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Reading improvement in English- and Hebrew-speaking children with reading difficulties after reading acceleration training

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Abstract A reading acceleration program known to improve reading fluency in Hebrew-speaking adults was tested for its effect on children. Eighty-nine Hebrew- and English-speaking children with reading difficulties were divided into a waiting list group and two training groups (Hebrew and English) and underwent 4 weeks of reading acceleration training. Results of pre- and post-testing of reading abilities point to a significant main effect of the test, demonstrating improvements in silent contextual reading speed, reading comprehension, and speed of processing in both Hebrew and English training groups as compared to their performance before the intervention. This study indicates that the Reading Acceleration Program might be an effective program for improving reading abilities in children, independent of language.

Keywords Dyslexia · Fluency · Oral and silent reading · Reading Acceleration Program

Introduction

Considerable research has converged to document reading deficits, both phonological (Liberman, Shankweiler, Fisher, & Carter, 1974; Morris et al., 1998; Stanovich & Siegel, 1994) and regarding fluency (Bowers, 1993; Bowers & Wolf, 1993; Breznitz, 1987, 2001, 2006), in developmental dyslexia. Fluency, or overall timing and smoothness in reading, can be related to deficits in working memory (Swanson & Siegel, 2001), rapid automatic naming (RAN) (Wolf, 2001), timing (Bowers & Wolf, 1993), and/or an asynchrony between the auditory-phonological and the visual-orthographic processing speeds (Breznitz, 2006; Breznitz & Misra, 2003). Concurrent with these processing deficits, children with dyslexia may be

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impaired in specific reading and writing skills: accuracy and rate of real word reading, pseudoword reading (decoding pronounceable words without meaning), accuracy and fluency of oral passage reading, and spelling (Berninger, Abbott, Thomson, & Raskind, 2001; Lyon, Shaywitz, & Shaywitz, 2003). Depending on the amount and type of intervention they experience, children with dyslexia tend not to be impaired in oral vocabulary or reading comprehension (Spencer, Quinn, & Wagner, 2014).

Research shows that developmental dyslexia occurs in most languages and countries, with an approximate rate of 10–15 % according to Fletcher, Lyon, Fuchs, and Barnes (2007) (see also Youman & Mather, 2012). Both commonalities and differences have been found across cultures, undoubtedly due to differences in educational practices and characteristics of the orthography (see Share, 2008, for review). Dyslexia is known to be a hereditary disorder (Gilger, Pennington, & De Fries, 1997; Schumacher et al., 2006), although it is responsive to instructional interventions and affected individuals may successfully compensate to some degree, especially if intervention occurs early in life (Vellutino et al., 1996). Other studies have demonstrated that compensation can also occur during the middle grades (Abbott & Berninger, 1999). However, if this disorder remains undiagnosed and untreated, it often causes psychological strain on the individual and thus adversely affects one's life trajectory and the society as a whole (Undheim, Wichstrom, & Sund, 2011).

For many years, attempts to find both the origin of reading impairments and effective treatments were based primarily on reading research conducted in English, with English-speaking participants. The current study, on the other hand, is a cross-language comparison designed to sort out what aspects of dyslexia are universal and what are language-specific. Research has shown that explicit phonological awareness and phonological decoding instruction are effective in the primary grades (ages 6 to 9) (National Institute of Child Health & Human Development, 2000), but adding "silent orthographic strategies" (Fayol, Thévenin, Jarousse, & Totereau, 1999) and morphological awareness activities may improve automatic decoding in the upper grades, as determined by behavioral (Berninger et al., 2008; Berninger & Wolf, 2009) and brain measures (Berninger et al., 2003). For students in grades 4 to 9, adding Breznitz's (2006) accelerated reading training improved phonological decoding rate over and beyond the improvements in phonological awareness and explicit decoding instruction have achieved alone (Horowitz-Kraus & Breznitz, submitted).

The Reading Acceleration Program (RAP) is a computerized reading intervention program that focuses on reading fluency (Breznitz et al., 2013). The program manipulates letter presentation rate, requiring clients to read at their fastest self-paced rate (Horowitz-Kraus & Breznitz, 2013; Breznitz et al., 2013). RAP has been shown to improve reading speed, accuracy, and comprehension in adults and children with and without reading difficulties (RD) in several orthographies, including Hebrew (Breznitz et al., 2013; Horowitz-Kraus & Breznitz, 2010; 2013), English (Breznitz, et al., 2013; Horowitz-Kraus, 2012; Niedo et al., 2013), German (Korinth, et al., 2009), and Dutch (Snelling et al., 2009). A recent EEG study suggests that the benefit of RAP training arises from a working memory mechanism, also attributed to the frontal lobes (Breznitz & Share, 1992; Horowitz-Kraus & Breznitz, 2013). The authors speculated that during the reading process, units of data were integrated into the working memory system at an increased rate and in more meaningful units for storage in the mental lexicon (also confirmed by Niedo et al., 2013). Niedo et al. also suggested that RAP training enhances orthographic working memory by requiring a reader to hold in his or her mind increasing amounts of text, incremented a letter at a time, as the reader processes the word's meaning. There is previous evidence of the positive effect of 8 weeks of RAP training on reading speed and accuracy as well as comprehension in Hebrew-speaking children (Horowitz-Kraus & Breznitz, 2013) and a pilot study in English-speaking children (Niedo et al., 2013). However, the current study is the first to directly compare the effectiveness of RAP in children with RD using shallow and deep orthographies after only 4 weeks of training.

In the current study, we aim to directly compare the effect of RAP training in a shallow (diacritic form of Hebrew) and deep orthography (English) in 8- to 12-year-old dyslexic children, which marks the transition from oral to silent reading, and to identify the universal effects of RAP. We hypothesized that both Hebrew- and English-speaking children with dyslexia (or with RD) would gain from training with the RAP, as compared to controls. Because RAP enhances reading fluency, we also measured the effect of training on speed of processing in the participants, and we postulated that speed of processing would be faster after training. Due to the relationship between oral and silent reading, we also hypothesized that both types of reading would improve.

Methods

Participants

Eighty-nine children, second to fifth grade, with reading difficulties (RD) participated in the current study (43 females, 45 males, mean age=9.15±1.22). Fifty-four Hebrew-speaking participants with RD (28 females, 26 males, mean age=8.65±0.72) were recruited from a school in the north of Israel. The participants were native Caucasian Hebrew speakers with average socioeconomic status, as reported by the families. All were right-handed, displayed normal or corrected-to-normal vision in both eyes, and were screened for normal hearing. None of the participants had a history of neurological or emotional disorders. Twenty-seven were enrolled in the RAP group (12 females, 15 males, mean age of 8.65±0.72) and 27 were enrolled in the waiting list group (14 females, 13 males, mean age of 8.64±0.55) by a "flip-of-a-coin." In the training group, 15 children were in the second grade, 8 in the third, and 4 in the fourth grade. In the waiting list group, 12 children were in the second grade, 14 in the third, and 1 in the fourth grade.

Thirty-five English-speaking RD participants (15 females, 20 males, mean age=9.94±1.48) were recruited by posted advertisement in the area of Cincinnati Children's Hospital Medical Center in Cincinnati, OH, USA. All were Caucasian, native English speakers with average socioeconomic status, as reported by the families. All were right-handed, displayed normal or corrected-to-normal vision in both eyes, and were screened for normal hearing. None of the participants had a history of neurological or emotional disorders. Twenty were enrolled in the RAP group (10 females, 5 males, mean age=9.8±1.27) and 15 were enrolled in the waiting list group (5 females, 10 males, mean age=9.99±1.77) by a "flip-of-a-coin." In the training group, four children were in the second grade, four in the third, four in the fourth grade, and eight were in the fifth grade. In the waiting list group, six children were in the second grade, two in the fourth grade, and seven in the fifth grade.

All participants were diagnosed with RD prior to the study. Their diagnosis was verified by a battery of normative reading tests in Hebrew (Aleph-Taph; Shany, Lachman, Shalem, Bahat, & Zeiger, 2006) or in English [The Woodcock and Johnson battery: Woodcock & Johnson, 1989: Gray Oral Reading Test (GORT) IV: Wiederholt & Bryant, 1992]. In the Hebrew-speaking group, participants had to have a standard score of (−1) or below on the 1-min word and pseudoword reading tasks, and on the fluency reading task from the Aleph-Taph battery. In the English-speaking group, participants must have had a standard score of (−1) or below on the "letter-word" and "word-attack" subtests from the Woodcock-Johnson III (WJ) (Woodcock & Johnson, 1989) and on the fluency and accuracy subtests from the GORT battery (GORT-IV: Wiederholt & Bryant, 1992) (see Table 1 for the study design). The IQs of the participants were measured by the TONI-3 test (Brown et al., 1997). Their scores were in the normal range (Table 2). No difference was found between the waiting list and training groups in attention ability, measured by the Diamond Test (Rudel, Denckla, & Broman, 1978) for the Hebrew-speaking children and by the "sky-search" subtest from the Test of Everyday Attention for Children (TEA-Ch) for the English-speaking children (Manly et al., 1999). In order to rule out the existence of cognitive differences between the training and waiting list groups in both languages, speed of processing [(speed factor symbol search and coding: WISC: Wechsler, 1991; naming test: "Aleph-taph" battery (Hebrew) and the Comprehensive Test of Phonological Processing subtest (English) (Wagner, Torgesen, & Rashotte, 1999)] and memory [(digit-span subtest (Wechsler, 1991)] measures were also collected and compared.

All participants gave their informed written assent and their parents provided informed written consents prior to inclusion in the study. The experiment was approved by the University of Haifa's Ethics Committee (No. 009\09\09) and by the Cincinnati Children's Hospital Medical Center Institutional Review Board Committee (No. 2011-2041). Participants were compensated for their time and travel.

Measures

Behavioral baseline measures

Behavioral baseline reading tests were administered to assess decoding and reading abilities and fluency, for verifying the existence of RD. In Hebrew, decoding ability was assessed using the 1-min test for words and 1-min test for pseudowords (Shany, Lachman, Shalem, Bahat, & Zeiger, 2006). Fluency was measured by reading connected texts, taken from the standardized reading battery in Hebrew (Aleph-Taph battery: Shany, Lachman, Shalem, Bahat, & Zeiger, 2006). The texts were read orally by the participants. The number of words read per second was calculated (the fluency measure). Comprehension was assessed using the reading comprehension subtests for oral reading in the Elul battery (Shatil, Nevo, & Breznitz 2008). In English, decoding ability was assessed using the "word-attack" and "letter-word" subtests from the WJ battery (Woodcock & Johnson, 1989). Fluency and comprehension were measured by texts from the GORT battery (GORT-IV: Wiederholt & Bryant, 1992). The behavioral test sessions lasted approximately 2 h each. (See Table 1 for these measures and study design).

Reading measures

The effect of the Reading Acceleration Program (RAP) training on oral reading was assessed by measuring decoding (Hebrew: 1-min test for words and pseudowords; English: "word-attack" and "letter-word" from the WJ III battery), fluency (in Hebrew: Aleph-taph battery; in English: GORT-IV), and reading comprehension abilities (in Hebrew: Aleph-taph; in English: GORT-IV) following training. Silent reading was measured by the diagnostic mode of the

Table 1 Study design

Language	Group	Test 1	Training	Test 2
Hebrew	Training	Cognitive and reading measures	4 weeks, 20 sessions overall	Reading measures (and speed of processing factor, only for the training groups)
	Waiting list		None	
English	Training		4 weeks, 20 sessions overall	
	Waiting list		None	

Table 2 Basic cognitive abilities before training

Measures	Hebrew		English		*F* test	Contrast	*t*
	Trained (A) *M* (SD)	Waiting list (B) *M* (SD)	Trained (C) *M* (SD)	Waiting list (D) *M* (SD)			
Nonverbal ability (standard score)	103.85 (11.22)	102.11 (9.68)	98.89 (6.49)	102.33 (8.97)	Language×group, $F(1, 85)=1.3$, ns, $\eta^2=0.01$	A>B	0.61, ns
						D>C	−1.257, ns
Verbal ability (standard score)	11.22 (2.13)	11.4 (2.06)	9.17 (1.78)	8.86 (2.55)	Language×group, $F(1, 85)=0.28$, ns, $\eta^2=0.003$	B>A	−0.324, ns
						C>D	0.422, ns
Attention (standard score)	0.34 (0.96)	−0.08 (0.97)	0.007 (0.87)	−0.008 (1.01)	Language×group, $F(1, 85)=0.12$, ns, $\eta^2=0.001$	A>B	1.63, ns
						C>D	0.401, ns
Memory (digit span, standard score)	9.85 (2.19)	9.88 (2.24)	7.95 (2.66)	7.57 (1.98)	Language×group, $F(1, 85)=0.17$, ns, $\eta^2=0.002$	B>A	−0.061, ns
						C>D	0.481, ns
Speed of processing factor (standard score)	9.64 (2.16)	9.12 (2.52)	9.1 (2.62)	8.83 (2.01)	Language×group, $F(1, 85)=1.64$, ns, $\eta^2=0.01$	A>B	0.81, ns
						D>C	−0.327, ns
RAN letters (s)	37.96 (7.62)	38.15 (8.79)	50.58 (13.04)	53.13 (22.08)	Group×training, $F(1, 85)=0.85$, ns, $\eta^2=0.002$	B>A	−0.085, ns
						D>C	−0.398, ns
RAN objects (s)	51.59 (8.74)	51.03 (9.83)	41.5 (7.75)	42.85 (7.76)	Language×group, $F(1, 85)=0.25$, ns, $\eta^2=0.003$	A>B	0.22, ns
						D>C	−0.512, ns
Fluency (percentile)	13.92 (4.48)	13.74 (4.4)	12.66 (2.77)	13.23 (3.22)	Language×group, $F(1, 85)=19$, ns, $\eta^2=0.66$	A>B	0.153, ns
						D>C	−0.545, ns
Decoding ability (standard score)	10.4 (4.69)	9.7 (4.3)	10 (4.63)	9.86 (4.59)	Language×group, $F(1, 85)=0.72$, ns, $\eta^2=0.001$	A>B	0.544, ns
						C>D	0.085, ns

RAP program. In order to examine the effect of RAP training on speed of processing ability, we calculated a "speed of processing factor" by adding the standard scores from the symbol search and coding subtests and then dividing by two (Wechsler, 1991). The post-training reading measures lasted approximately 1 h.

Reading acceleration program

Stimuli

The RAP bank of 1,500 sentences composed of moderate- to high-frequency words (in Hebrew: Frost, 2001; in English: http://www.wordfrequency.info/) was used. Due to the chosen age range, which is an age at which Hebrew-speaking children still use a diacritic orthography, the presented stimuli in Hebrew used diacritics (e.g., symbols that represent the vowels of the letters). Each stimulus was a sentence followed by a multiple-choice question with four possible answers. Sentence length was between 9 and 12 words and between 45 and 70 letters per sentence, extending over one to two lines and with 18 mm between lines. The letters were black, 5 mm wide, and presented on a gray background at 60 % contrast. Each sentence was presented on the computer screen only once during the entire training. The sentences were tested and verified for their level of difficulty in previous studies (Breznitz, 2006).

Training procedure

Reading training was administered using a personal computer. The participants were trained for 4 weeks, five times a week, 15–20 min per session, for a total of 20 sessions, reading a different set of 50 randomly presented sentences in each session. The pre- and post-training reading pace and reading comprehension of each participant were determined using the diagnosis mode of RAP, which measures the duration of a sentence on the screen (see also "Presentation rate"). The duration was controlled by text erasure, starting from the beginning of the sentence and advancing at a given per-character rate. All participants were presented with the same sets of sentences and in the same order. They were instructed to read each sentence silently. While doing so, the sentence disappeared from the computer screen, one letter at a time. After the sentence disappeared, a multiple-choice comprehension question appeared and remained on the screen until the participant responded. They were instructed to choose an answer by clicking on the corresponding number on the numeric keypad of the computer. The disappearance of the question from the computer screen prompted the next sentence.

Presentation rate

The initial presentation rate for sentences was determined using a test consisting of 18 sentences and 18 multiple-choice questions (Breznitz & Leikin, 2000). The mean reading rate (milliseconds per letter) for the sentence answered correctly determined the initial presentation rate for RAP training for that participant.

Accelerated training condition

In the first training session, 50 sentences were presented consecutively on the computer screen. The letters in each sentence disappeared one after the other according to the mean reading rate (milliseconds per letter) recorded on the pre-test. Following the disappearance of the sentence from the computer screen, the participant was instructed to answer the question at a self-paced rate. The presentation rate decreased from one sentence to the next in gradations of 2 % (Breznitz, 1997a, b). The presentation rate decreased only when the participant's answers to the probe questions were correct on 10 consecutive sentences.

Statistical analyses

In order to rule out differences in IQ and attention abilities between the English- and Hebrew-speaking participants, two separate analysis of variance analyses (ANOVAs) were performed using these measures. Several separate 2×2 [language (Hebrew, English) and group (training, waiting list)] repeated measures (RM) ANOVAs were performed as well as between-groups independent *t* test analysis was performed in order to rule out differences between the training and waiting list groups in IQ, attention, working memory, and speed of processing. Several 2×2 group (training, waiting list) and test (test 1, test 2) RM ANOVAs as well as paired *t* test analysis were performed within each language in order to compare the effect of training within each group. The percentage of gain from training was calculated and compared between the trained groups as well.

Pace and comprehension for silent reading, as measured by the diagnostic mode of RAP, as well as the speed of processing factor, were submitted to three separate 2×2 two-way RM ANOVA analyses, with test (test 1, test 2) as the within-participant variable and language (Hebrew, English) as the between-participant variable. Bonferroni corrections for multiple comparisons for the behavioral statistics were applied. Due to the differences in ages and grades (see Table 1), we controlled for age (i.e., included it as a covariate of no interest) throughout all our analyses.

Study design and procedure

Following the verification of the existence of RD using the baseline reading measures, children were enrolled to either the training or the waiting list groups. Both Hebrew- and English-speaking training and waiting list groups performed the baseline cognitive and reading measures. Then, only the training group started training in RAP for an overall of 4 weeks (five times per week, 20 min per day) in its own language. After 20 sessions of training, participants both from the waiting list and the training group were tested for reading ability. After completion of the study, children from the waiting list group were given the opportunity to train on RAP as well.

Results

Baseline measures

Test 1 (T1) baseline behavior measurements were analyzed using several 2×2 [(language: Hebrew, English)×(group: training, waiting list)] univariate ANOVA tests and *t* tests. No significant differences in IQ and attention scores were found between English- and Hebrew-speaking participants [for IQ: $F(1, 87)=1.621$, $p=0.206$; for attention scores: $F(1, 87)=0.382$, $p=0.538$]. No significant differences between the waiting list and training groups on IQ and attention tests were found. No differences were found for reading as well as in speed of processing, working memory, and decoding measures (see Table 2 for *F* tests' interaction and *t* tests' contrast results). Since silent reading comprehension measures were taken from the RAP, this test was administered only to Hebrew- and English-speaking children who trained with the program. No baseline differences were found for silent reading comprehension between the two training groups (see Table 3).

Table 3 The effect of RAP training in Hebrew- and English-speaking children with dyslexia in silent reading and speed of processing measures

	Hebrew		English		*F* test	Contrast	*t*
	Test 1 Trained	Test 2	Test 1 Trained	Test 2			
	M (SD) (A)	*M* (SD) (B)	*M* (SD) (C)	*M* (SD) (D)			
Pace (ms/letter)	195.23 (94.52)	106.41 (51.83)	166.88 (60.31)	125.91 (44.1)	Test [$F(1, 45)=21.41$, $p<0.001$, $\eta^2=0.32$]	A>C	1.252, ns
						A>B	4.383***
						C>D	2.321*
						D>B	−1.357, ns
Comprehension (percent)	65.42 (12.58)	87.83 (6.12)	64 (7.16)	88.37 (7.4)	Test [$F(1, 44)=163.21$, $p<0.001$, $\eta^2=0.78$]	A>C	0.485, ns
						B>A	−8.836***
						D>C	−9.921***
						D>B	−0.26, ns
Speed of processing (symbol search, standard score)	9.64 (2.16)	10.42 (1.821)	9.1 (2.62)	10.55 (2.34)	Test [$F(1, 42)=33.51$, $p<0.001$, $\eta^2=0.44$]	A>C	0.785, ns
						B>A	−5.54***
						D>C	3.289**
						D>B	−0.63, ns

*$p<0.05$; **$p<0.01$; ***$p<0.001$

ns=did not reach significant differences (p>0.05)

Effect of RAP training on reading measures

The effect of RAP training on silent reading measures

Reading speed The language×test (2×2) RM ANOVA analysis revealed a main effect of the test [$F(1, 45)=21.41$, $p<0.001$, $\eta^2=0.32$], which implies faster reading pace after RAP training in both languages [in Hebrew—test 1, 195.23 (94.52)>test 2, 106.88 (60.31), $t=4.383$, $p<0.001$; in English—test 1, 166.88 (60.31)>test 2, 125.91 (44.1), $t=2.321$, $p<0.05$]. No main effect for language [$F(1, 45)=0.099$, $p=0.75$, $\eta^2=0.002$] or language×test interaction [$F(1, 45)=2.91$, $p=0.095$, $\eta^2=0.061$] was found. See Fig. 1 and Table 3 for details.

Reading comprehension The language×test (2×2) RM ANOVA analysis revealed a main effect of the test [$F(1, 44)=163.21$, $p<0.001$, $\eta^2=0.78$], which implies greater comprehension scores after RAP training in both languages [in Hebrew—test 1, 65.42 (12.58)<test 2, 87.83 (6.12), $t=-8.836$, $p<0.001$; in English—test 1, 64 (7.16)<test 2, 88.37 (7.4), $t=-9.921$, $p<0.001$]. No main effect for language [$F(1, 44)=0.051$, $p=0.822$, $\eta^2=0.001$] or interaction [$F(1, 44)=0.28$, $p=0.59$, $\eta^2=0.006$] was found. See Fig. 2 and Table 3 for details.

Speed of processing The language×test (2×2) RM ANOVA analysis using the speed of processing factor revealed a main effect of the test [$F(1, 42)=33.51$, $p<0.001$, $\eta^2=0.44$], which implies greater speed of processing scores after training with RAP in both languages [in Hebrew—test 1, 9.64 (2.16)<test 2, 10.42 (1.82), $t=-5.54$, $p<0.001$; in English—test 1, 9.1 (2.62)<test 2, 10.55 (2.34), $t=3.2289$, $p<0.01$]. No main effect for language [$F(1, 42)=0.003$, $p=0.95$, $\eta^2=0.00$] or interaction [$F(1, 42)=0.97$, $p=0.32$, $\eta^2=0.02$] was found. See Table 3 for details.

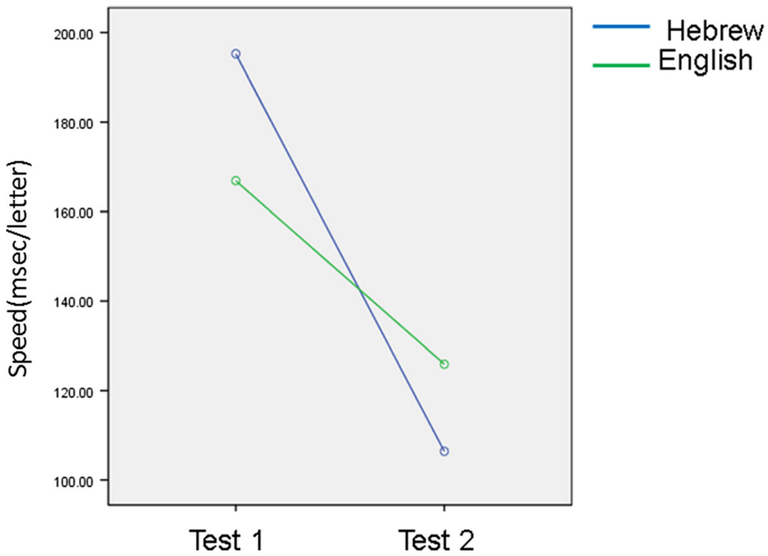

Fig. 1 The effect of RAP on silent reading pace (ms/letter) of Hebrew- and English-speaking children. Reading speed (in ms/letter) before (test 1) and after (test 2) reading training in Hebrew-speaking (*blue*) and English-speaking (*green*) children. No significant differences between the test 2 scores for Hebrew- and English-speaking children (see also Table 3, contrasts B and D) were found

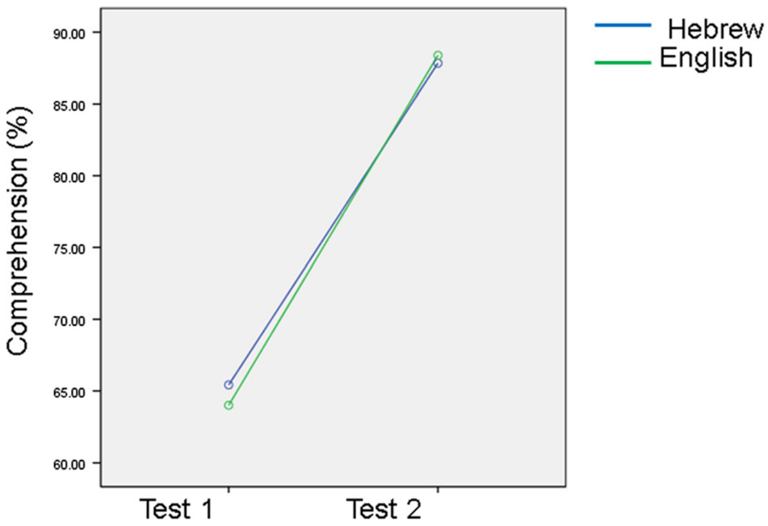

Fig. 2 The effect of RAP on silent reading comprehension of Hebrew- and English-speaking children. Reading comprehension (in percentage) before (test 1) and after (test 2) reading training in Hebrew-speaking (*blue*) and English-speaking (*green*) children. No significant differences between the test 2 scores for Hebrew- and English-speaking children (see also Table 3, contrasts B and D) were found

The effect of RAP training on oral reading in each orthography

Hebrew-speaking children with RD In order to measure the effect of training on oral reading measures, several different group×test (2×2) RM ANOVA analyses were used. For word reading, analysis revealed a main effect of the test [$F(1, 52)=42.26$, $p<0.001$, $\eta^2=0.44$] as well as a significant interaction [$F(1, 52)=53.33$, $p<0.001$, $\eta^2=0.5$]. Participants in the training group read more words per minute after training [words—training groups, 57.67 (12.15)> waiting list, 43.9 (8.78)]. The same analysis for pseudowords resulted in a main effect of the test [$F(1, 52)=4.799$, $p<0.05$, $\eta^2=0.08$] as well as a significant interaction [$F(1, 52)=10.11$, $p<0.01$, $\eta^2=0.16$] [pseudowords—training groups, 43.16 (10.64)>waiting list, 33.77 (8.7)]. These results reveal greater scores after intervention and a greater difference between test 2 and test 1 scores in the training group than in the waiting list group. Oral reading speed of children in the training group was faster after intervention, as demonstrated by the main effect of the test [$F(1, 52)=37.07$, $p<0.001$, $\eta^2=0.41$] as well as a significant interaction [$F(1, 52)=25.86$, $p<0.001$, $\eta^2=0.332$] [training groups, 580.37 (150.37)<waiting list, 842.64 (422.28)], and more accurate than the waiting list group as demonstrated by the moderate main effect of the test [$F(1, 52)=3.53$, $p=0.06$, $\eta^2=0.064$] as well as a significant interaction [$F(1, 52)=5.48$, $p<0.05$, $\eta^2=0.09$] [error rates in training groups, 3.85 (4.5)<waiting list, 8.66 (9.68)]. The training group subjects also improved their reading comprehension following RAP training, whereas reading comprehension in the waiting list group remained stable as shown by the main effect of the test [$F(1, 52)=11.004$, $p<0.01$, $\eta^2=0.17$] as well as a significant interaction [$F(1, 52)=5.48$, $p<0.05$, $\eta^2=0.09$] [training groups, 15.11 (3.48)<waiting list, 12.48 (4.61)]. No significant differences in any of these measures were found within the waiting list group. See Table 4.

English-speaking children with RD Several different group×test (2×2) RM ANOVA analyses were used also among the English-speaking children. Analysis for words revealed a main effect of the test [$F(1, 33)=6.25$, $p<0.05$, $\eta^2=0.15$] as well as a significant interaction [$F(1, 33)=7.05$,

Table 4 The effect of RAP training in Hebrew-speaking children with dyslexia in oral reading measures

Measures	Test 1		Test 2		F test	Contrast	t
	Trained (A) M (SD)	Waiting list (B) M (SD)	Trained (C) M (SD)	Waiting list (D) M (SD)			
Words per minute (number)	46.61 (9.94)	44.54 (9.2)	57.67 (12.15)	43.9 (8.78)	Test [$F(1, 52)=42.26, p<0.001, \eta^2=0.44$]; group×test [$F(1, 52)=53.33, p<0.001, \eta^2=0.5$]	A>B	0.795, ns
						C>D	4.774***
						C>A	−7.202***
						B>D	1.402, ns
Pseudowords per minute (number)	37.53 (9.8)	34.81 (8.32)	43.16 (10.64)	33.77 (8.7)	Test [$F(1, 52)=4.799, p<0.05, \eta^2=0.08$]; group×test [$F(1, 52)=10.11, p<0.01, \eta^2=0.16$]	A>B	1.097, ns
						C>D	3.545**
						C>A	−3.375**
						B>D	0.817, ns
Oral reading accuracy (errors)	8.62 (6.4)	8.14 (4.66)	3.85 (4.5)	8.66 (9.68)	Test [$F(1, 52)=3.53, p=0.06, \eta^2=0.064$]; group×test [$F(1, 52)=5.48, p<0.05, \eta^2=0.09$]	A>B	0.316, ns
						D>C	−2.342*
						A>C	3.697**
						D>B	−0.279, ns
Oral reading pace (ms)	872.51 (334.14)	868.74 (454.5)	580.37 (150.37)	842.64 (422.28)	Test [$F(1, 52)=37.07, p<0.001, \eta^2=0.41$; group×test [$F(1, 52)=25.86, p<0.001, \eta^2=0.332$]	A>B	0.035, ns
						D>C	−3.04**
						A>C	6.447***
						B>D	0.998, ns
Oral reading comprehension (number of correct responses)	12.11 (4.63)	12.22 (4.53)	15.11 (3.48)	12.48 (4.61)	Test [$F(1, 52)=11.004, p<0.01, \eta^2=0.17$]; group× test; [$F(1, 52)=5.48, p<0.05, \eta^2=0.09$]	B>A	−0.089, ns
						C>D	2.363*
						C>A	−4.684***
						D>B	−1.637, ns

*$p<0.05$; **$p<0.01$; ***$p<0.001$

ns=did not reach significant differences (p>0.05)

$p<0.05$, $\eta^2=0.17$]. Participants in the RAP training group read more words per minute after the intervention as compared to the waiting list group [words—training group, 57.67 (12.15)>waiting list, 43.9 (8.78)]. For pseudowords reading, a main effect of the test [$F(1, 33)=6.29$, $p<0.05$, $\eta^2=0.16$] and a moderate interaction [$F(1, 33)=3.2$, $p=0.08$, $\eta^2=0.08$] were observed. Participants in the RAP training group read more pseudowords per minute after intervention as compared to the waiting list group [training groups, 28.27 (10.8)>waiting list, 23.27 (11.88)]. A significant interaction was observed for oral reading speed as well [$F(1, 33)=4.183$, $p<0.05$, $\eta^2=0.113$], whereas children in the training group showed greater change following intervention than the waiting list group [training groups—in test 1=5.94 (1.66), test 2=6.95 (1.98)>waiting list—in test 1=6.57 (3.11), test 2=6.15 (1.64)]. A significant main effect of the test for reading comprehension was observed as well [$F(1, 33)=9.41$, $p<0.01$, $\eta^2=0.22$], demonstrating greater comprehension scores in test 2 vs. test 1 for both groups. Despite the trend of higher scores in the training group as compared to the waiting list group, no significant differences in oral reading accuracy and comprehension were found between groups. See Table 5.

The effect of RAP training on gains in oral reading measures

Before comparing the differences in gain from RAP in the Hebrew- and English-speaking training groups, we ruled out baseline differences in these measures. Due to the different tests that were used to assess oral reading, we separately converted the results for these tests before intervention (test 1) from each group to *Z* scores. Independent *t* test analysis showed no baseline differences for oral reading measures between Hebrew- and English-speaking training groups in oral reading measures. See Table 6.

In order to compare the gain from training in each of the oral reading objective measures, independent *t* tests were calculated using the gain percentage. A greater gain in word reading [Hebrew 24.14 (17.65), English 12.98 (14.41)], as well as oral reading speed [Hebrew 30.53 (12.91), English 18.26 (20.47)], accuracy [Hebrew 49.42 (51.72), English 12 (28.75)], and reading comprehension [Hebrew 39.4 (47.39), English 18 (22.31)], was observed in the Hebrew-speaking training group, compared to the English-speaking group. No differences in gain from training were observed in pseudoword reading or speed of processing scores. See Table 7.

Discussion

The aim of the current study was to directly compare the effect of RAP training in two orthographies—Hebrew and English—in children with RD. By this, we wanted to highlight the universal effect of RAP on reading ability as well as the centrality of fluency in the reading process. Both Hebrew and English children with RD demonstrated more fluent silent contextual reading and comprehension as well as faster speed of processing and greater oral single word reading. However, the Hebrew-speaking children gained more than the English-speaking children. Hebrew speakers showed higher comprehension scores and faster and more accurate contextual reading as compared to their peers on the waiting list after training.

The universal effect of RAP training in shallow and deep orthographies

When comparing the effect of training on reading in both orthographies, data indicated smaller gains for English-speaking children as compared to the Hebrew sample. It can be suggested

Table 5 The effect of RAP training in English-speaking children with dyslexia in oral reading measures

Measures	Test 1		Test 2		*F* test	Contrast	*t*
	Trained (A) *M* (SD)	Waiting list (B) *M* (SD)	Trained (C) *M* (SD)	Waiting list (D) *M* (SD)			
Words per minute (number)	65.11 (12.99)	65.244 (21.43)	73.2 (15.05)	65 (11.06)	Test [$F(1, 33)=6.25$, $p<0.05$, $\eta^2=0.15$]; group×test [$F(1, 33)=7.05$, $p<0.05$, $\eta^2=0.17$]	B>A	−0.23, ns
						C>D	1.282*
						C>A	−4.424***
						B>D	0.091, ns
Pseudowords per minute (number)	21.95 (8.67)	22.22 (11.27)	28.2 (10.8)	23.27 (11.88)	Test [$F(1, 33)=6.29$, $p<0.05$, $\eta^2=0.16$]; group×test [$F(1, 33)=3.2$, $p=0.08$, $\eta^2=0.08$]	B>A	−0.088, ns
						C>D	1.261, ns
						C>A	−3.077**
						D>B	−0.528, ns
Oral reading accuracy (standard score)	6.81 (2.81)	6.28 (1.94)	7.1 (1.8)	6.53 (1.75)		A>B	−0.772, ns
						C>D	1.262, ns
						C>A	−0.55, ns
						B>D	−0.533, ns
Oral reading pace (standard score)	5.94 (1.66)	6.57 (3.11)	6.95 (1.98)	6.15 (1.64)	Group×test [$F(1, 33)=4.183$, $p<0.05$, $\eta^2=0.113$]	A>B	−0.772, ns
						C>D	1.297, ns
						C>A	−4.181**
						D>B	0.563, ns
Oral reading comprehension (standard score)	7.25 (1.39)	7.5 (2.55)	8.4 (1.56)	8.23 (2.39)	Test [$F(1, 33)=9.41$, $p<0.01$, $\eta^2=0.22$]	B>A	−0.371, ns
						C>D	0.238, ns
						C>A	−3.46**
						D>B	−1.319, ns

*$p<0.05$; **$p<0.01$; ***$p<0.001$

ns=did not reach significant differences (p>0.05)

Table 6 A comparison of *Z* scores for oral reading measures in Hebrew- and English-speaking children before RAP intervention (test 1)

Measures	Hebrew (A) *M* (SD)	English (B) *M* (SD)	Contrast	*t*
Words per minute	1.08 (1.04)	−0.03 (0.77)	A>B	0.405, ns
Pseudowords per minute	0.14 (1.07)	−0.013 (0.89)	A>B	0.548, ns
Oral reading accuracy	−0.004 (0.84)	−0.11 (0.70)	A>B	0.509, ns
Oral reading pace	0.04 (1.15)	0.09 (1.1)	B>A	−0.143, ns
Oral reading comprehension	−0.12 (1.02)	−0.05 (0.71)	B>A	0.16, ns

ns=did not reach significant differences ($p>0.61$)

that, as opposed to the deep/irregular English orthography, Hebrew has two forms (Bar-Kochva & Breznitz, 2012): with diacritics (transparent/shallow orthography) and without diacritics (deep/irregular orthography). At the end of second grade or at the beginning of third grade, the diacritics are removed and the child has to be able to decode and understand the printed materials. The Hebrew-speaking children with reading difficulties in the current study were still reading with diacritics in their classroom. As such, they had to be trained with diacritics, and at this stage, their reading skills could therefore experience a greater gain from the training program than the English-speaking group. Interestingly, the improvement of the Hebrew-speaking children was despite the fact that these children are not used to read vowelized words. According to Frost (1994), these children are still proficient in extracting the phonological component out of the written Hebrew orthography, even when it is vowelized (Frost, 1994). This is based on the orthographic depth hypothesis (ODH), which suggests that shallow orthographies can easily support a word recognition process that involves the printed word's phonology. This is because the phonologic structure of the printed word can be easily recovered from the print by applying a simple process of grapheme-to-phoneme conversion (GPC). That leads us to believe that although Hebrew-speaking children were trained on vowelized words, the orthographic characteristics were easily extracted. Regardless, it seems that training was more effective in the Hebrew-speaking children. It is conceivable that due to the structure of the English language (compared to the language structure in Hebrew), longer RAP training might be more effective for reading enhancement. Does this mean that it is more

Table 7 A comparison of the gain from RAP training in Hebrew- and English-speaking children with dyslexia in oral reading measures

Measures	Hebrew Gain from training (A) *M* (SD)	English Gain from training (B) *M* (SD)	Contrast	*t*
Words per minute	24.14 (17.65)	12.98 (14.41)	A>B	2.517*
Pseudowords per minute	18.43 (26.16)	34.3 (43.39)	B>A	−1.452, ns
Oral reading accuracy (percent)	49.42 (51.72)	12 (28.75)	A>B	3.048**
Oral reading pace	30.53 (12.91)	18.26 (20.47)	A>B	2.515*
Oral reading comprehension (percent)	39.4 (47.39)	18 (22.31)	A>B	2.058*

*$p<0.05$; **$p<0.01$

ns=did not reach significant differences (p>0.05)

challenging for children with reading difficulties to overcome their decoding problems in English than in Hebrew due to the different nature of orthographies (deep vs. shallow)? A future study that uses a longer training period in the two groups should confirm if these differences are due to greater exposure, which may be needed in English. Alternatively, a comparison of training Hebrew-speaking children in deep form of Hebrew (no diacritics) vs. shallow one (with diacritics) will be able to validate if this differential effect on Hebrew- and English-speaking children is due to the differences in orthographies.

One of the possible general effects of RAP may be on speed of processing (SOP) abilities. Both training groups exhibited an increase in speed factor following training. The relationship between speed of processing (SOP) and reading has been reported in multiple studies (Breznitz, 2006; Breznitz & Misra, 2003; Kail, 1991). It has been suggested that SOP is an underlining factor of fluency (Breznitz & Misra, 2003). As such, it is conceivable that training fluency also enhanced SOP. However, the direct relations between these two measures should be further examined.

The important role of fluency in silent and oral reading

The RAP program trains silent reading fluency as well as silent reading comprehension (see effect of “Test” for both Hebrew- and English-speaking children in the training groups, and Table 3, contrasts B and D for the absence of difference between groups). Although, practically, RAP trains fluency, a possible explanation to the positive effect it has on comprehension is due to the nature of its manipulation. As described in Breznitz and Share (1992), the manipulation of this program forces the reader to process more meaningful units (i.e., words) in a given time and, therefore, decreases the bottleneck in working memory. These working memory resources then become available for comprehension processes, including inferences and integration with world knowledge. Interestingly, the improvement in reading comprehension was observed for both groups in the silent reading domain, but was limited to the Hebrew-speaking group in the oral reading domain. One possible reason for the lack of significant results in English-speaking children is that the English-speaking waiting list group outperformed in its reading comprehension scores in test 2 (although not significantly, see Table 5, contrasts B and D), which resulted in a nonsignificant change between the training and the waiting list groups (despite a significant improvement within the training group, see Table 5, contrasts A and C). However, since the current study did not explicitly examine the cognitive abilities underlying reading comprehension, a future study should be conducted in order to provide a mechanistic model for the effect of RAP on silent vs. oral reading comprehension. On the contrary to the reading comprehension ability, our results indicated the beneficial effects of RAP in both silent and oral reading and in both Hebrew and English orthographies. The relationship between oral and silent reading has been well established in literature (Ashby, Yang, Evans, & Rayner, 2012; Elgart, 1978; Galin et al., 1992; De Jong & Share, 2007; Salasoo, 1986). At the initial stages of silent reading acquisition, in the lower grades, silent reading is accomplished by decoding letters to their corresponding oral sounds, because children are still paying attention to all letters sounds (Elgart, 1978). Our participants were poor readers and were also tested at the age/grade during which the transition between oral and silent reading takes place. At least at this stage of reading, it is conceivable that, in both orthographies, the effects of RAP are not limited to one reading mode, but rather improve measures of both silent and oral reading in RD children.

Although the RAP trains silent fluency and comprehension in context, the improvement in oral reading in the current study was not limited to contextual reading, but was also observed in single word reading. Based on previous studies regarding the acceleration phenomenon in

Hebrew (see Breznitz, 2007 for review), this gain can be due to a decrease in hesitations, distractibility, and more focused attention toward the written stimuli, as all were seen previously after RAP training in slow readers (Breznitz, 2006; Breznitz et al., 2013; Breznitz & Berman, 2003). Moreover, data from a previous study (Horowitz-Kraus & Breznitz, 2010) indicated a larger activation of a cognitive mechanism that increases the awareness for word-reading errors after RAP training. This decrease in hesitations and increase in awareness might assist in creating more solid connections between the phonological and orthographical processes, making the cognitive processes involved in reading more automatic, thereby resulting in more fluent reading, even at the single word level (Breznitz, 2002). These overall improvements, in basic (word level) and higher levels (contextual reading and comprehension), in silent as well as in oral reading, highlight the importance of fluency in the reading process. Evidence for an improvement in letter-sound connection can be found in the significantly increased scores in phonological abilities (pseudowords reading) both in Hebrew and English after RAP training, even though this ability was not directly trained. The results of the current study should be concerned with the following limitations: (1) the average age (and the age span) of the Hebrew- and the English-speaking children was slightly different, which might affect the gain in oral reading and the differences in verbal ability. This might also be caused due to a larger standard deviation in age for the English-speaking children which might cause greater differences in reading gains within the group. (2) The group of Hebrew-speaking children was larger than the group of the English-speaking children. (3) The children who participated in this study were all from an average socioeconomic status (SES). It is therefore not reflecting the effect of RAP training on the entire SES spectrum. Future study should look at the effect of RAP training on lower SES children (who may also suffer from lower literacy and reading skills, see Ardila et al., 2010) as compared to middle and high SES children, as well as on the effect of education level of the parents on these outcomes (see van Ryn & Burke, 2000). (4) The oral reading measures that were used in the two orthographies used two different scaling methods (actual values in Hebrew and standard scores in English), which made it challenging to compare the gain from training in between the two groups. We tried to address this issue by converting the values into percentages. Future study should use standard scores in both orthographies.

Conclusions

The current study demonstrates, for the first time, that the effect of RAP on reading ability in children with RD is a universal effect, regardless of the type of orthography used. These findings strengthen the possibility that RAP trains more basic cognitive abilities in addition to reading. This was supported by the universal effect of this program on speed of processing. It also highlights the important role of fluency in the reading process directly affecting reading comprehension. These results are encouraging, especially given that RAP is a computerized tailor-made program that can be used in parallel by several users and in different orthographies, making it extremely easy to administer, at scale, anywhere in the world where there is a computer. In order to understand the exact mechanisms underlying the effects of RAP training, future studies should employ neuroimaging and eye-tracking devices that can pinpoint the cognitive processes and the neural circuitries underlying reading before and after intervention.

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