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An examination of the process of acquiring visual word representations in dyslexic children

Abstract

Skilled reading relies on the ability to access word representations, conceptualized as connections established between a word's orthography, phonology and meaning in memory. This study set out to explore the process of acquisition of these representations. The central hypothesis was that dyslexic readers would present difficulties in forming and maintaining word representations in memory, presumably due to instability in processes of decoding. Their performance was compared to the performance of age-matched and reading-level-matched typical readers (n = 20 per group).

The hypothesis was tested by repeatedly exposing the readers to the same target words embedded in word-lists and meaningful texts. The targets were words which the dyslexic participants had difficulty to read in a pre-test, while being part of their spoken vocabulary. The output of each encounter with a target word was analyzed.

The results indicate reduced accuracy rates of dyslexic readers compared to typical readers, despite the repeated exposures to the same targets. In addition, dyslexic readers showed larger variability in types of output and higher rates of inconsistency in producing the same output across encounters with the same target. The results therefore uphold the hypothesis of a deficiency of dyslexic readers in forming and retaining word representations in reading, and point to instability in processes of decoding orthography to phonology.

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Keywords

Developmental dyslexia; Word recognition; Decoding; Phonology; Orthography

Untersuchung des Aneignungsprozesses von visuellen Wortrepräsentationen bei Kindern mit Dyslexie

Zusammenfassung

Kompetentes Lesen stützt sich auf die Fähigkeit, auf Wortrepräsentationen, d. h. die im Gedächtnis hergestellten Verbindungen zwischen der Orthographie eines Wortes, seiner Phonologie und seiner Bedeutung, zugreifen zu können. Ziel der vorliegenden Studie ist es, den Aneignungsprozess dieser Repräsentationen zu untersuchen. Die zentrale Hypothese ist dabei, dass Kinder mit Dyslexie Probleme haben, diese Repräsentationen aufzubauen und im Gedächtnis zu speichern, wobei angenommen werden kann, dass dies auf Grund einer Instabilität während des Prozesses der Wortdekodierung erfolgt. Die Leseleistung von Kindern mit Dyslexie wurde dafür verglichen mit der Leistung von Leserinnen und Lesern gleichen Alters sowie mit Leserinnen und Lesern, die auf demselben Niveau lesen (n = 20 pro Gruppe). Getestet wurde die Hypothese, indem den Leserinnen und Leser mehrmals dieselben Zielwörter vorgelegt wurden, welche in Wortlisten und sinnvolle Texte eingebettet waren. Dabei handelte es sich um Worte, bei denen die Kinder mit Dyslexie in einem Pre-Test Leseschwierigkeiten hatten, die jedoch Teil ihres gesprochenen Vokabulars waren. Analysiert wurden die Ergebnisse der jeweiligen Konfrontationen mit einem Zielwort.

Die Befunde zeigen für Kinder mit Dyslexie auch bei einer wiederholten Auseinandersetzung mit denselben Zielworten geringere Genauigkeitsraten im Vergleich zu typischen Leserinnen und Lesern. Darüber hinaus ergeben sich bei den Kindern mit Dyslexie stärkere Schwankungen in der Art der Ergebnisse und mehr Inkonsistenzen, wenn es darum geht, dasselbe Ergebnis bei mehreren Konfrontationen mit demselben Zielwort wiederzugeben. Insofern stützen die Ergebnisse die Hypothese eines Defizits beim Aufbau und der Speicherung von Wortrepräsentationen während des Lesens bei Leserinnen und Leser mit Dyslexie und weisen auf eine Instabilität im Prozess des Dekodierens von Orthographie zu Phonologie hin.

Schlagworte

Entwicklungsbedingte Dyslexie; Worterkennung; Dekodierung; Phonologie; Orthographie

1. Introduction

Visual word recognition, the building block of skilled reading, remains a core and continuing difficulty for readers with developmental dyslexia (Compton & Carlisle,

1994; Fletcher, 2009; Lyon, Shaywitz, & Shaywitz, 2003). Dyslexic readers show inaccurate and/or dysfluent reading and often difficulties in spelling (Fletcher, 2009). Subsequent effects on the essence of reading, i.e. comprehension, frequently follow. Physiological investigations converge to indicate a neurobiological origin of dyslexia, involving mainly a dysfunction of processing systems of the left hemisphere (Shaywitz & Shaywitz, 2005).

The manner in which words are represented and accessed in the long-term memory has been a subject of debate between different models of word recognition (e.g., Coltheart, 1978, 2005; Frost, 1998; Harm & Seidenberg, 2004; Perfetti, Bell, & Delaney, 1988; Plaut, 2005; Seidenberg & McClelland, 1989). Nevertheless, what the models do have in common is the underlying assumption that with reading experience and print exposure an internal mental lexicon of words previously encountered in print is established. This lexicon was suggested to be created through the constitution and strengthening of connections between orthography, its pronunciation and its meaning in memory (Ehri, 2005; Perfetti, 1992; Rack, Hulme, Snowling, & Wightman, 1994). According to the Self-Teaching Hypothesis (Share, 1995), the acquisition of word-specific orthographic information depends not only on the exposure to printed words, but also on their correct decoding. When readers are confronted with an unknown printed word, they must pay close attention to the written structure of the word, by thoroughly transforming each grapheme into its appropriate sound. Each successful decoding of a new word provides the reader with the opportunity to acquire word-specific orthographic information (Share, 1999).

The reliance on previous word representations in reading facilitates word recognition in subsequent encounters, until they are automatically recognized (Ehri, 1992, 2005). In fact, skilled readers were found to be able to read familiar words as quickly as they named their symbols (e.g., digits). This was taken to indicate that the words were read “by sight” – as single whole units. According to connectionists’ models of word recognition, the activation of such representations promotes efficient reading by reducing demands of grapheme-phoneme conversion, allowing fewer steps of processing until a word is recognized (Ehri, 2005; Harm & Seidenberg, 2004; also see Katz & Frost, 1992). The fewer the cognitive resources dedicated to word recognition, the more resources are available for comprehension. Consequently, the reliance on internal representations is considered essential for achieving efficiency in reading (Cunningham, Perry, Stanovich, & Share, 2002; Ehri, 2005; Harm & Seidenberg, 2004; Share, 1999, 2004).

Deficient decoding, however, is strongly associated with dyslexia (Rack, Snowling, & Olson, 1992), hence representations of dyslexic readers in the mental lexicon may be lacking or vague (Elbro, 1996). And indeed, dyslexic readers were shown to have deficient orthographic learning compared to skilled readers following several exposures to a target pseudoword embedded in texts (Share & Shalev, 2004), in addition to difficulties with reading words “by sight” (Ehri & Saltmarsh, 1995; Ehri & Wilce, 1983). Findings by Bruck (1990) indicate that even dyslexic adults who were college students, still relied markedly on the use of spelling-sound

information, a strategy of reading associated with early stages of reading acquisition. In fact, their pattern of performance was most similar to those of beginning skilled readers and of dyslexic children. In contrast, typical readers were found to rely more on the fast visual recognition of familiar words or word-parts.

The central question tested in the present study was whether repeated exposures to the same words would result in the acquisition and retaining of their representations in the mental lexicon in dyslexic readers. To this end, dyslexic as well as typical readers, speakers of Hebrew, were visually presented with the same target words seven times within two tasks (reading of word-lists and meaningful texts). One problem in current research of word recognition is that it usually focuses on the end product, or the output, of the process. The present study, however, was designed to explore the *process* of generation of word-representations and their preservation in memory. A difficulty in relying on orthographic representation in reading may be a result of instable processes of reading, leading to varying word reading errors each time a specific word is encountered in print. Such variability may prevent the development of stable traces of words in memory. When traces are discrepant or vague, learning about the similarities and the distinguishing features of words is impeded. In this case, each time a word is read incorrectly, the distorted output fails to match any stored representation. Consequently, search and retrieval processes may differ considerably with each encounter with the same word. In order to test this assumption, the output of *each* encounter with a target word was analyzed.

To sum up, based on the reviewed literature, it was hypothesized that (a) dyslexic readers would present difficulties in creating and retaining word representations, despite repeated exposures to the same targets. They were expected to show high rates of mistakes in target identification and non-continuous pronunciation of the targets across encounters. Non-continuous pronunciation (with breaks) was taken as an indication that the word was not recognized “by sight” (Ehri, 2005). (b) If dyslexic readers have instable processes of reading, inconsistency in output would be expected across encounters with the same target. (c) The third hypothesis relates to the task presented: both typical and dyslexic readers were expected to benefit from the presentation of words in a meaningful text, compared to a word-list, as meaningful texts may provide the readers with semantic cues. At the same time, due to the deficiency of dyslexic readers in decoding, they may benefit more from context than typical readers.

2. Method

2.1 Participants

Sixty Hebrew speaking children, divided into three groups, participated in the study. One group comprised fourth graders with dyslexia (mean age = 9.7 years, $SD = 0.64$), scoring $-1.5 SD$ and below in a reading achievement test (Israeli

Ministry of Education Criteria, 2002). These children were recruited from an after-school public learning disability clinic. The other two groups were control groups: chronologically age-matched fourth graders (mean age = 9.7 years, $SD = 0.82$) who were typical readers, and second graders (mean age = 8.1 years, $SD = 0.34$), matched for reading-level to the dyslexic participants (Table 1). The children were all within normal IQ range, without neurological or attention problems, right handed and from middle class areas. Each participant in the group of dyslexic readers was matched to a participant in the age-matched and the reading-level-matched groups. The matching was made in terms of non-verbal IQ and gender (16 boys and 4 girls), and the dyslexic readers were also matched to the reading level group on decoding efficiency (one minute words/pseudowords tests; Shatil, 1995) and comprehension (Israeli Ministry of Education, 2002). All participants in the age-matched group reached the 50th percentile or above on decoding (Shatil, 1995) and comprehension tests (Israeli Ministry of Education, 2002). The study adheres to the APA Ethics Code.

2.2 Materials

It should first be mentioned that Hebrew has two forms of script: pointed and unpointed. Reading instruction of the pointed Hebrew script takes place in Grades 1 and 2. In this form of script, diacritics, carrying mostly vowel information, are inserted into consonant letters. Together, these create highly transparent relations between spelling and sound. In the course of Grades 3 and 4 children are expected to gradually proceed to reading without diacritics, i.e. in the unpointed script, which is an opaque orthography. From Grade 5 on readers of Hebrew are exposed mainly to unpointed texts. As the participants in this study were second to fourth graders, all reading tests were presented in the pointed form of script.

2.2.1 Baseline measures

General ability. Verbal and nonverbal cognitive abilities were assessed using the Wechsler Intelligence Scale for Children (WISC-R; Wechsler, 2003). Full IQ was estimated based on Vocabulary and Block Design subtests using the abridged model after Sattler (1982). Scores of these tests are presented in standardized scores (Table 1).

Short-term memory. Two tests were used to evaluate short-term memory. The first was the Memory for Syllables Test (Breznitz & Share, 1992) which includes five strings of nonsense syllables, ranging in length from 2 to 9 items. Participants were asked to repeat the strings of items in the same order spoken out loud by an experimenter. Participants scored one point for each string correctly recalled. The second test was the Digit Span Test (WISC-R), requiring participants to repeat strings of digits in the same order given by the experimenter, and in reverse

order. There were 16 strings in each task, and the test was stopped when the participant failed to recall two strings of the same length. Strings recalled correctly on each test scored one point.

Word reading efficiency. The One Minute Reading Test for Real Words (Shatil, 1995) was administered. This test consists of 115 real words from different lexical categories (nouns, verbs, adjective etc.) and varying degrees of frequency and length (1–5 syllables). The items in the list were arranged in an ascending order of difficulty (from short and high frequency words to long and low frequency words). Participants scored one point for each word correctly read within one minute.

Decoding efficiency. The One Minute Reading Test for Nonwords (Shatil, 1995) was administered. This test comprises 40 items, phonologically legal in Hebrew, created on the basis of real morphological patterns of the language. The items were 1–3 syllables in length arranged in ascending order. The score represents the number of nonwords read correctly within one minute.

Reading comprehension. Participants completed The Silent Reading Comprehension Test of the Israeli Ministry of Education (2002). The maximum comprehension score was 14.

Phonological awareness. The Phoneme Synthesis and Phoneme Analysis tests were administered (Ben Dror & Shani, 1996), each comprising 18 items, 2–4 phonemes in length. In the first, the participants were asked to combine phonemes spoken out by the experimenter into nonwords, and in the second the participants were asked to analyze nonwords into their constituting phonemes. Scores are based on the total number of accurate responses.

Orthographic processing. A spelling test was administered (Breznitz, 2008), comprising 10 highly frequent words (Balgur, 1968). Each word has at least one homophone. The score represents the number of correctly spelled words. A Word Parsing Test (Breznitz, 1996) was also presented. The test contains six rows of sentences, comprising 4 to 19 words each. The words are presented as a continuous line of print (i.e., they are not separated by blank spaces). Participants were asked to identify the words in each row by drawing a line to indicate where the spaces should be. Performance time and number of mistakes are presented in Table 1.

2.2.2 Experimental measures

Pretest. An initial test was administered in order to select appropriate target words for the word-lists and meaningful texts used in the experiment. A list of 100 words was presented to the children, which they were required to read out loud. The words were age-appropriate, taken from Balgur's (1968) word-list of basic words for elementary school children. All were high frequency content words of various lexical categories (nouns, verbs and adjectives), comprising more than two syllables and four to seven letters. As all reading tests were presented in the highly transparent pointed form of Hebrew script, there were no cases of phonological ambiguity.

The purpose of the pretest was to identify words semantically and phonetically familiar to each participant (i.e. individual target words) from spoken language, but pronounced incorrectly in reading. Each participant read the word-list out loud, and all incorrect pronunciations were noted. In a subsequent test resembling the WISC-R Vocabulary test in format, knowledge of the meaning of each word was examined. For each dyslexic participant, 10 words were selected which were incorrectly pronounced but for which correct definitions were given when the word's pronunciation was provided by the experimenter (if more than 10 words were identified, the first 10 were selected as targets). Individual target words familiar to the readers in spoken language but incorrectly read could not be identified for the two control groups, as reading accuracy of typical readers of Hebrew is very high as early as the end of the first grade (Share & Levine, 1999), and near perfect by the fourth grade (Bar-Kochva & Breznitz, 2014). Hence, the participants in the two control groups were presented with the same 10 target words which their matched dyslexic readers saw. Notably, out of the 10 words, two target words were identified which were consistently mispronounced but correctly defined across all dyslexic readers. The 10 words were divided randomly between the two experimental conditions: reading of words and reading of meaningful texts.

Test of Word Recognition in a List. This test included five word-lists. Each list consisted of one target word appearing seven times and 25 different distracter words. The locations of the target word in the list were randomly selected using a computer program designed for this purpose. Distracters were identical across participants and were randomly placed in each list. Four of the five word-lists comprised individual target words. The fifth list was identical across-participants.

Test of Word Recognition in Texts. This test included five short narratives describing short conversations between people and descriptions of situations and events. Each text comprised seven lines and 85–95 words. One target word appeared on each line of text (i.e. a total of seven times throughout each text). Four of the five texts contained individual target words. The fifth text contained a common target word and was identical across participants. A multiple-choice question followed each text in order to verify comprehension.

Each of the texts was composed for the purpose of this experiment, and was tested for readability (accuracy in reading and comprehension) prior to the experiment on a separate sample of 25 second-grade and 25 fourth-grade typical readers. The children read each text out loud and answered the multiple-choice questions. In four of the texts, a normal distribution across participants was found on these measures. In the fifth text, distribution was slightly skewed, and the necessary adjustments in the texts and questions were made until the distribution resembled the distribution of the other texts in a pilot study.

2.3 Procedure

The 60 participants were selected out of a large pool of children, based on the criteria described in Section 2.1 (Participants). All participants were tested individually on the background tests prior to the administration of the experimental reading tests. Half of the children in each group read the word-lists prior to the texts, and the second half completed the two tasks in the reverse order. The different word-lists and texts of the experimental paradigm were randomly assigned to participants, whose reading was recorded. Analysis of reading of the targets was conducted offline.

3. Results

3.1 Baseline measures

In order to examine group differences in the background measures, ANOVA analyses were carried out, with group (3 levels) as a between-participant factor. Results of this analysis and the contrasts appear in Table 1.

General ability. No differences were found between the three groups on the non-verbal measure of the IQ subtest (Block Design). Dyslexic readers showed lower vocabulary scores than the two control groups, which may be a consequence of reading avoidance often characterizing struggling readers (Stanovich, 1986).

Short-term memory. Dyslexic readers obtained significantly lower scores on the Memory for Syllables Test (Breznitz & Share, 1992) and on the Digit Span Test (WISC-R, 2004) compared to the two control groups.

Reading ability. No significant differences were found between dyslexic and reading-level-matched children in word and nonword reading efficiency and reading comprehension. The group of children whose chronological age was matched to the group of dyslexic children achieved higher scores in these measures than the dyslexic children and the reading-level-matched children. In addition, dyslexic readers obtained the lowest scores compared to the two control groups in measures of silent reading time.

Phonological awareness. Differences were found between dyslexic readers and age-matched controls on phonological synthesis and analysis.

Orthographic processing. Dyslexic readers reached the lowest scores compared to the two control groups on the spelling and parsing tests.

Table 1: A comparison between dyslexic, reading-level matched and age-matched children on the baseline measures

Cognitive Construct	Measure	Dyslexic Readers	Reading Level – Matched Control Group	Age-Matched Control Group	$F(2, 57)$	Contrast
General Ability	Vocabulary (WISC-R)	9.7 (3.1)	11.7 (3.8)	11.4 (2.6)	4.7*	1X2 1X3
	Block Design (WISC-R)	10.9 (3.7)	10.7 (2.7)	11.6 (3.2)	<i>ns</i>	
Working Memory	Syllable Span	2.8 (0.7)	3.3 (1.0)	3.8 (0.5)	10.9***	1X2 1X3 2X3
	Digit Span (WISC-R)	4.4 (0.9)	5.3 (1.2)	5.5 (1.2)	6.4***	1X2 1X3
Reading	Word Reading	34.6 (11.1)	38.6 (10.6)	48.0 (9.0)	5.4**	1X3 2X3
	Pseudoword Decoding	13.7 (9.6)	15.3 (6.7)	29.6 (5.2)	26.9***	1X3 2X3
	Comprehension Accuracy (silent text reading)	6.0 (1.8)	6.1 (1.2)	11.1 (0.9)	20.6***	1X3 2X3
	Reading Time (silent text reading)	168.4 (77.9)	104.6 (40.9)	77.6 (30.1)	11.8***	1X2 1X3 2X3
Phonological Awareness	Phoneme Synthesis	5.1 (4.3)	6.3 (4.3)	9.3 (5.4)	4.8*	1X3
	Phoneme Analysis	2.5 (3.1)	3.4 (4.0)	7.5 (5.2)	8.4***	1X3 2X3
Orthographic Processing	Dictation	5.7 (2.6)	8.7 (1.2)	9.3 (1.2)	32.2***	1X2 1X3
	Parsing Test time (in sec)	18.6 (4.7)	27.9 (4.2)	36.2 (3.0)	19.3***	1X2 1X3 2X3
	Parsing Test mistakes	3.1	1.4	1.1	12.9***	1X2 1X3

Note. All scores are presented as raw scores, except the general ability measures which are presented in standardized scores.

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

3.2 Experimental measures

3.2.1 Accuracy in target word reading

Accuracy rates were analyzed across encounters with the target words. An ANOVA analysis with group as a between-participant factor was carried out (followed by Scheffé's post-hoc comparison) on accuracy achieved in the first appearance of the target word in the two types of reading material (the mean of both). A main effect was found for group ($F(2,57) = 75.12, p < .001$), indicating that the dyslexic readers

were less accurate ($M = 35\%$, $SD = 21.34$) than the reading-level ($M = 86.84\%$, $SD = 19.48$) and age-matched ($M = 96.67\%$, $SD = 6.49$) groups. The means suggest a stepwise pattern with the reading-level matched control group scoring in-between the two other groups, although the differences between the two control groups were not significant. Significant gains in accuracy rates occurred in the group of dyslexics readers only by the third encounter ($t(19) = -3.69$, $p < .01$). Accuracy rates reached 51.11% in this group by the fourth encounter, with similar accuracy rates in the following encounters. The improvement in accuracy rates was significant in the reading-level group by the second encounter ($t(19) = -2.31$, $p < .05$), reaching 89.47% by the third encounter. Changes in accuracy rates thereafter were not significant. As age-matched readers reached almost perfect accuracy as soon as the first encounter, their progress across encounters was insignificant.

3.2.2 Target word representations

3.2.2.1 Description of the outputs across encounters with the targets

The output from each encounter with the target words could be classified according to five different categories. No differences were found between the two reading conditions (word-list or text) for type and frequency of output. Consequently, the means for frequency and type of decoding output were combined across the two reading conditions. The categories were: (a) correct output – correct pronunciation of the target; (b) real word related to text – substitution of the target with a real word which is semantically consistent with the content of the text; (c) real word unrelated to text – substitution of the target by a real word which is semantically unrelated to the text's content; (d) same word class – a substitution of the target by a real word grammatically related to the target; (e) nonword.

For each of these categories it was also described whether pronunciation was continuous or with breaks (e.g., syllable by syllable). Table 2 presents the distribution of the categories of output in each of the reading groups. Analysis of the output was carried out by two independent coders, and inter-rater reliability was significant at $\alpha = .94$.

This description addressed two purposes. First, while the analysis of accuracy does not contribute much to the understanding of whether word representations were involved in reading, the measure of accuracy combined with continuity of pronunciation is more informative as an indication of words read “by sight” (Ehri, 2005). The vast majority of outputs of the two control groups were from the type of correct and continuous pronunciation of the target (above 94%), while dyslexic readers read only 38.2% of the words in this way across encounters with the targets. In addition, typical readers seldom showed non-continuous pronunciation of a target when it was correctly decoded (less than 1% in each control group), while this type of output appeared in 12.8% of the words which the dys-

lexic children read. Dyslexic readers also replaced around a third of the targets by nonwords, while the frequency of appearance of this type of output was negligible in the two control groups (less than 1.6 %). This suggests that the dyslexic readers frequently applied decoding in reading, while the control groups mainly addressed word representations. The second purpose of this analysis was to provide some insight into the question of stability of processes of reading. The outputs of dyslexic readers were dispersed across all five categories, suggesting unstable decoding of the targets, while the outputs of controls concentrated on one type – correct and continuous pronunciation.

Table 2: Distribution of mean percentages of target word reading by output type and group

Output Type	Dyslexic	RL Matched	CA Matched
Correct output – continuous	38.2	94.6	97.1
Correct output – non-continuous	12.8	0.3	0.6
Real word related to text – continuous	7.5	2.4	1.0
Real word related to text – non-continuous	0.3	0.1	0.1
Real word unrelated to text – continuous	3.4	0.1	0.1
Real word unrelated to text – non-continuous	0.8	0.0	0.0
Same word class – continuous	2.6	0.3	0.0
Same word class – non-continuous	0.5	0.0	0.0
Nonword – continuous	26.1	1.6	0.5
Nonword – non-continuous	7.8	0.7	0.2

Note. RL Matched = Reading level-matched; CA Matched = Chronologically age-matched. CA Matched sums to 99.6, RL Matched sums to 100.1.

3.2.2.2 Consistency in target identification.

The retaining of word representation in reading should be expressed in consistent pronunciation of the target accurately and continuously across consecutive encounters. A measure taking into account these three aspects was created based on the previous analysis of the outputs' coding from each encounter with the targets. Repeated Measure ANOVA analysis with group (3 levels) as a between-participant variable, and type of reading material (word-list/text) as a within-participant factor was carried out on this measure. Main effects for group ($F(1, 57) = 154.46$, $p < .001$) and reading material ($F(1, 57) = 13.15$, $p \leq .001$) were obtained. Post-hoc contrasts (Scheffé's tests) showed that the two control groups (*mean age-matched* = 81.52; *mean reading-level matched* = 78.91) read more words based on their representation than dyslexic readers ($M = 26.36$) and more words were read based on their representation when presented in texts ($M = 65.33$, $SD = 28.95$) than when presented in word-lists ($M = 59.59$, $SD = 27.56$). The interactions were insignificant.

Table 3: Percentages of target words read based on their representations across successive encounters

	Dyslexic Readers		RL Matched		CA Matched	
	Word List	Text	Word List	Text	Word List	Text
Consistency	25.6 (17.7)	28.2 (19.3)	75.1 (11.7)	82.7 (6.5)	78.0 (9.0)	85.0 (3.4)

Note. RL Matched = Reading level-matched; CA Matched = Chronologically age-matched.

4. Discussion

The background measures indicate lower performance of dyslexic readers in measures examining orthographic representations of words (parsing and spelling) compared to typical readers, similarly to findings from other studies (e.g., Castles & Coltheart, 1993; Siegel, 1986). This study set out to explore the *process* of acquisition of these representations following repeated exposures to the same target words in dyslexic readers. The experimental paradigm used to investigate this hypothesis involved the exposure of participants to the same target words for seven times, with or without context. The targets were words which the dyslexic children had difficulty to read in a pre-test, while being part of their spoken vocabulary. The reading performance of dyslexic, chronologically age-matched, and reading-level-matched children was compared.

The central hypothesis of this investigation was that dyslexic readers would have difficulty in the formation and retention of word representations. Three types of analyses carried out in this study uphold the hypothesis. First, the analysis of overall accuracy in target word identification indicates that both control groups showed very high to near perfect accuracy in target identification. Dyslexic readers, however, identified correctly about a third of the targets upon the first encounter, and accuracy increased with successive encounters, reaching only around 50 % on the fourth encounter, with similar accuracy rates in subsequent encounters. The second analysis, describing the participants' different outputs, suggests that about a third of the items correctly identified by dyslexic readers were not read based on their representation in the mental lexicon (as their pronunciation was non-continuous). In contrast, the rate of words read correctly and pronounced continuously was above 94 % in the control groups, suggesting a reliance on word representations in reading. Furthermore, the high rates of targets read as nonwords in dyslexic readers imply an extensive use of decoding as a strategy of reading. The third analysis indicates higher rates of consistency of the control groups compared to the dyslexic readers in identifying the targets based on their representations across encounters. Together, these findings suggest that the targets were well integrated into the mental lexicon of the two control groups, while dyslexic readers failed to form and maintain the targets' representations, despite repeated encounters with the targets.

It should be noted, that the difficulty in finding a sufficient number of words, which the typical readers failed to read in the pre-test, is well in line with studies on reading acquisition of other transparent orthographies, indicating high to near perfect accuracy rates achieved early on in the process of reading acquisition (Aro & Wimmer, 2003; Mann & Wimmer, 2002; Seymour, Aro, & Erskine, 2003; Share & Levin, 1999). As a result, however, it is not clear from the present investigation whether the typical readers were already familiar with the targets in their printed form prior to the experimental procedure, which imposes a limitation on the direct comparison of dyslexic and typical readers. At the same time, the dyslexic readers failed to approach, let alone reach, the accuracy rates of the typical readers, even after seven exposures to the same targets. Moreover, the large differences in frequency of output types indicating the use of decoding strategy in reading, and the highly significant difference between dyslexic readers and typical readers in the indicators of consistency, strongly suggest a gap between the abilities of dyslexic readers and typical readers to form and retain word representations in reading.

These results converge with the study by Share and Shalev (2004), who used a different method to examine the acquisition of word representations in readers of Hebrew. Children read out loud 10 texts in which target pseudowords were embedded. The texts were followed by comprehension questions. Three days later, orthographic learning of the targets was tested using spelling, word naming and orthographic choice tasks. Impaired orthographic learning was found in poor readers (both with and without a discrepancy between reading level and IQ) in Grades 4–6 compared to chronological-age controls. The use of target pseudowords in this study eliminated the variance resulting from prior exposures to the targets, while at the same time, most words which readers encounter in print are already familiar to them in spoken form. The current results therefore add to the findings by Share and Shalev (2004), by using targets which already had semantic representation in spoken language. The present study also confirms that dyslexic readers do not lack the ability to acquire word representations in reading altogether. In this study, as was found by Share and Shalev (2004), reading performance of dyslexic readers increased with exposures (up to the fourth exposure) but remained significantly lower than performance of typical readers. It should be mentioned that these results appear not be limited to readers of Hebrew, as difficulties in constituting target word representations following repeated exposures to their written form were also found in readers of other languages, such as English (Ehri & Saltmarsh, 1995) and Dutch (Reitsma, 1983).

The second hypothesis of this study, pertaining to instable processes of reading in dyslexic readers, was also confirmed, thereby shedding some light on the possible reasons for their difficulty in forming and retaining word representations. The description of the types of outputs indicates that the reading of dyslexic readers was dispersed across all different types, while the reading of controls concentrated on correct and continuous pronunciation of the target. These results, together with the higher rates of inconsistency in target word recognition across encounters in dyslexic readers compared to typical readers, strongly suggest instable processes of

decoding in the former, which presumably led to a considerable difficulty in forming solid word representations in the long-term memory. The outcome of persistent and variable decoding mistakes may then be a number of diffused, faint, and typically inaccurate mental representations for the same word in the lexicon, leading to unstable traces of the word in the mental lexicon.

As mentioned in the introduction, according to the Self-Teaching Hypothesis, correct decoding of a word is the primary mean of acquiring specific orthographic knowledge of that word (Jorm & Share, 1983; Share, 1995), hence decoding deficits should hamper the formation of precise word representations in the lexicon (Cunningham et al., 2002). In the study by Share and Shalev (2004) of typical and dyslexic readers, the level of orthographic learning indeed increased with success in target decoding (also see Share, 1999). The high rates of decoding errors of the dyslexic readers in the present study provides further support to the close link between the quality of decoding and the acquisition of word-specific representations.

Nevertheless, additional skills seem to affect the formation of a mental lexicon. Studies indicating the existence of dissociations between reading and spelling (Bar-Kochva & Amiel, 2015; Bruck & Waters, 1988, 1990; Frith, 1980; Holmes & Carruthers, 1998; Holmes & Castles, 2001; Holmes & Ng, 1993; Lovett, 1987; Treiman, 1993; Wimmer & Mayringer, 2002) suggest that intact decoding does not guarantee the acquisition of spelling skills. In an analysis of spelling errors, Frith (1980) found that good readers who were poor spellers relied on phonology in spelling, but could not recall word-specific orthographic information (also see Moll & Landerl, 2009). Cunningham et al. (2002) directly investigated additional possible sources for orthographic learning in typically developing second graders, by testing different cognitive abilities in addition to decoding. The skills tested were general cognitive ability, rapid automatized naming (RAN) and orthographic knowledge (tested using an orthographic choice task). Orthographic knowledge predicted significant variance in orthographic learning, over and above the contribution of target decoding. These findings support Share's (1995) two-component hypothesis of the Self-Teaching Theory, according to which phonological decoding is the primary source of orthographic learning, whereas orthographic processing is a secondary source. It should also be mentioned, that a sub-group of dyslexic children with difficulties in reading of frequent words but not in reading of nonwords was found by Lachman, Berti, Kujala, and Schroeger (2005). The researchers suggested that this difficulty reflects a problem in recognizing frequently used words as visual or phonological (as the words were read out loud and therefore required phonological skills) gestalts, which enables a fast and direct access to the lexicon.

According to models of word recognition from the connectionist approach, recurring information about orthography, phonology and semantics is acquired through statistical learning (see review by Rueckl, 2010). This procedure is used to adjust the strengths of connections between processing units, and the division of labor between the different pathways of the system (Harm & Seidenberg, 2004). Accordingly, if the same word results in different outputs across different encoun-

ters, statistical learning is disrupted. Consequently, solid connections between orthography, phonology and meaning may not be established.

The Synchronization Theory proposed by Breznitz (2006, 2008) may provide an explanation at an earlier stage of word processing. According to this view, exact synchronization of information arriving from the visual-orthographic and the auditory-phonological systems involved in word recognition is crucial for correct decoding and for the formation of orthographic representations. When the timing is well-regulated, correct word patterns are generated (also see Bowers & Wolf, 1993), presumably by the detainment of orthographic information in the processing system until the subsequent arrival of phonological information (Breznitz, 2006; 2008). Decoding automaticity is achieved when a sufficient number of accurate phonological-orthographic matches have been successfully replicated. Decoding errors, however, may stem from a lack of “synchronization” or a “mismatch” between the processing in these two systems, resulting in impaired word pattern formation in the mental lexicon.

The question arises whether dyslexic readers would have benefited from more encounters with the targets. The current finding, indicating no increase in accuracy performance following the fourth encounter in dyslexic readers, suggests that more than seven encounters would not have resulted in the integration of the targets into the mental lexicon. Converging results were also found by Share and Shalev (2004) indicating no differences in orthographic learning between two and six exposures either in typical or in dyslexic readers.

The third hypothesis, pertaining to the contribution of context to the formation and retrieval of word representations, was confirmed for all groups. Inconsistency was found more in reading of word-lists than in reading of texts, regardless of reading level. This finding is in line with previous studies indicating the contribution of context to word identification (Abu-Rabia, 1997; Nation & Snowling, 1998; Stanovich, Cunningham, & Feeman, 1984; Stanovich & Feeman, 1981; West & Stanovich, 1978). The addition of the present study to these previous findings is that context appears to support the formation and preservation of word representations in the mental lexicon. At the same time, the analysis did not point to a larger contribution of context in dyslexic readers than in typical readers. Based on the high rates of decoding errors across all encounters with the targets in dyslexic readers, it may be speculated that they invested much of their cognitive resources in decoding, while less was left to rely on context for the purpose of decoding.

To conclude, the main addition of the present study to previous studies examining word representations in dyslexic readers is the in-depth analysis of the *process* of numerous encounters with the same words, which were familiar in spoken form, but not in printed form. The results indicate significant difficulties in the formation and retention of visual word representations, which may result from unstable processes of decoding.

In practical terms, current intervention programs, addressing mainly young readers at risk for dyslexia, focus on phonological skills in an attempt to enhance processes of decoding, as these are associated with the early stages of reading ac-

quisition more than with the later stages (Bruck, 1990). Intervention programs addressing older children often focus on repeated exposures to the same orthographic items in an attempt to enhance their representation in memory (Abbott & Berninger, 1999; Kuhn & Stahl, 2003; Lovett, Steinbach, & Frijters, 2000; Meyer & Felton, 1999; Torgesen, Alexander, Wagner, Rashotte, Voeller, & Conway, 2001). According to the current study, training of repeated exposures to the same orthographic items may not suffice. In addition, the instable processes of decoding found in the dyslexic readers in Grade 4 suggest that the training of phonological decoding is still relevant at this grade-level. Struggling readers in the mid-end grades of elementary school may therefore benefit from the combination of phonological training and repeated exposures to the same items more than from each of these trainings administered alone. Another intervention method proven to enhance reading ability (fluency and comprehension) is the *Reading Acceleration Program* (Breznitz, 2006) in which texts are presented on a computer screen and deleted, one letter after the other, according to the fastest speed which the participant can read and comprehend. It was suggested that the imposed time-limit encourages efficient processing in the cognitive domains involved in reading, thereby reducing the gap in processing speed of the visual-orthographic and the auditory-phonological systems (Breznitz 2006, 2008; Breznitz & Misra, 2003; Breznitz, Shaul, Horowitz-Kraus, Sela, Nevat, & Karni, 2013). The specific effect of this manipulation on the creation and maintaining of word representations in the mental lexicon remains, however, to be established.

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