processed. Various theories have tried to account for all types of words, but the bulk of previous research (e.g., Duffy, Kambe, & Rayner, 2001; Rayner & Duffy, 1986; Swinney, 1979) has focused on meaning selection within a particular syntactic category, usually nouns (as in the example above: *organ* and *date)*. Within this category of literature, studies of context effects have manipulated the presence of semantic constraints, based either on lexically associated words or on sentence meaning (e.g., Leinengera & Rayner, 2013; Martin, Vu, Kellas, & Metcalf, 1999; Vu, Kellas, & Paul, 1998).

Another type of ambiguity occurs when words have meanings belonging to different syntactic classes, such as the word *watch*, which can refer to either a noun or a verb. For such words, syntactic features can also play a role in ambiguity resolution. It appears that the more limited literature specifically addressing syntactic context effects on meaning ambiguity resolution for noun–verb homonyms has yielded notably different conclusions than the literature on noun–noun homonyms. Namely, most studies demonstrate that syntactic category information alone is not sufficient for determining the context-intended meaning of noun–verb homonyms (e.g., Lee & Federmeier, 2006, 2009, 2012; Stites & Federmeier, 2015). This evidence, which indicates a greater effect of semantic information than syntactic information in resolving ambiguous words, is based on studies conducted in European languages, primarily English. It remains unknown whether this pattern occurs in additional languages, such as Semitic languages. The two Semitic orthographies—Hebrew and Arabic—are characterized by a greater

degree of lexical ambiguity, expressed mainly in the extremely high prevalence of *heterophonic-homographic* words in texts. In the current study, we explored the contribution of semantic and syntactic information in resolving Hebrew heterophonic-homographic words.

Phonological and orthographic representations of ambiguous words might also play a role in the meaning selection process. The most general case of ambiguity in English involves *homophonic*-homographic words, in which different meanings share the same spelling and pronunciation (e.g., *organ, date, watch*; Leinengera & Rayner, 2013). Research on meaning-selection processes in reading has focused on this type of word (Peleg & Eviatar, 2012). Another type, which is relatively rare in English and other languages (Perfetti & Hart, 2001), but highly prevalent in the two Semitic languages, Arabic and Hebrew (Abu-Rabia, 2001; Bar-On, Dattner & Ravid, 2017; Shimron & Sivan, 1994), is *heterophonic*-homographic words, in which the different meanings share the same spelling but differ in pronunciation (e.g., the string *lead* can be pronounced as /lid/or/led/).

Homophonic-homographic words (henceforth referred to as *homonyms*) are relevant to comprehension of both spoken and written sentences, whereas heterophonic-homography (henceforth *ht-homography*) is relevant to written language alone. In deciphering ht-homographic words, readers must decide on the relevant meaning early in the word recognition process, during the phonological retrieval stage (Bar-On, Dattner & Ravid, 2017). Given the differences between them, it is not surprising that the two types of the homographic words are processed differently in both English (Folk & Morris, 1995, 2000) and Hebrew (Bitan, Kaftori, Meiri-Leib, Eviatar & Peleg, 2017; Peleg & Eviatar, 2009, 2017).

Effects of syntactic constraints on the resolution of lexical ambiguity have been investigated in the context of homonyms alone. Thus, the first aim of the current study was to explore the effects of such constraints on the deciphering of Hebrew ht-homographic words. The second aim was to explore developmental aspects of this process. Specifically, while the crucial role of context in reading and reading acquisition in Hebrew is widely accepted (Bar-On et al., 2017; Ravid, 2005; Share & Bar-On, 2018), it remains unclear (1) how exactly semantic information and syntactic constraints contribute to accurate and efficient reading of ht-homographic words in Hebrew text, and (2) how reading proficiency (i.e., reader age) affects this contribution.

Lexical ambiguity resolution in semantic contexts

Decades of work have established that semantic constraints, built up incrementally over the course of a sentence or other higher-order language context, can facilitate word processing (Kutas, Van Petten, & Besson, 1988; Marslen-Wilson & Tyler, 1980; Van Petten & Kutas, 1990, 1991). Within the domain of lexical ambiguity resolution, a core question has been whether such contextual information can affect lexical access, enabling selective activation of the contextually appropriate meaning of a homonym. Accumulated data suggest that it can, albeit in a manner that interacts with meaning dominance (Carpenter & Daneman, 1981; Duffy et al. 1988; Rayner & Duffy, 1986). Preceded by a neutral context, where no disambiguating

information is provided, a balanced ambiguous word (i.e., the two primary meanings are balanced in frequency) will be processed more slowly than a matched (for length and frequency) unambiguous word. This finding indicates that without a biasing context the two alternatives of the balanced ambiguous word are activated simultaneously. When the word is preceded by a context that better supports one of the two meanings, it will be processed as fast as the matched word, indicating selective activation of the contextually appropriate meaning (Rayner & Duffy, 1986; Swinney 1979).

More common than balanced ambiguous words are *polarized* homonyms (e.g., *bat*), which have a more frequently used (dominant) meaning (e.g., *baseball bat*) and one or more less frequently used (subordinate) meanings (e.g., *flying mammal*; Vu, Kellas, & Paul, 1998). When preceded by either a neutral or dominant-biasing context, the dominant meaning of a polarized homonym is accessed faster than the subordinate meaning and the word is processed as fast as a matched unambiguous control word (Hogaboam & Perfetti, 1975; Simpson, 1981; Simpson & Burgess, 1985). A different pattern is elicited when a polarized homonym is preceded by a subordinate-biasing context: the homonym is processed more slowly than a matched control word. This phenomenon, termed the subordinate bias effect (Pacht & Rayner, 1993), has been demonstrated repeatedly and served as the basis for the reordered access and context-sensitive models of lexical ambiguity resolution. The reordered access model (Duffy, Morris, & Rayner, 1988) assumes exhaustive retrieval of the meanings of an ambiguous word in all contexts. According to this view, the order in which the meanings are accessed corresponds to the frequency with which each meaning is given as an associative response in norming studies. Biasing context can change this order by boosting the activation of the contextually appropriate meaning, but it cannot prevent the inappropriate meaning(s) from being accessed.

The context-sensitive model (Vu, Kellas, & Paul, 1998; Vu, Kellas, Metcalf & Herman, 2000) also recognizes the importance of meaning frequency and biasing context, but claims that the parameter of context *strength* determines the pattern of meaning activation. According to this model, when a polarized homonym is preceded by a subordinate-biased context, there are two possible outcomes: either the subordinate bias effect will occur, or only the subordinate meaning of the homonym will be activated, contingent on the strength of the subordinate-biased context. Vu, Kellas, & Paul (1998), for example, manipulated the semantic constraints that the subject noun and the predicate verb placed on the subordinate meaning of homonymous direct object (e.g., *bat*). They found a priming effect in both conditions: when the subject noun alone (e.g., *the biologist located the bat*) and when the verbal predicate alone (e.g., *the man wounded the bat*) was associated with the subordinate meaning (e.g., *flying mammal*). However, the convergence of multiple semantic constraints (e.g., *the biologist wounded the bat*) had a greater influence on word meaning activation.

Recent neuropsychological studies support the reordered access model and other models, defined as "hybrid models," such as the "graded salience hypothesis" (Giora, 1997, 1999, 2003; Peleg, Giora & Fein, 2001, 2004). Using the divided visual field technique, Peleg & Eviatar (2008) showed that even when the context is strongly biased towards the subordinate meaning, dominant meanings are activated

in both hemispheres. Of particularly relevance to the current study are additional findings clearly demonstrating that the type of the ambiguous word—homonym versus ht-homograph—modulates the pattern of the meaning activation. Specifically, Peleg & Eviatar (2009) showed that the two noun-meanings of a homonym were associated with activation in the left hemisphere, regardless of the type of the context, semantic neutral or subordinate-biased. In contrast, left hemisphere activation was associated with the dominant meaning of a ht-homograph when the context was ambiguous (semantic neutral) and with the subordinate meaning when the context created a bias toward the subordinate meaning.

Lexical ambiguity resolution in syntactic contexts

Ambiguous words with meanings belonging to two different syntactic classes (e.g., noun, verb) provide an opportunity to investigate the influence of prior syntactic constraints on lexical ambiguity resolution. Less research addresses the effect of syntactic contexts on lexical ambiguity resolution than the effect of semantic contexts. However, the processing of cross-categorical homonyms in the presence of syntactic restrictions has been studied fairly extensively. Evidence from behavioral (e.g., Tanenhaus, Leiman & Seidenberg, 1979), eye-tracking (Chen & Tsai, 2015; Stites, Federmeier & Stine-Morrow, 2013), and event-related potential (ERP) studies converge on the conclusion that syntactic information alone is not sufficient to immediately resolve meaning ambiguity for noun–verb homonyms. For example, using ERP, Federmeier and colleagues (Federmeier, Segal, Lombrozo, & Kutas, 2000; Lee & Federmeier, 2006, 2009, 2012) found that noun–verb homonyms with two semantically distinct meanings (e.g., *park*) elicited a sustained negativity over frontal channels (relative to unambiguous words) when they appeared in semantically neutral but syntactically constraining contexts (e.g., *to/the park*). This negativity did not appear when the two meanings overlapped (e.g., *drink*; Lee & Federmeier, 2006). When semantic constraints were present, noun–verb homonyms were processed in a qualitatively similar manner to unambiguous words.

Stites, Federmeier, and Stine-Morrow (2013) replicated these ERP findings in an eye-tracking study. They embedded noun–verb homonyms at the end of sentences representing two types of context: congruent sentences, which have both semantic and syntactic cues indicating the context-appropriate meaning (e.g., *You can usually find the registration desk of a hotel in the lobby*), and syntactic prose sentences, which maintain the syntactic cues of congruent sentences but lack coherent semantics (e.g., *You can usually install the math student of a day in the lobby*). Eye-tracking revealed increased durations of the first fixation on the noun–verb homonyms in the contexts with constraining syntax but lacking coherent semantics, but did *not* find similarly increased reading times in the semantically rich contexts. Similar findings have been reported for different languages. Chen and Tsai (2015) compared the effect of subordinate-biased contexts on noun–verb (verb is the subordinate alternative) and verb-noun (noun is the subordinate alternative) Chinese homonyms. Eye-tracking revealed a larger subordinate bias effect when reading noun–verb homonyms than verb-noun homonyms

on both target and post-target words. These results join previous data providing strong support for the idea that, in the absence of semantic constraints, additional processes must be recruited to enable ambiguity resolution of noun–verb homonyms.

Nevertheless, this evidence from lexical (noun–verb) ambiguity studies is surprising, considering that syntactic information is generally thought to be deterministic (Hahne & Friederici, 1999, 2002), based on many studies. For example, in examining resolution of *syntactic* ambiguity, Ferreira, Christianson, and Hollingworth, (2001) showed that when reading a garden path sentence (e.g., *While Anna dressed the baby spit up on the bed*), the preliminary cumulative syntactic information *(While Anna dressed…)* misleads readers who interpret *the baby* as a direct object. Using a different method, Brothers and Traxler (2016) observed higher word skipping rates for syntactically valid previews (e.g., *The admiral would not confess…*), as compared to violation previews (*The admiral would not surgeon…*). Their results indicated that readers use grammatical constraints to generate syntactic expectations for upcoming words, particularly at the word category level (noun, verb, preposition). The lesser impact of syntactic constraints in noun–verb ambiguity studies might be attributed to the structure of the sentences they used. Ambiguity was created in these sentences by preceding the noun–verb homonym with a mental verb (e.g., *John hated, wanted, liked, forgot,* etc.) that, by nature, could be followed by either a definite noun (e.g., the trip, the fly, the date, the notice), or an infinitive (e.g., to trip, to fly, to date, to notice; see for example, Stites & Federmeier, 2015). Accordingly, the syntactic cue for reading the homonym as a verb or a noun in these sentences is located in very specific words: *the* or *to*. To summarize, data derived from within (noun–noun) and cross (noun–verb) syntactic category lexical-ambiguity studies has led researchers to believe that semantic constraints build incrementally and can therefore, at least sometimes, determine access to meanings of ambiguous words. The influence of syntactic context seems to be more localized (Marslen-Wilson & Tyler, 1980; Tyler & Warren, 1987).

The effect of syntactic contexts on lexical ambiguity resolution has predominantly been studied in the context of homonyms. In a recent study of the Hebrew language, Evanhaim (2018) compared noun–verb homonyms and ht-homographs. Similar to Peleg & Eviatar (2009), who looked at the same question in a semantic context, they found that the type of ambiguous word (homonym, ht-homograph) modulated meaning activation in the context of syntactic constraints.

Taking these two Hebrew studies together, we propose that ambiguity resolution processes are affected by the phonological status of the ambiguous word (i.e., whether the pronunciation of the two meanings is identical or not). It is possible, then, that the conclusions drawn from studies examining homonyms cannot be generalized to ht-homographs in Hebrew. In investigating the relative contribution of semantic and syntactic information in reading Hebrew, ht-homographic words can shed further light on lexical ambiguity resolution processes. Given the widespread distribution of ht-homographic words in the Hebrew orthography, this research is particularly important in understanding the processes underlying reading of Hebrew texts**.**

Homographic Hebrew Text

Hebrew is written from right to left and uses a consonantal alphabetic script (*abjad*) with 22 letters, 18 denoting consonants alone and 4 (AHWY) denoting both consonants and vowels. Modern Hebrew employs two versions of the same orthography: pointed and unpointed. The pointed version fully and transparently represents the Hebrew vowels using two graphemic sets: diacritic-like signs (referred to here as vowel-signs) and the four AHWY letters noted above. However, much more commonly used is the unpointed script, which is fairly opaque with respect to the vocalic structure of words.

In unpointed Hebrew script, vowels are represented opaquely and partially by the four vowel letters alone, with no vowel-signs**.** Due to the underrepresentation of vowels (as well as stop/spirant alternation in three consonantal letters), a high percentage of the words in any unpointed Hebrew text are ht-homographic. For example, the written word MDBR[1] (Hebrew: מדבר) can be read as the noun *midbar* (desert), the verb *medaber* (talking), and the prepositional phrase *mi-davar* (from something). Shimron and Sivan (1994) reviewed ten 200-word Hebrew texts and found that, on average, 23% of the words in each text were ht-homographic. Recently, Shrem (2021) re-examined the percentage of ht-homographic words in twenty 200-word Hebrew texts using a computerized morphological analyzer (Bar-Haim, Sima'an, & Winter, 2008), which presents all the reading options for each word. Using the digital tool expanded the percentage of ht-homographic words to 30%. Two-thirds of the words that were identified as homographic had two alternative meanings, 23% had three, and the rest had four to seven. Further analysis of the morpho-syntactic characters of the words with two alternatives revealed that the vast majority (about 70%) were of the cross-category type. The two alternatives demonstrated various combinations of the five lexical categories—nouns, verbs, adjectives, adverbs, and function words—with noun–verb words constituting the largest group (Markus, 2021). Given the findings that most ht-homographs have two alternatives that differ in terms of their syntactic features, the context of a ht-homographic Hebrew word can provide readers with a constrained set of syntactic features, limiting the reading of the ht-homograph to the appropriate categorical meaning (Bar-On, 2015).

The role of context in reading Hebrew

Studies investigating the role of context in English reading acquisition have mostly focused on the recognition of unambiguous words. Findings indicate a greater context effect in young readers and students with dyslexia than in skilled readers, who are able to efficiently recognize words in a text without relying on context (Stanovich, Nathan, West, & Vala-Rossi, 1985; West, Stanovich, Feeman, &

[1] We CAPITAL LATIN LETTERS in representing unpointed written Hebrew words so as to facilitate understanding in readers who are not familiar with Hebrew (Ravid, 2005).

Cunningham, 1983). In Hebrew, an opposite pattern emerges (Bar-On, 2011; Share & Bar-On, 2018): novice readers learn to read the transparent, pointed version, which provides them with reliable phonological tools for accurate decoding. Thus, while context helps students cope with unfamiliar words in English, it is less needed by children in the initial phase of reading acquisition in Hebrew.

In the second phase of Hebrew reading acquisition (second and third grades), students still use the pointed version, but begin to establish the lexico-morpho-orthographic identification strategies required for filling in the missing phonological information in unpointed words. These strategies allow them to gradually reduce their reliance on vowel-sign information, in favor of top-down processes (Bar-On & Ravid, 2011). The third phase starts in fourth grade, when the transition to unpointed text reaches a peak. From this point onward, reliance on context becomes an essential process and its effect on reading increases with age.

Bar-On et al. (2017) tested the effect of context on reading ht-homographic words. Seven groups of participants (beginning and end of second, third, fourth, seventh, and eleventh grades, and adults) were asked to read aloud sentences in which ht-homographic words were embedded in supportive contexts. The effect of context was measured based on accuracy in reading the target ht-homographic word (i.e., the contextually-appropriate word). A significant increase in accuracy was found between the third and fourth grades and between the fourth and seventh grades. A similar developmental pattern was reported by Booth, Harasaki, and Burman (2006), who asked 9-, 10-, and 12-year-old English-speaking children to read aloud sentences that ended with a homonym. The results indicated that, in contrast to the pattern demonstrate for unambiguous English words, the effect of sentential context increased with development and skill. Additional findings (Khanna & Boland, 2010) indicated that, by minimizing task demands and encouraging attention to context, 9- to 10-year-old children were capable of engaging top-down mechanisms during meaning selection for ambiguous words in sentences. However, 7- to 9-year-olds were relatively insensitive to context, even within a study paradigm that encouraged them to use top-down contextual information.

Resolving ambiguous words not only recruits attention to context; it also elicits monitoring processes in cases of erroneous reading (i.e., reading the contextually-inappropriate word). Monitoring abilities were tested in Bar-On et al. (2017)'s study by embedding ht-homographic words in garden-path contexts. Findings revealed that the ability to deploy monitoring and repair processes, which call for higher-order cognitive resources, develops later than context reliance processes, starting with virtual absence of correction ability at the beginning of second grade and steadily improving to near-perfect correction in adults.

The Present study

The findings of Bar-On et al. (2017) support the highly accepted view that reliance on context is necessary and inherent in reading Hebrew text. Still, little is known about the relative contribution of semantic and syntactic contexts to Hebrew ht-homographic word resolution. The current study aimed to explore the contributions of

syntactic versus semantic constraints to resolving Hebrew ht-homographic words, and how these contributions are affected by reading skill. For this purpose, the study compared two types of ht-homographic words: noun–noun (e.g., the two reading alternatives of 9GLH [Hebrew: [עגלה are *?agala* 'stroller' and *?egla* 'female calf'), and noun–verb (e.g., the two reading alternatives of ḤDR [Hebrew: [חדר are the noun *xéder* 'room' and the verb *xadar* '[he/it] penetrated'). The two noun meanings of the noun–noun word were embedded in sentences that share the same syntactic features, with the context preceding each alternative semantically biased to suit the intended meaning (e.g., 'the mother picked up the baby and put the *stroller* into the house'; 'the cow got sick so the farmer fed the *calf* with a bottle'). The noun and verb alternatives of the noun–verb words were embedded in sentences that differed in their syntactic features: noun-constrained context (e.g., 'the parents chose a *room* for each child') and verb-constrained context ('the long branch *penetrated* the tent and tore it apart'). In line with the subordinate bias effect, we expected a relatively high number of errors in reading aloud the less frequent meanings (i.e., reading *?agala* 'stroller' instead of *?egla* 'calf' or *xéder* 'room' instead of *xadar* '[it] penetrated'). Questions remained, however, about how type of context would affect this outcome.

Based on findings on homonymy in English, we would predict a greater effect of semantic context, i.e., the difference between the reading errors of the two alternatives of the noun–noun ht-homographs will be smaller than that of the two alternatives of the noun–verb ht-homographs. However, considering that homonym resolution does not involve the same processes as ht-homograph resolution (Bitan, Kaftori, Meiri-Leib, Eviatar & Peleg, 2017; Evanhaim, 2018; Peleg & Eviatar, 2008, 2009, 2012, 2017; Peleg, Markus & Eviatar, 2012), and given the high rate of cross-categorical homographs in Hebrew (Markus, 2021), it is possible that Hebrew readers are more effective in using syntactic context to resolve the ambiguity than English readers. We therefore hypothesized that in the case of Hebrew, syntactic context would have the same or an even greater effect than semantic context. Based on the developmental studies presented above, we also hypothesized that the reliance on context would increase with age and be expressed in fewer reading errors.

Method

Participants

One hundred twenty-five Hebrew-speaking elementary school students, balanced with respect to gender, in fourth (60 students) and sixth grade (65 students), participated in the study alongside 40 young adults (26 females) between the ages of 20 and 40 years ($M = 26.50$, $SD = 4.05$) who constituted the control group. The two student groups were chosen to reflect two developmental points in reading unpointed Hebrew script: fourth graders who had just made the move to unpointed text and sixth graders who had been reading unpointed text for two to three years. The adult group included students and university graduates from various fields of practice, such as Communication Disorders and Law. All students attended the same regional school, which serves villages of mid- and mid-high socioeconomic status. The students were

recruited on a voluntary basis with parental permission. Students reported by their teachers to have learning difficulties were not included in the study. In addition, all students performed two reading subtests taken from the *Hebrew Standardized Reading and Writing Achievement Test—Alef Ad Taf* (Shani, Lahman, Shalem, Bahat, & Zieger, 2006), both of which required them to read aloud pointed narrative texts. Five 6th-graders who scored below the 16th percentile on an accuracy measure were excluded from the study. Accordingly, the final number of students was 120, including 60 students in each grade. Subjects in the adult group were undergraduate students or graduates with no learning, attention, or reading disorders. All participants were native speakers of Hebrew with normal or corrected-to-normal vision.

Words

To create the two types of contexts, 24 noun–noun and 24 noun–verb ht-homographs were employed. The words were chosen in a three-step process. First, 43 noun–noun and 43 noun–verb ht-homographs were selected after excluding ht-homographs for which one meaning constitutes a unit constructed of a syntactic clitic (a preposition, an article, or a conjunction) attached to a lexical element (e.g., the noun–noun ht-homograph BLYLH בלילה represents both *blila*, 'a mixture,' and *ba-laila*, 'at night'). In the second step, each ht-homograph was embedded in two short sentences (172 sentences total), with the context of each sentence matching one of two meanings of the word. Twenty teachers and speech and language pathologists were then asked to indicate meanings that would be unfamiliar to fourth-graders and to rate the familiarity level of each meaning from 1 (low familiarity) to 5 (high familiarity). In the third step, the two final noun–noun and noun–verb word lists, each composed of 24 words, were built based on three considerations: (1) *word length*: the average of number of syllables in the noun–noun words ($M = 1.96$, $SD = 0.51$) was similar to that of the noun–verb words ($M = 2.1$, $SD = 0.64$; $t = 0.87$, $p = 0.38$), and the average of number of letters did not differ between the noun–noun ($M = 3.58$, SD = 0.83) and noun–verb ($M = 3.33$, $SD = 0.64$) words ($t = -1.17$, $p = 0.91$); (2) *orthographic frequency*: based on the word frequency database for printed Hebrew (Frost & Plaut, 2005), the total frequency average (per million words) of noun–noun words ($M = 1.61$, $SD = 0.65$) was similar to that of noun–verb words ($M = 1.63$, $SD = 0.65$; $t = -0.1$, $p = 0.91$); and (3) *polarization*: based on the familiarity judgments, the two meanings of each ht-homograph were classified into a higher-familiarity word list (i.e., the dominant meaning list) and a lower familiarity word list (i.e., the less dominant/subordinate meaning list), creating four lists organized in a 2X2 design—Meaning Dominance (dominant, less-dominant) X Ht-homograph Type (noun–noun, noun–verb). The vast majority of noun–verb ht-homographic words (approximately 80%) showed a similar pattern, with verb meanings rated lower than or the same as noun meanings. As a result, the dominant meaning list for noun–verb ht-homographs consisted of nouns and the less-dominant list of verbs. After controlling for the different criteria, the mean familiarity difference between the two meanings (i.e., polarity) was 1.2 ($SD = 0.89$) in the noun–noun list and 1.12 ($SD = 1.09$) in the

noun–verb list. A *t*-test revealed no significant difference between the two lists ($t = 2.01$, $p = 0.79$).

Sentences

Each ht-homograph was embedded in two sentences. Thus, the study included 96 sentences, half containing noun–noun words and the other half noun–verb words. The types of ht-homographs enabled creation of two types of sentences, as follows: the two meanings of the noun–noun ht-homographs appeared in two sentences that shared a similar syntactic structure, with each sentence semantically biased towards one meaning. Conversely, the sentential contexts of the noun–verb ht-homographs were semantically neutral but constrained the syntactic category of the word to be read as a noun or a verb. All 96 target words appeared in the middle of the sentence, so they were preceded and followed by matching contexts. To ensure that the syntactic contexts restricted word reading to a noun or a verb, the 48 contexts that preceded the noun–verb ht-homographs were presented to 20 new participants, who were asked to complete the sentences. All the completions were either nouns or verbs, as expected. None of the participants completed the sentences using the target word, indicating the absence of semantic bias. To ensure that the semantic contexts targeted the specific meaning of the noun–noun ht-homograph, the same 20 participants were asked to rate the extent to which they associated the target word with the context that preceded it, on a 5-point scale ranging from (1) very unrelated to (5) very related. The participants were presented with more than one option for each target meaning and the contexts that were rated higher were chosen. The final four sentence lists created a 2 × 2 design based on Context Type (semantic, syntactic) and Meaning Dominance (dominant, subordinate). Examples of the four types of the sentences are shown in Table 1.

Design and procedure

The four sentence lists were divided into two lists using the Latin square method. Thus, each ht-homograph appeared only once in each list, and each list included equal numbers of the two ht-homographic word types (noun–noun and noun–verb) and of the two levels of dominance (dominant and less-dominant). The 48 sentences on each list appeared on three A4-sized pages, written in font 16 with 2.5 rows between the sentences. Participants in each group were divided into two subgroups balanced with respect to gender. The two student groups were also balanced with respect to reading scores. Accordingly, each list was given to 80 participants. The study included a 15-min session conducted privately at the school or at the participant's home. Participants were given the following instructions: "Here is a list of sentences. Please read the sentences aloud. There is no connection between the sentences and each sentence stands on its own. I will record your reading. I'm not going to measure the reading time or ask any question about the sentences. If you feel that you have read the sentence incorrectly, you can go back and correct your reading."

Table 1 Translated Examples of the Four Types of Sentences

Type and ht-homograph	Pronunciation and meaning	Context type and sentence
Noun–noun: BYCH (ביצה)	Dominant (Noun): (1) *beitsa* (egg)	Semantic context (1) The kids fried the egg a little too much (1) יידים רתוי תצק תא ונגיט מידליה הציבה
	Subordinate (Noun): (2) *bitsa* (swamp)	(2) The workers dried the swamp on their own (2) ממצע תוחוכב הציבה תא ושביי מילעופה
Noun–verb: GZR (גזר)	Dominant (Noun): (3) *gezer* (carrot)	Syntactic context (3) The strange man sitting next to us asked for a carrot from the waitress (3) תירצלמהמ רזג שקיב ונידיל בשיש רזומה שיאה
	Subordinate (Verb): (4) *gazar* (cut)	(4) The nice boy sitting next to me cut the thread in his shirt (4) ולש הצלוחה לעש טוחה תא רזג ידיל בשיש דמחנה דליה

Coding and scoring

Recording oral reading of a sentence that includes a ht-homographic word is a reliable and straightforward method to learn about the reader's choice of one alternative or another. It can also provide indications of the reanalysis process in cases of erroneous reading. Accordingly, two measures were used to assess oral reading (based on Bar-On et al., 2017): (1) *Contextualized accuracy*, i.e., reading the contextually appropriate meaning and (2) *Correction*, when the contextually inappropriate meaning was read. The first measure provided an indication of the first meaning that was activated or, to be more precise, the first meaning that reached the pronunciation level. This measure was defined as incorrect even if it was subsequently amended, including cases in which the reader started pronouncing the first syllable/s of the competing meaning and immediately switched to the correct one. The second measure provided an indication of monitoring processes. We also coded non-lexical readings, which mainly occurred in fourth graders, who had just begun reading unpointed texts.

Results

Two analyses were conducted to test the effect of semantic versus syntactic context on resolving Hebrew ht-homographic words. The first examined *contextualized accuracy*. The dependent variable in this analysis was the percentage of sentences in which the contextually-appropriate alternative was read. We expected to find a smaller difference between the two alternatives of the noun–verb ht-homographs (words in a syntactic context) than between the noun–noun ht-homographs (words in a semantic context). The second analysis examined the effect of context type on monitoring processes by looking at the *correction* measure. The dependent variable in this analysis was the percentage of corrections following incorrect readings. A generalized linear mixed model was conducted for both the *contextualized accuracy* and *correction* measures. In both analyses, the independent variables were as follows: (1) Group (fourth grade, sixth grade, adults), (2) Context Type (semantic, syntactic), and (3) Meaning Dominance (dominant, less-dominant).

Contextualized Accuracy

Table 2 presents the percentage of sentences in which the contextually-appropriate meaning was read for each of the three groups determined by context type and level of dominance. The number of non-lexical errors appearing in the four conditions was similar (about 3%) and they were therefore not calculated separately.

The generalized linear mixed model revealed three effects. There was a main effect of Group [$F(2,160) = 40.76$, $p < 0.001$], with post hoc tests showing that adults ($M = 94\%$, $SD = 24\%$) were more accurate than fourth-graders ($M = 82\%$,

Table 2 Means and Standard Deviation (in Brackets) of Contextualized Accuracy Rates in Each of The Three Groups (4th, 6th and Adults) Classified by Context (Semantic, Syntactic) and Level of Dominance (Dominant, Subordinate)

		4th grade	6th grade	Adults
Semantic context (Noun–noun)	Dominant (Noun)	89 (31)	93 (25)	96 (19)
	Subordinate (Noun)	62 (48)	78 (42)	87 (34)
Syntactic context (Noun–Verb)	Dominant (Noun)	91 (29)	94 (23)	97 (18)
	Subordinate (Verb)	84 (37)	91 (29)	95 (21)

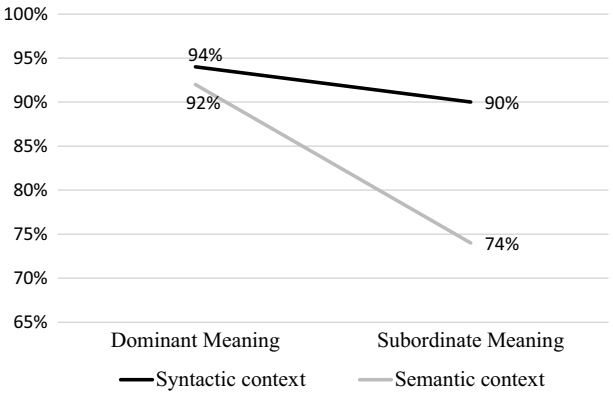

Fig. 1 Contextually- appropriate reading: Interaction between context and dominance

$SD = 39\%$) and that sixth-graders ($M = 89\%$, $SD = 31\%$) were more accurate than fourth-graders ($t = 2.57$, $p < 0.01$, including Bonferroni correction for multiple comparisons). There was also a main effect of Context [$F(1,160) = 50.19$, $p < 0.001$], confirming our hypothesis that accuracy of reading ht-homographic words in a syntactic context ($M = 92\%$, $SD = 28\%$) was higher than in a semantic context ($M = 83\%$, $SD = 37\%$). The main effect of Meaning Dominance was also significant [$F(1,160) = 101.11, < 0.0001$], indicating that, as expected, reading accuracy was higher for dominant meanings ($M = 93\%$, $SD = 26\%$) than for less-dominant meanings ($M = 82\%$, $SD = 38\%$). Most notably, as seen in Fig. 1, there was a significant interaction between Context and Meaning Dominance [$F(2,160) = 23.01$, $p < 0.001$].

The differences between the dominant and less-dominant meanings were significant in both contexts, but the gap between them was larger in the semantic context than in the syntactic context. In addition, while the difference between the two dominant meanings was not significant, the less-dominant meaning in the syntactic context was read significantly more accurately than the less-dominant meaning in the semantic context [$F(1,160) = 100.71$, $p < 0.001$].

Table 3 Means and Standard Deviation (in Brackets) of Correction Rates in Cases of Erroneous Reading Within the Three Groups (4th, 6th, and Adults), Classified by Context (Semantic, Syntactic) and Level of Dominance (Dominant, Subordinate)

		4th grade	6th grade	Adults
Semantic context (Noun–noun)	Dominant (Noun)	35 (48)	52 (50)	50 (51)
	Subordinate (Noun)	16 (36)	28 (45)	42 (50)
Syntactic context (Noun–Verb)	Dominant (Noun)	39 (49)	41 (50)	50 (52)
	Subordinate (Verb)	46 (50)	64 (48)	50 (51)

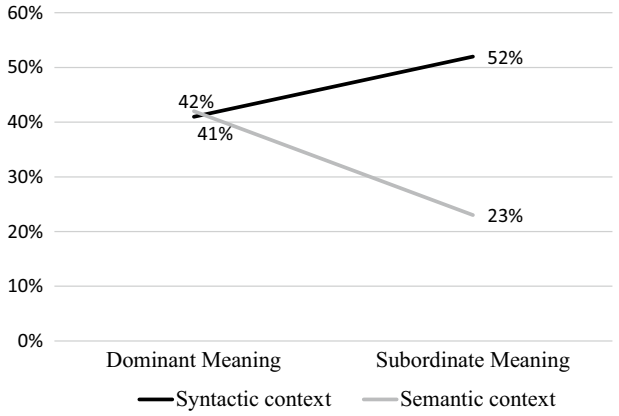

Fig. 2 Corrections: Interaction between context and dominance

Correction

The corrections in each group were calculated in relation to the number of reading errors and are presented in Table 3, classified by context type and level of dominance.

The generalized linear mixed model revealed two main effects, of Group [$F(2,153) = 5.49$, $p < 0.001$] and of Context [$F(1,114) = 9.5$, $p < 0.01$]. The hierarchy between the three groups (28% in fourth grade, 41% in sixth grade, and 46% in adults) was not found to be significant in post hoc tests. The correction results strengthened the accuracy findings: the likelihood of reading a syntactically incompatible meaning is lower than the likelihood of reading a semantically incompatible meaning, and when an error is made, a syntactically incompatible meaning is more likely to be corrected. More informative, however, was the significant interaction between Context and Meaning dominance [$F(1,28) = 12.35$, $p < 0.01$], which indicated that Context Type affects corrections only for less-dominant meanings. The interaction is presented in Fig. 2.

Discussion

While the relative contributions of syntactic and semantic contexts to ambiguous word reading have been studied for more than two decades, it has not yet been investigated with respect to the highly ht-homographic Hebrew text. In the current study, we addressed this question using words representing two meanings from the same syntactic category (noun–noun), in which the interpretation of meaning is based on semantic information, and cross-category words, which are interpreted as verbs or nouns based on syntactic constraints. The results confirmed our hypothesis, clearly showing a greater effect for syntactic context than for semantic context.

Specifically, we found that when ht-homograph meanings were constrained syntactically, there was almost no effect of meaning dominance, with an accuracy difference between the dominant and less-dominant (i.e., subordinate) alternatives, occurring mostly in the younger group, of 4% on average. However, when the two alternatives of the ht-homograph were embedded in sentences that were syntactically identical but included semantic biases toward one or the other meaning, a significant subordinate bias effect was found. In this case, the difference between the dominant and less-dominant alternatives reached 18% on average, and was demonstrated in all three groups.

The between-context category results revealed no difference between the two dominant meaning lists (92% and 94% accuracy in semantic and syntactic contexts, respectively) but did reveal a difference between the two less-dominant meaning lists (74% and 90% accuracy in semantic and syntactic contexts, respectively). In the discussion below, we address the results of the dominant alternatives in the two contexts together, while the results of the less-dominant alternatives are addressed separately in the semantic and the syntactic contexts.

Reading the dominant meanings in semantic and syntactic contexts

The high level of accuracy in reading the dominant alternatives in both context types is not surprising, considering that reading a dominant meaning in a context that supports it is equivalent to reading an unambiguous word (Rayner & Frazier, 1989; Rayner, Pacht & Duffy, 1994). Fourth-graders, who had just made the shift to reading unpointed texts, made reading errors in 10% of the sentences, with most involving homographs for which the two meanings were rated as having relatively low familiarity (e.g., the word KCB בצק, which means *kétsev* 'rhythm/tempo' and *katsav* 'butcher'). The challenge posed by the vowel completion task when reading the low familiarity unpointed word was reflected in non-lexical reading errors (e.g., *katsev* in the above example), which constituted a third of the errors, or in reading the less-dominant meaning (*katsav*). On the other end of the reading proficiency scale, the adult group almost reached a ceiling effect, but still produced a small number of reading errors (4% and 3% in semantic and

syntactic contexts, respectively). Errors in reading unpointed Hebrew text have been reported in previous studies in which adult participants were asked to read aloud from real texts (Bar-On, 2015) or sentences with contexts supporting the ht-homographic target word (Bar-On et al., 2017). This indicates that reading unpointed and homographic text can sometimes be a resource-consuming process even among proficient readers. Some of the errors might also be related to the familiarity judgment method used in the current study: to avoid using relatively unknown words, the judges were asked to rate the words with reference to the lexical knowledge of fourth-graders. It is possible that for a small number of words, the direction of the polarization was not the same for children and adults. In these words, the meaning that was defined as dominant for fourth graders might be the less-dominant meaning for adults. For example, the word GWLH הלוג can be decoded as *gula* 'a marble (small ball)' and as *gola* 'diaspora'. The first meaning was rated as dominant from a fourth-grader's perspective, but it is likely to be the less-dominant meaning for adults. Still, even if this phenomenon occurred, it was probably marginal.

Reading the less-dominant meaning in a semantic context

The finding related to the less-dominant alternatives in the semantic context condition was also expected, and demonstrates that the subordinate bias effect, well-described in resolving homonyms (Rayner, Pacht & Duffy, 1994; Seidenberg, Tanenhaus & Leiman, 1982; Tabossi, 1988), characterizes the resolution of ht-homographic words as well. The simple measure of reading a whole sentence aloud seems to reinforce the dominance effect: activation of the dominant alternative extends to the later stages of the decoding process, during which the system is already set for phonological production (Laubrock & Kliegl, 2015). At this point, the context following the ht-homographic word can also contribute to its accurate reading, at least for proficient readers (Bar-On, Dattner & Braun-Peretz, 2019). For example, DWD can be read as *dod* 'uncle' and as *dud* 'boiler.' The last was defined as the less-dominant meaning and appeared in the sentence: 'We had no hot water and tried to repair the boiler that broke down last week.' The post-word context ('that broke down') reinforces the boiler's meaning.

Despite these advantages, a significant number of reading errors (i.e., reading the dominant alternative, or starting to pronounce it) appeared in the three study groups, with the percentage hierarchy reflecting proficiency level: 38% in fourth grade (3% non-lexical readings), 22% in sixth grade, and 13% in adults. With respect to reading acquisition, the findings support previous studies in English (Booth, Harasaki, & Burman, 2006; Khanna & Boland, 2010) and Hebrew (Bar-On et al., 2017; Share & Bar-On, 2018), indicating that reliance on context in resolving lexical ambiguity becomes more significant and effective with increasing age and reading proficiency.

Reading the less-dominant meaning in a syntactic context

The most significant finding of the current study is the dramatic influence that syntactic constraints had on reading the context-appropriate meanings of ht-homographic words. The effect of meaning dominance was almost eliminated in the syntactic context condition. Importantly, the two alternatives of the ht-homographs in the syntactic context condition not only differed in familiarity level, but also in syntactic category type: based on the familiarity ratings, the noun meanings were dominant and the verb meanings as less-dominant. The fact that the less-dominant meanings were verbs even strengthens the finding, because verb processing is believed to be more complex and difficult than noun processing (Frazier & Rayner, 1987; Gentner, 1981, 1982; Landau & Gleitman, 1985; Pickering & Frisson, 2001; Vigliocco, Vinson, Druks, Barber & Cappa, 2011). With specific reference to Hebrew ht-homographic words, Bar-On (2010) showed that Hebrew-speaking readers decode *isolated* noun–verb words as nouns, regardless of the familiarity level of the two meanings. The evidence from the current study suggests that this advantage for nouns disappears when the words are presented within sentences.

This evidence contrasts with the studies of Federmeier and her colleagues (see Introduction), who repeatedly found that syntactic cues alone are insufficient to constrain lexical access. The contradicting findings might be attributed to (1) different types of ambiguity—ht-homographic words in the Hebrew study and homonyms in the English studies; (2) experimental methods that target different points along the course of word decoding; and (3) the nature of the syntactic constraints – whether they were global or local. Nevertheless, the current study findings are in line with previous evidence suggesting that grammatical constraints are deterministic and have a rapid influence during language comprehension, particularly at the word category level (noun, verb, preposition; Gibson, 2006; Jones, Folk & Brusnighan, 2012; Macdonald, 1993). In describing the resolution process of Hebrew ht-homographic words, Allon (1995) suggested that the context preceding the ambiguous form provides grammatical constraints for identifying its morpho-syntactic features (e.g., lexical category), as each word can create morpho-syntactic expectations for the upcoming word. In the case of cross-categorical ht-homographic words or alternatives that differ with respect to other morpho-syntactic features (e.g., gender), syntactic constraints are sufficient for accurate reading; in other cases, additional semantic and/or pragmatic information is needed.

Corrections in semantic and syntactic contexts

A similar interaction between context and meaning dominance was found for the success rate of ht-homographic word reading and for the correction rate in cases of erroneous reading. Specifically, context did not affect the correction rate

of the dominant alternatives, and the rate of correction of less-dominant meanings in the syntactic context was significantly higher (52% on average) than in the semantic context (23% on average). In accordance with the deterministic and primary nature of syntactic analysis in sentence comprehension, listeners or readers have been found to be more sensitive to syntactic errors, detecting them faster and more automatically than semantic violations (Gunter & Friederici, 1999; Hagoort, 2003; Hahne & Friederici, 1999, 2002; Lau, Stroud, Plesch & Phillips, 2006). In the current study sentences, accessing a noun instead of a verb, or vice versa, created illegal sentences (e.g., The nice boy carrot [/cut] the thread in his shirt). Meanwhile, reading a word that was syntactically consistent with the sentence but semantically incompatible created illogical but possible sentences (e.g., The workers dried the egg [/swamp] on their own). Overall, the rate of correction was low in the three groups, but it was greater in sixth-graders than in fourth-graders and greater in adults than in sixth-graders. Our results in this area join those reported by Bar-On et al., (2017), demonstrating the gap between effective reliance on context and effective monitoring processes, which require greater cognitive resources.

Implementations in reading Ht-homographic Hebrew text

The conclusions drawn of the present study add a typological perspective to the psycholinguistic discussion concerning sentence comprehension and lexical ambiguity. The findings also provide an essential pillar for understanding reading in the Hebrew ht-homographic text. There is no doubt that unpointed Hebrew text is extremely vague, and that reliance on context is the way to overcome this vagueness. Nevertheless, the current study shows that context does not always guarantee successful decoding. While context containing syntactic constraints eliminates dominance differences, semantic information appears to be insufficient in reducing the subordinate bias effect. Integrating the current study findings with the recent findings of Markus (2021) reveals how Hebrew readers manage to read the highly ht-homographic Hebrew text. Most Hebrew ht-homographic words are of the cross-category type, so their reading is restricted by syntactic constraints that have a dramatic impact on meaning selection. Accordingly, it can be assumed that while reading the highly opaque text relies massively on context, the process does not necessarily require attention resources. Hebrew readers hardly notice ht-homographic words and are unaware that they have resolved their ambiguity. Homography overloads the reading process when contexts are less supportive (as in the current experimental sentences) or misleading (e.g., garden-path sentences). These cases, which are not common but also not very rare, explain why acquiring full mastery of Hebrew reading is a long journey that continues well into the high school years and even into adulthood.

The current study can serve as a foundation for further studies. First, the accuracy results were based on a "low-tech" method: reading aloud a list of sentences written on paper. Examining reading time in a silent reading condition, in line with natural text reading, can reinforce the current findings and add information on reading efficiency. This can be done using methods such as self-paced reading or eye-tracking.

Second, the current study examined students who had exhibited typical reading and language development. Future studies can investigate the effect of the two contexts on reading among populations with disorders or disabilities in the fields of literacy and learning, such as reading, language, and attention, as well as students from low socio-economic backgrounds or with hearing impairments. Further, studies can explore the contribution of executive functions, such as working memory, inhibition, or shifting abilities, to reading in both contexts. The study also carries clinical and educational implications; the sentence lists could be used as a diagnostic tool and provide clinicians with in-depth information on reading abilities. Regarding instruction, the context of a word is mainly perceived as relating to the semantic and/or pragmatic content enveloping it. The present study underscores the importance of syntactic context in reading the Hebrew text, and suggests that it should be emphasized in promoting reading among students with reading disabilities.

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