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Auditory Morphological Knowledge Among Children With Developmental Dyslexia

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ABSTRACT

The aim of the present study is to examine the morphological knowledge of readers with developmental dyslexia compared to chronological age and reading-level matched controls. The study also analyzes the errors dyslexics make and their metamorphological awareness compared to controls. Participants included 31 seventh-grade dyslexic children and two matched control groups of normal readers: 34 seventh graders matched for chronological age and 32 third graders matched for reading age. Two tasks were administered via the auditory modality—morphological priming and morphological analogies task. We also performed error analysis and a metamorphological interview. Our analyses reveal that although dyslexics perform equally to chronological age matched controls on the priming task and similarly to reading-level matched controls on the morphological analogies task, their errors and metamorphological awareness are qualitatively different.

Developmental dyslexia is characterized by nonfluent word identification and poor spelling performance that are not the result of sensory impairments, impairments in intelligence, or inadequate educational experience (American Psychiatric Association, 2013; Pennington, 2009). So far, little attention has been devoted to the study of morphological knowledge in individuals with dyslexia, an area in which a growing body of data indicates that they score lower than skilled readers (Robertson, Joanisse, Desroches, & Terry, 2013; Schiff & Raveh, 2007; Schiff & Ravid, 2007; 2013). In this study, the term morphological knowledge (Bowers, Kirby, & Deacon, 2010) encompasses three constructs: morphological processing, morphological awareness, and metamorphological awareness. Although morphological processing refers to less conscious processing of morphological information (e.g., Deacon, Parrila, & Kirby, 2008), morphological awareness is defined as “awareness of morphemic structures of words and the ability to reflect on and manipulate that structure” (Carlisle, 1995, p. 194). By metamorphological awareness we mean a higher degree of analyzed morphological knowledge and a high level of processing control, which manifests itself as an intentional focus on word forms.

In this study we examined the morphological knowledge of children with dyslexia using the auditory modality. Using a within-participant design, we tested children dyslexic readers and chronological age matched and reading-level matched controls (respectively) on auditory morphological tasks of two kinds—a morphological priming task and an analogy completion task. Participants’ responses were analyzed for accuracy and response time, as well as for error types. In addition, qualitative data from a follow-up metamorphological interview was analyzed to pinpoint processing differences between the dyslexia and controls.

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Morphological processing in dyslexia and the priming paradigm

Studies on normal adult readers indicate that morphological processing may be influenced by orthographic and phonological factors (Feldman, Rueckl, DiLiberto, Pastizzo, & Vellutino, 2002; Rueckl, Mikolinski, Raveh, Miner, & Mars, 1997). These findings are theoretically and methodologically relevant for investigating the quality of morphological processes in individuals with dyslexia. One method that has been especially useful for investigating the effect of morphological structure on automatic word recognition is the priming paradigm, where the presentation of a morphologically related word (e.g., scanner) facilitates the identification speed and accuracy of the target word (e.g., scan). This facilitation is considered evidence for readers’ sensitivity to morphological structure during visual word recognition (Beyersmann, Iakimova, Ziegler, & Colé, 2014; Quémart, Casalis, & Colé, 2011).

A few studies have examined morphological processing in students with dyslexia using the priming paradigm. In Schiff and Raveh (2007), university undergraduates diagnosed with dyslexia were tested on two visual morphological priming tasks to examine whether well-compensated dyslexic adults represent and analyze the morphological structure of the words they read in the same manner as skilled readers. Evidence from these studies reveals that in contrast to students with normal reading ability, none of the students with dyslexia showed morphological priming. Working on the assumption that morphological priming reflects the psychological reality of the root morpheme and its role in lexical access, the lack of morphological priming in students with dyslexia suggests that their lexical access does not involve morphological decomposition.

Raveh and Schiff (2008) continued this research path by examining whether morphological priming among dyslexic adults may be related to modality-specific processes, testing dyslexic adult participants via the auditory modality, compared with a group of chronological age matched controls and a group of reading-level matched controls. The priming conditions (repetition, morphological, control [phonological]) were manipulated within participants and the group as between-participants. Findings show that, in contrast to visual priming, both repetition and morphological priming effects were at magnitudes comparable to those of the chronological age matched and reading-level matched controls. The strong morphological priming suggests that when the words are presented via the auditory modality, students with dyslexia are able to extract and activate the roots of the prime and the target words.

The abovementioned studies demonstrate that the dyslexic children have deficient morphological processing compared to normal readers. They are insensitive to the internal structure of words and have difficulty breaking words up into morphological segments. However, a study on French children with dyslexia (Quémart & Casalis, 2015) demonstrate that these children utilize the presence of a morphologically related prime when processing a target word and that this processing contrasts with priming based on form or meaning overlap alone. In other words, despite their difficulties in decoding, they are able process morphemic units.

The aim of the study presented here was thus to examine morphological processing in dyslexic children and to extend the investigation to clarify the locus of the failure in morphological processing in children. The main question addressed here was whether the absence of visual morphological decomposition might reflect a modality-based impairment, as shown previously regarding dyslexic adults.

Morphological awareness in dyslexia

Morphological awareness is defined as the capacity to reflect on and explicitly manipulate the smallest meaningful units or morphemes in a word (Carlisle, 1995). It contributes to decoding, word recognition, and reading comprehension (Deacon & Kirby, 2004; Nagy, Berninger, & Abbott, 2006; Schiff, Schwartz-Nahshon, & Nagar, 2011). However, recent models of reading comprehension suggest a two-way association between children’s morphological awareness, reading comprehension (Kieffer, Deacon, & Laroche, 2014; Perfetti, Landi, & Oakhill, 2005), and accuracy (Deacon, Benere,
Because morphological awareness plays a pivotal role in reading acquisition (Roman, Kirby, Parrila, Wade-Woolley, & Deacon, 2009; Wolter, Wood, & D’zatko, 2009), it is important to gain knowledge about it in dyslexic populations. The goal of the present study is to evaluate morphological awareness of dyslexic children compared to chronological age matched controls and reading-level matched controls with the objective of determining the quantitative and qualitative differences between these populations.

Given the bidirectional association between morphological awareness and reading ability (Deacon et al., 2013), studies have compared dyslexic children’s performance on morphological awareness tasks with both chronological age matched and reading-level matched controls. These studies reveal that dyslexic children and adults perform less well than chronological age matched controls, and equally well or better than reading-level matched controls, on morphological awareness tasks (Leong, 1999; Tractenberg, 2002). These results are seen across different modalities and languages, for example, in French (Casalis, Colé, & Sopo, 2004; Martin, Frauenfelder, & Colé, 2013), English (Tsesmeli & Seymour, 2006), and Hebrew (Schiff et al., 2011). Dyslexics’ performance on morphological awareness tasks depends on the type of task employed. Although dyslexics are behind reading-level matched controls in morphemic segmentation, both groups perform similarly on sentence completion (Bowers et al., 2010). Studies utilizing production morphological awareness tasks have indicated that dyslexics outperform reading-level matched controls, suggesting that less able readers may use morphological awareness as a compensatory strategy that scaffolds more effective use of phonological knowledge. For example, Traficante, Marcolini, Luci, Zoccolotti, and Burani (2011) showed that children with dyslexia benefit from the presence of morphemes when reading aloud Italian complex words and pseudowords (see also Burani, Marcolini, De Luca, & Zoccolotti, 2008). Therefore, making students more aware of the connection between morphemic units in words and orthographic, semantic, phonological, and grammatical features may activate the binding quality offered by morphology (Casalis et al., 2004; Perfetti, 2007).

Taken together, dyslexic children have been shown to develop morphological awareness to a lower level than that of chronological age matched controls, corresponding at least to their reading level. However, the nature of morphological awareness in dyslexic children was seldom assessed and characterized. Thus, the question of whether their word decomposition is qualitatively deviant compared to reading-level matched controls is still unanswered and should be addressed using a carefully designed methodology.

**Hebrew morphology**

Morphology is one of the building blocks of the mental lexicon (Aitchinson, 2003; Marslen-Wilson, 1999). It is particularly significant in Hebrew, a highly synthetic Semitic language, where word structure reflects a wide range of semantic notions (Bolozy, 1999; Deutsch & Frost, 2002; Ravid, 1990). Unlike words in English, the basic morphemes that make up Hebrew words are not sequentially ordered (Berent & Shimron, 1997, 2002; Ravid, 2005). Rather, these two entities, the root and pattern, constitute two interdigitated morphemes that together create the basic Hebrew word (Berman, 1987; Ravid & Schiff, 2006b; Schiff & Ravid, 2004).

In speech, the Semitic root is a discontinuous morpheme, usually consisting of three to four consonants (e.g., g-d-l ‘grow’). The spoken root is not a pronounceable or semantically independent entity, but it carries a core meaning that serves to connect all words in the same morphological family (Ravid & Bar-On, 2005). Written roots appear as continuous strings at the core of the Hebrew word, separated only by the letters W and Y, whereas written patterns are represented at most as prefixes and/or suffixes on words (Bar-On & Ravid, 2011; Ravid, 2012). Due to its cardinal function in Semitic word structure, root perception is an inherent device of Semitic lexical and morphological knowledge (Ravid, 2003), even in disadvantaged populations (Ravid & Schiff, 2006a). A large body of research indicates that the root has a central role in the organization of the lexicon in Semitic languages (Boudelaa & Marslen-Wilson, 2005). Given that the root is bound and
discontinuous in nature, it must combine with the pattern. Spoken patterns, like roots, are not pronounceable units; rather, they are prosodic templates into which root consonants are applied to specified slots and which may be preceded and/or followed by consonantal affixes. Pattern semantics is inherently distinctive from that of roots—it is categorical rather than lexical, as patterns classify verbs, nouns, and adjectives into categories comparable to English derivational suffixes such as -ize, -ic, -ity (Ravid, 2006). The current study aims to evaluate the ability of Hebrew-speaking children to analyze words into their root and pattern components in two auditory tasks: a priming task, reflecting unconscious word processing, and an analogy completion task, measuring morphological awareness.

The current study

The literature portrays morphological knowledge in dyslexic readers as both intact and deficient, depending on the measurement (Deacon et al., 2008). Some studies employ priming tasks reflecting unconscious, automatic online word recognition performance (Raveh & Schiff, 2008; Schiff & Raveh, 2007). Other studies utilize explicit tasks to investigate morphological awareness, identification, and analysis of words into their components (e.g., Martin et al., 2013; Schiff et al., 2011). In the current study, we used both types of tasks to examine the morphological knowledge of children with developmental dyslexia. In addition, because individuals with dyslexia present deficient visual word identification, in this study we examined the morphological knowledge of children with developmental dyslexia using the auditory modality.

The current study had two goals: first, to assess the performance of dyslexic adolescents on auditory priming and analogy completion Hebrew morphological tasks; and second, to find out whether the performance of adolescent dyslexic students is qualitatively different from that of chronological age matched controls and reading-level matched controls. Because deficits in verbal working memory have been linked to dyslexic children (see Swanson, 2012, for a comprehensive meta-analysis), we considered the variable of working memory in the analysis by making sure that it would not have an effect on the participants' scoring on the morphological tasks. Little is known about morphological knowledge in dyslexia beyond accuracy and speed of performance. Therefore, the present study not only examines priming and morphological awareness of readers with dyslexia but also compares their errors and metamorphological awareness to those of normal readers. To the best of our knowledge, this is the only study to date that examines different aspects of morphological knowledge within the same participants in Hebrew, a language with a morphology differing greatly from that of English due to the centrality of root in the organization of the lexicon (Ravid, 2012).

Methodology

Participants

Participants were 97 Hebrew-speaking children divided as follows. The experimental group consisted of 31 seventh graders (18 boys, 13 girls) with dyslexia (age $M = 12.9$, $SD = 0.33$). The first control group consisted of 34 (18 boys, 16 girls) chronological age matched typically developing seventh graders (age $M = 12.10$, $SD = 0.35$), and the second control group included 32 (15 boys, 17 girls) reading-level matched typically developing fourth graders (age $M = 10.0$, $SD = 4.86$).

Participants with dyslexia were selected and recruited from seven schools in the greater Tel Aviv area. All had been diagnosed with dyslexia by a certified learning disability diagnostician and had records documenting reading problems. Participants' last diagnoses had been performed within 1 year prior to or while attending junior high school. To make sure that these participants were still struggling with a reading disability, the researchers first screened all the diagnostic files.
Diagnoses showed that all the students’ IQ scores were within the normal range ($M = 103$, $SD = 15$). Neither of the children had any hearing impairment, attention deficit disorder, or a history of neurological or emotional disorder, as reported by the teacher, the school counsellor, and the family.

The control group of students with no dyslexia was randomly selected from the same schools. All parents agreed to children’s participation in the study by signing consent forms, and all methods and procedures were approved by the Institutional Review Board of Bar-Ilan University and the Israeli Ministry of Education.

To verify the group division, accuracy and speed word-reading tasks (Schiff, Raveh, & Kahta, 2008) were administered (Table 1). The word reading accuracy test required children to read aloud a list containing 112 vowelized words. Scores ranged from 0 to 112, reflecting the number of correct answers given, with higher scores indicating higher reading accuracy. In the word reading speed test, children read aloud as many words as possible in 45 s from a list containing 104 words (Schiff et al., 2008). The word list used in the speed test differed from the words used in the accuracy test. Scores ranged from 0 to 104, reflecting the number of accurate words the participant read in 45 s, with higher scores indicating higher reading speed. Words in both tests increased in difficulty in the number of syllables, phonological structure, length, frequency, and morphological complexity, providing a range of difficulty appropriate for all three groups. The words in each list included all the vowels and consonants of Hebrew.

Four children were not included in the reading-level matched controls because the number of words they read correctly was below their group’s 15th percentile. Reading fluency and accuracy differed as a function of group, $F(2, 94) = 89.91, p = .001; F(2, 94) = 40.08, p = .03$, respectively. Planned comparisons (Bonferroni) demonstrated that, on average, participants with dyslexia read fewer words correctly within the time limit and made more errors than the chronological aged matched control group but matched the reading-level matched control group in reading fluency and accuracy. In addition, all participants took vocabulary and digit span tests (Raven, Raven, & Court, 1993; WISC–R). Although the scores of the vocabulary test were similar for all groups, $F(2, 94) = 2.43, p = .001; F(2, 94) = 2.91, p > .06$, with respect to the digit span tests, measurements revealed that participants with dyslexia scored significantly lower compared to controls, $F(2, 94) = 26, p = .001$ (see Table 1).

**General procedure**

Administration of all tasks took place in a quiet room at the school during the school day. Each student participated in three individual test sessions. The first session consisted of the diagnostic tests, and the second and third sessions included the priming, analogies, and metamorphological interview tasks. To neutralize possible effects of learning and transfer of knowledge, the data collection tools were administered in random order.

| Table 1. Mean scores and standard deviations of diagnostic tests by group. |
|------------------|------------------|------------------|
|                   | Dyslexia          | CA              | RA              |
| Fluency           | 46.77 (15.74)     | 71.56 (10.91)   | 52.69 (7.09)    |
| Accuracy          | 58.42 (16.63)     | 94.12 (5.31)    | 65.09 (11.45)   |
| Raven             | 103.03 (6.13)     | 104.23 (5.47)   | 105.06 (4.37)   |
| Vocabulary        | 10.25 (1.61)      | 10.82 (1.29)    | 10.73 (1.10)    |
| Memory            | 8.7 (1.88)        | 10.94 (1.51)    | 11.25 (2.145)   |

Note. CA = chronological age matched controls; RA = reading age matched controls.
Design and materials

Task 1: the priming lexical judgment task

Participants listened to a stimulus word followed by a target word for which they had to determine whether the word existed in Hebrew.

Stimuli

To generate the stimuli for this task, a list of 70 frequently used roots in Hebrew was derived from the Sapir Hebrew dictionary (2013). For each root, a target word was selected. Target words were nouns, adjectives, and present-tense verbs. Target words were paired with sets of three primes each to create the three priming conditions: a word identical to the target for the repetition priming condition; a word derived from the same root as the target for the morphological priming condition; and a word phonologically, but not morphologically, related to the target, for the baseline condition (Table 2). The baseline primes had the same mean number of phonemes as the morphologically related primes (M = 5.6, SD = 0.6). The morphologically related primes and the phonologic baseline primes also shared the same number of phonemes with the target (M = 5.8, SD = 0.8; M = 5.7, SD = 0.7 respectively). Each target was paired with each of its three primes. The initial list included 210 words.

In the absence of frequency vocabulary lists for children in Hebrew, word lists were inspected by three language experts for the nature of morphological relationship between the stimuli and target words on a scale from 1 (no relationship) to 5 (strong relationship). Twelve stimuli words that, on average, rated as weakly (mean lower than 3) morphologically connected to the target words were subsequently removed from the list. In addition, a frequency judgment questionnaire including a scale from 1 (infrequent) to 5 (very frequent) was administered to 30 grade-school teachers. Five words with medium frequency (2.8–3.5) were removed from the list. Furthermore, 25 seventh graders and 25 third graders who did not participate in the study indicated the nature of morphological relationship between the stimuli and target words on a 1-to-5 scale. This removed 10 more words from the list. Children also completed a familiarity questionnaire, in which they were instructed to rate the level of familiarity they had with the word on a scale from 1 (I have never seen the word and I don’t know it) to 5 (I have seen the word many times and I know it well). Three stimuli words with a low familiarity score (lower than 2) were removed from the list.

The final word list included 180 words—60 target words, 60 stimuli morphologically related to the target words, and 60 stimulus words bearing a phonological but not a morphological relationship to the target words. Three types of relationships held between the stimulus and target words: (a) Repetitions—the stimulus word was identical to the target word (e.g., metukan ‘fixed’; metukan ‘fixed’), (b) Morphological—the stimulus word and the target word shared the same root (e.g., tikun ‘fixing’; metukan ‘fixed’), and (c) Phonological—the stimulus and target word shared three phonemes, which together made up a different root than in the target word (e.g., hamtaka ‘sweetening’; metukan ‘fixed’). An English equivalent example for the target word scanning would thus be scanning–scanner–scandal for the repetition, morphological, and phonological primes, respectively.

Table 2. An example of a stimulus set for the priming task (Task 1).

<table>
<thead>
<tr>
<th>Prime</th>
<th>Control (Phonological)</th>
<th>Priming condition</th>
<th>Repetition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>hamtaka</td>
<td>tikun</td>
<td>metukan</td>
</tr>
<tr>
<td>Gloss</td>
<td>sweetening</td>
<td>repair</td>
<td>repaired</td>
</tr>
<tr>
<td>Target</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Structure</td>
<td>metukan</td>
<td>tikun</td>
<td>metukan</td>
</tr>
<tr>
<td>Gloss</td>
<td>repaired</td>
<td>repair</td>
<td>repaired</td>
</tr>
</tbody>
</table>

Note. Root letters appear in bold.
All stimulus words were meaningful words. Half of the target words were meaningful words, and the rest were pseudowords with a primary function to distract participants from producing a “yes” response to all target words. The latter were excluded from the analysis.

**Procedure**

Participants listened to the words via headphones connected to a computer and had to indicate their judgment by clicking the “m” key (a sticker with the word “yes” in Hebrew) or the “c” key (a sticker with the word “no” in Hebrew), respectively. Following the instructions, participants practiced the test with 12 word pairs—six real words and six pseudowords. Verifying that the task was clear, the researcher started the experiment. Participants were instructed to respond as quickly and accurately as possible. In case of the absence of a response to a trial, there was a time cutoff of 3 s and the software moved to the next target word. The trial was coded as an error. In addition, because the words were presented via the auditory modality, the prime duration depended on the length of the word. However, the number of phonemes was supervised so that, on average, the length of the words was similar in all three conditions. SOA was 500 ms.

**Task 2: the morphological analogies task**

This task required the participant to complete the missing word in a word pair analogy following a stimulus analogy. This task was based on the derivational morphology task first used in Schiff and Ravid (2007), composed of 52 analogy sets, each consisting of a horizontal structure with two double pairs of morphologically related words, where the right-most member, the target noun, was missing. The target noun was related to the first word in the pair by root and to the second word in the first pair by pattern. To solve the analogy, the participants had to analyze the morphological root-and-pattern structure of each of the double pairs constituting the three-sided analogy structure. Then they had to detect the root relation between members of the top horizontal pair and infer a similar relation between the target noun and the left member of the bottom horizontal pair, based on its root. Next, the participant had to detect the pattern relation between members of the left vertical pair and infer a similar relation between the target noun and the top member of the right vertical pair, having analyzed its pattern. This resulted in selecting the correct response with correct root and pattern.

**Stimuli**

Material selection (with respect to the assessment of frequency and familiarity of words) was similar to Task 1. The initial list including 80 nouns was reduced to 52 target nouns arranged as 26 analogy sets recorded and normalized using the CDex software.

**Procedure**

The task was administered using the auditory modality. Participants were first instructed to listen to a pair of related Hebrew words. They were then asked to listen to a third word and complete the set with a fourth word. They were told to say the word out loud and as quickly and accurately as possible. Participants were instructed to say the word *avor* “next” when they could not complete the analogy. Only after completing the three-item training session, verifying that the task was clear, did the experiment start. Participants were instructed to respond as quickly and accurately as possible. In case of the absence of a response to a trial, there was a time cutoff of 3 s, and the software moved to the next analogy set. The trial was coded as an error.

**Data treatment**

Participants’ responses were recorded by the researcher, and reaction time was measured using the SuperLab software. Participants’ errors were also analyzed as follows: Pattern error—correct root elicitation, incorrect application of root to pattern (e.g., *tasrit* ‘script’ for *masreta* ‘screening machine’); Root error—incorrect root elicitation, correct/incorrect application of root to pattern (e.g., *magrefa* ‘rake’ for *masreta* ‘screening machine’); Semantic error—completing the analogy with
a semantically, nonmorphologically associated word (e.g., *kolnóa* ‘cinema’ for *masreta* ‘screening machine’); and I don’t know.

**Task 3: metamorphological interview**

This task utilized four linguistic analogies that had not been used in the priming knowledge task. They were presented orally, with the participant instructed to say the word that completed the set. Having solved the analogy, participants were asked the following open-ended question pertaining to the cognitive process underlying the suggested completion: “How did you come up with the missing word?” (Sénéchal, Basque, & Leclaire, 2006). The aim of the task was to examine participants’ awareness of the morphological relationships and processes that had led them to produce the missing word.

A qualitative analysis of responses to this task yielded the following categories. (a) Root and pattern responses, reflecting an awareness of both components of the task (e.g., “I applied the root to the word pattern”); (b) Root-only responses—attesting to consciousness of the root radicals, with no reference to the pattern (e.g., “I used the root letters T-Q-P”); (c) Pattern-only responses—indicating awareness of the word pattern or its meaning, without consideration to the root consonants (e.g, “I did it according to the prefix and suffix of the word”); (d) Irrelevant responses (e.g., “the word popped up in my head”); and (e) Don’t know responses.

**Results**

**Task 1: the priming lexical judgment task**

Analyses were conducted on response times only as levels of correct responses manifested a ceiling effect. Incorrect responses and responses that were more than 2.5 standard deviations above or below the mean were not analyzed. The mean lexical response times for the different conditions by group are presented in Figure 1.

Two-way analyses of variance (ANOVAs) for repeated measures were conducted on response times with priming conditions (repetition, morphological, control [phonological]) as within-subjects effect and group (dyslexia, chronological age, reading age) with both participants (F1) and items (F2) analyses. This revealed a significant condition effect, $F1(2, 188) = 67.37, p = .000, \eta^2_p = .42$; $F2(2, 58) = 63.33, p = .000, \eta^2_p = .40$. Bonferroni tests

![Figure 1](Note. Condition for the dyslexia, chronological age matched controls and reading-level matched controls (Task 1). The error bars represent standard error. CA = correct answers; RA = reading accuracy.)
indicated that performance was faster for the repetition condition \((M = 666 \text{ ms}, \ SD = 328)\) than for the morphological condition \((M = 749 \text{ ms}, \ SD = 378; \ p < .05 \text{ here and throughout})\), which in turn was faster than for the control [phonological] condition \((M = 954 \text{ ms}, \ SD = 470)\). In addition, there was a significant group effect, \(F_1(2, 94) = 7.36, \ p = .001, \ \eta^2_p = .14; \ F_2(2, 58) = 5.64, \ p < .001, \ \eta^2_p = .32\). Bonferroni tests indicated that the group with dyslexia \((M = 818 \text{ ms}, \ SD = 473)\) did not differ from both the chronological age matched \((M = 619 \text{ ms}, \ SD = 188)\) and reading-level matched \((M = 943 \text{ ms}, \ SD = 331)\) groups. However, the reading-level matched group was slower than the chronological age matched group. The Priming Condition \(\times\) Group interaction was not found significant, \(F_1(4, 186) = 1.44, \ p > .05; \ F_2(4, 116) = 1.51, \ p = .12\).

**Task 2: the morphological analogies task**

Because working memory was found to be significantly associated with both response times \((r = -0.26, \ p = .012)\) and accuracy \((r = 0.47, \ p = .000)\), it was entered as covariate in all the subsequent analyses.

**Reaction time**

Incorrect responses and responses that were more than 2.5 standard deviations above or below the mean were not analyzed. The mean lexical response times and standard deviations by group are presented in Table 3.

A one-way analysis of covariance conducted on response times by group (dyslexia, chronological age, reading level) with working memory as covariate revealed a significant group effect, \(F(2, 93) = 3.15, \ p = .048, \ \eta^2 = .07\). Bonferroni’s tests indicated that response times was similar for the group with dyslexia and the reading-level matched group, with both being slower than the chronological age matched group.

**Accuracy**

A one-way analysis of covariance conducted on number of correct responses by group (dyslexia, chronological level, reading level) with working memory as covariate revealed a significant group effect, \(F(2, 93) = 30.96, \ p = .000, \ \eta^2 = .40\). Bonferroni’s tests indicated that accuracy was similar for the group with dyslexia and the reading-level matched group, with both being less accurate than the chronological age matched group \((p < .05)\). The mean correct responses by group are presented in Table 4.

### Table 3. Mean lexical response times and standard deviations by group (Task 2: morphological analogies task).

<table>
<thead>
<tr>
<th></th>
<th>RA</th>
<th>CA</th>
<th>DYS</th>
</tr>
</thead>
<tbody>
<tr>
<td>(M)</td>
<td>1,700</td>
<td>1,459</td>
<td>1,856</td>
</tr>
<tr>
<td>(SD)</td>
<td>733</td>
<td>323</td>
<td>519</td>
</tr>
<tr>
<td>(M) estimated</td>
<td>1,729</td>
<td>1,542</td>
<td>1,712</td>
</tr>
</tbody>
</table>

*Note. RA = reading age matched controls; CA = chronological age matched controls; DYS = dyslexia.*

### Table 4. Mean correct responses and standard deviations by group (Task 2—accuracy).

<table>
<thead>
<tr>
<th></th>
<th>RA</th>
<th>CA</th>
<th>DYS</th>
</tr>
</thead>
<tbody>
<tr>
<td>(M)</td>
<td>17.11</td>
<td>22.47</td>
<td>12.64</td>
</tr>
<tr>
<td>(SD)</td>
<td>6.7</td>
<td>3.14</td>
<td>6.59</td>
</tr>
<tr>
<td>(M) estimated</td>
<td>13.62</td>
<td>22.09</td>
<td>15.25</td>
</tr>
</tbody>
</table>

*Note. RA = reading age matched controls; CA = chronological age matched controls; DYS = dyslexia.*
Table 5. Mean number of different type of errors and standard deviations by group in percentages (Task 2—morphological analogies task).

<table>
<thead>
<tr>
<th>Type</th>
<th>M</th>
<th>SD</th>
<th>RA</th>
<th>CA</th>
<th>DYS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Root</td>
<td>0.05</td>
<td>6.68</td>
<td>4.48</td>
<td>7.89</td>
<td>4.10</td>
</tr>
<tr>
<td>Pattern</td>
<td>0.13</td>
<td>15.54</td>
<td>68.53</td>
<td>61.59</td>
<td>67.61</td>
</tr>
<tr>
<td>Semantic</td>
<td>0.18</td>
<td>0.00</td>
<td>0.00</td>
<td>4.49</td>
<td>3.13</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Don’t know</th>
<th>M</th>
<th>SD</th>
<th>RA</th>
<th>CA</th>
<th>DYS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Root</td>
<td>0.02</td>
<td>25.73</td>
<td>29.09</td>
<td>25.16</td>
<td></td>
</tr>
<tr>
<td>Pattern</td>
<td>1.22</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Semantic</td>
<td><strong>5.86</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. RA = reading age matched controls; CA = chronological age matched controls; DYS = dyslexia. **p < .01.

Error analysis

Table 5 shows the distribution of error types out of all erroneous responses by grade. Because the distribution of erroneous responses was not normal, with large standard deviations, we conducted a nonparametric test (the Kruskal-Wallis one-way ANOVA ranks), which revealed the same results as the following ANOVAs. Table 5 indicates that the most frequent error was pattern error. Separate one-way ANOVAs conducted on each type of error revealed the group effect was significant only for semantic errors, $F(2, 94) = 5.86, p = .000, \eta^2 = 0.13$. Bonferroni’s tests indicated that only the group with dyslexia made semantic errors. Multiple comparisons (with Bonferroni’s adjustment of significance level) indicated the difference between the positive results of the group with dyslexia and the null ones for the chronological age and the reading-level groups is significant.

Task 3: metamorphological interview

The distributions of different types of response by group, pooled over the four analogies, are presented in Table 6. A chi-square analysis was found significant, $\chi^2(8, N = 388) = 121.12, p < .001$, indicating a dependency between group and response type. Separate analyses conducted for each analogy revealed that the dependency between response type and group is significant for each analogy ($ps < .001$). To further investigate the pattern of group differences in response types, chi-square for goodness-of-fit analyses were conducted for each type of response. The analyses revealed that group differences are significant for responses “root plus pattern,” “pattern only,” “irrelevant,” and “don’t know” ($ps < .001$). There was no difference in group distribution for the “root only” response ($p = .12$). Inspection of group distributions indicates that the age-matched controls provided more “root and pattern” responses than the group with dyslexia and the reading-matched group, which provided almost no “root plus pattern” responses. In addition, the age-matched control group gave more “pattern only” responses than the reading-matched controls, which in turn provided more “pattern only” responses than the dyslexics. The patterns of “irrelevant” and “don’t know” responses is similar: The group with dyslexia and the reading group gave more of these responses compared to the age-matched control group, which gave almost no “irrelevant” and “don’t know” responses.

Table 6. Distributions (and % within response type) of type of response by group for Task 3—metamorphological interview.

<table>
<thead>
<tr>
<th>Group</th>
<th>Don’t know</th>
<th>Irrelevant</th>
<th>Pattern only</th>
<th>Root only</th>
<th>Root plus pattern</th>
</tr>
</thead>
<tbody>
<tr>
<td>DYSys</td>
<td>45 (53%)</td>
<td>29 (63%)</td>
<td>24 (15%)</td>
<td>24 (39%)</td>
<td>2 (7%)</td>
</tr>
<tr>
<td>CA</td>
<td>33 (39%)</td>
<td>10 (22%)</td>
<td>59 (35%)</td>
<td>25 (40%)</td>
<td>1 (3%)</td>
</tr>
<tr>
<td>RA</td>
<td>7 (8%)</td>
<td>7 (15%)</td>
<td>83 (50%)</td>
<td>13 (21%)</td>
<td>26 (90%)</td>
</tr>
</tbody>
</table>

Note. DYS = dyslexia; CA = chronological age matched controls; RA = reading age matched controls.
Discussion

The goal of the current study was to examine the morphological knowledge of dyslexic children compared to chronological age matched and reading-level matched controls in a within-participant design. We tested children on different morphological tasks with the objective of characterizing the quantitative and qualitative differences between these populations. A different pattern of findings emerges from the analysis of the priming and analogy completion data. Our findings show that dyslexic children performed similarly to the chronological age matched control group and the reading-level matched control group on the priming morphological task, but they performed less well than chronological age matched controls and equally to well to reading-level matched control group on the analogy completion task. Further, qualitative analyses revealed that the latter groups differed on error types and metamorphological awareness. Recall that all tasks utilized the auditory modality, confirming that children with reading deficits also show morphological weaknesses on oral language measures (Catts, Adlof, & Ellis Weismer, 2006).

Previous research examining visual morphological processing in dyslexic adults and children presents conflicting results (Deacon et al., 2008; Martin et al., 2013; Raveh & Schiff, 2008; Schiff & Raveh, 2007; Schiff et al., 2011). Although studies on Hebrew and English indicate that dyslexic individuals do not exhibit priming effect (Raveh & Schiff, 2008; Schiff & Raveh, 2007), a study on French provides evidence that dyslexic children utilize the presence of a morphologically related prime when processing a target word (Quémart & Casalis, 2015). These contradicting findings highlight the importance of the language at stake. Perhaps the results observed in French, yet in other languages, more precisely in Hebrew and English, may be attributed to the methodological differences between studies with respect to the data collection tools used and the comparison groups selected (Quémart & Casalis, 2015). Future research would do well examining priming effect for dyslexic children in other languages using the same paradigm and procedure.

In contrast to previous studies examining visual morphological processing in dyslexic adults and children, the current study focused on auditory processing in children alone, and in doing so revealed new information about age groups that have not been previously tested. The results of this priming experiment demonstrate that there were no differences between the dyslexic group and the two control groups on response time on the morphological priming condition. This suggests that dyslexic children have a priming effect in auditory tasks; and although this finding has been noted in the literature for dyslexic adults in long-term priming tasks (Raveh & Schiff, 2008), it is now evident for a short-term priming task for dyslexic children. These findings are in line with evidence from previous research regarding older participants, showing that dyslexic school-going participants were not impaired in oral morphological processing compared to reading-level matched controls (Bryant, Nunes, & Bindman, 1998; Egan & Tainturier, 2011; Elbro, 1989).

Furthermore, using an analogies completion task, we tested the morphological awareness of dyslexic children compared to chronological age matched and reading-level matched control groups. In line with the literature (Casalis et al., 2004; Leong, 1999; Tractenberg, 2002; Tsesmeli & Seymour, 2006) on morphological awareness among dyslexics, results of the current study indicate that dyslexics function lower than chronological age matched controls and similarly to reading-level matched controls on a task that requires morphological awareness. The finding that dyslexic children perform less well compared to chronological age-matched controls on the analogy task supports the hypothesis that language problems in dyslexia extend beyond the domain of visual word recognition and phonology. The finding that they function similarly to reading-level matched controls on the analogy task strengthens the bidirectional relationship between morphological awareness and reading. On one hand, children’s knowledge of grapheme-phoneme correspondences and their phonological awareness promotes their reading development. On the other hand, children might learn about the morphological composition of words through their reading experience (Deacon et al., 2013; Kuo & Anderson, 2006). The current findings suggest that dyslexic children’s morphological
awareness is associated with reading abilities (e.g., Nagy et al., 2006; Wolter et al., 2009). That is, although the words were presented orally, for decomposition to take place, dyslexic children need orthographic representations—especially in Hebrew, a language where phonology, morphology, and orthography are closely related (Ravid, 2012).

However, the picture is somewhat different when we examine the performance of the different study groups on the morphological awareness task. By carrying out error analysis, we were able to assess whether dyslexics showed evidence of having impaired metamorphological awareness beyond what would be predicted by their more general word-decomposition. Although the group with dyslexia did not differ significantly from the reading-level matched control group on the morphological awareness measures of accuracy and response time, the main finding in this study was the apparent distinction between the types of errors that the different groups made. Findings suggest that in comparison to chronological age matched controls and reading-level matched controls, only the dyslexics made semantic, non-morphological errors. For example, on the same stimulus set, dyslexic participants produced non-morphological, semantically related responses like netina ‘giving’ or zedaka ‘charity’ instead of the morphologically related truma ‘donation’ (Schiff & Ravid, 2007).

The finding that chronological age-matched controls and reading level-matched controls made no semantic errors on the analogy completion task measuring morphological awareness indicates an early and robust perception of the Semitic root in Hebrew-speaking children (Ravid, 2003). The finding that only the dyslexics made semantic errors is explained by the fragile root and pattern perception and their later emergence in language development (Ravid & Kubi, 2003). Although consonantal roots carry the main lexical substance of the word, vocalic patterns contribute categorical meaning. These properties enhance the salience of the root and facilitate its identification even in the dyslexic adults. Patterns are not fully represented in the written Hebrew word, as they consist mostly of vowels with scant representation in the writing system, relying mostly on prefixes/suffixes written at the edges of the word (Bar-On & Ravid, 2011). Limited orthographic and phonological processing may account for the semantic errors within the dyslexic group. That is, being at a disadvantage in their phonological processing, instead of relying on morphemic segmentation, they rely more on semantic information (Casalis et al., 2004; Schiff & Ravid, 2007). A limitation of the study is that the evidence is primarily based on morphological processing in Hebrew, in which the consonants of the root are intertwined with the phonemes of the word pattern. Unlike base forms in English, roots and word patterns are sublexical structures because only their joint combination results in specific phonemic word forms with specific meanings. We think the results may be generalizable to other Semitic languages such as Arabic; however, due to the remarkable morphological difference between English and Hebrew, they might not be fully applicable to English or other Indo-European languages. In these languages, most the base forms not only function as morphemes in complex forms but also constitute free word forms in their own right (e.g., day—daily), and moreover morphological structure is mostly characterized by a sequential concatenation of morphemic units to form multimorphemic words. It is important to note that aside from root and pattern, the same morphological functions—the lexical core and affixal envelope of the word—are shared by other languages with morphologically complex words. That is, we can expect the lexical core—a word or a root—to have a much stronger representation than the categorical suffix.

The final and most interesting question was whether dyslexic readers displayed distinct metamorphological awareness compared to chronological age-matched controls and reading level-matched controls. Results of the metamorphological interview analysis suggest that dyslexics relied on different strategies for solving the analogies task than did the control groups. Compared to the chronological age-matched controls, who explicitly said, “I applied the root to the word pattern,” dyslexic readers and reading-level matched controls gave fewer root and pattern and pattern responses and more “don’t know” responses. They apparently ignored patterns, making no mention of them as aiding their performance in the follow-up interview. This finding suggests that dyslexic children often do not use morphological decomposition. In some cases, their morphological decomposition was partial (e.g., “I knew the word because of the vowel in the beginning”), indicating a
partial identification of the pattern. In addition, compared to reading-matched controls, dyslexics provided more irrelevant responses, for example, “It fits because it fits,” “I had an intuition,” or “The word popped up in my head.” It might be the case that in struggling to decode some of the task words, a dyslexic child may not have much capacity left for morphological decomposition. The results of the current study suggest a need for further research investigating dyslexic children’s metamorphological awareness while solving a morphological task. Using different measures of metamorphological awareness (other than follow-up interview) could paint a different picture of dyslexic children’s differing morphological knowledge.

In sum, recent studies have established that morphological knowledge is not absent in dyslexic readers. However, the nature of morphological knowledge dyslexic readers have is still to be determined. The present study was designed to characterize the morphological processing and morphological awareness of dyslexic children compared with and chronological-age matched and reading-level matched control groups. Our results show for the first time that dyslexic readers display a particular profile in their oral morphological knowledge. They may have similar morphological awareness as reading levels, but their errors and metamorphological awareness are qualitatively different. Gaining more insights into the idiosyncratic mechanism in which dyslexic readers process morphological input has important implications for more meaningful morphological instruction.

References

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