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What are the underlying skills of silent reading acquisition? A developmental study from kindergarten to the 2nd grade

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Abstract Research on reading acquisition and on the processes underlying it usually examined reading orally, while silent reading, which is the more common mode of reading, has been rather neglected. As accumulated data suggests that these two modes of reading only partially overlap, our understanding of the natural mode of reading may still be limited. The present study was set out to explore the underlying skills of reading acquisition examined using silent measures of reading. To this end, children acquiring reading of the phonologically transparent vowelized Hebrew orthography were followed from kindergarten to the 2nd grade. The relations between a range of verbal and visual-spatial skills with measures of silent reading were tested. Phonological awareness, RAN and vocabulary explained a significant amount of variance in fluency in word recognition and in fluency in decoding of pseudo-homophones, while visual speed of processing of numeric symbols explained a notable amount of variance in fluency in word recognition only. Phonological awareness, morphological awareness and phonological working memory were the main skills explaining the variance in reading comprehension. The relations of these skills with the quality of oral reading have been widely established in the reading literature. Furthermore, a similar developmental picture was obtained in the relations between some of these skills and silent reading, as was found with oral reading. Therefore the role of these skills in reading may not be restricted to a certain mode of reading. Also consistent with findings on oral reading, the role of the visual non-orthographic skills in the measures of silent reading was insignificant to very small. Together these results imply that the processes underlying measures of silent reading are not substantially different from the ones

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underlying measures of oral reading, at least not at the early stages of reading acquisition of a transparent orthography.

Keywords Silent reading · Phonological awareness · Rapid naming · Transparent orthographies · Reading acquisition

Introduction

Reading is a complex procedure which relies on a cognitive infrastructure involving a variety of skills, from visual perception to high order functions of information processing (Breznitz, 2006). Developmental studies have identified a number of such key skills explaining the variance in reading acquisition, which can be measured as soon as kindergarten age or early in G1, such as phonological awareness, rapid automatized naming (RAN), grammatical skills, memory, speed of processing (SOP), vocabulary and other aspects of general ability (e.g. Bowey, 2005; Carlisle, 1995; de Jong & van der Leij, 1999; Georgiou, Parrila, & Kirby, 2006; Meyler & Breznitz, 1998; Näslund & Schneider, 1996; Plaza & Cohen, 2005; Scarborough, 1990; Share, Jorm, Maclean, & Matthews, 1984; Share, 1995; Shatil & Share, 2003; Snowling, Bishop, & Stothard, 2000; Wagner et al., 1997).

However, most of the knowledge accumulated to date on reading acquisition and on the skills underlying it was based on studies examining reading orally. Much less is known on silent reading, which is the more common mode of reading. Oral reading tasks permit the extraction of more detailed information on decoding skills than silent reading tasks, and are therefore favored in both research and clinical practice as diagnostic tools. However, oral reading tasks may not fully represent silent reading ability (Share, 2008; Spache, 1976). For instance, the correlation between these two modes of reading (examined using oral naming and silent semantic decision of pseudo-homophones) was found to be only moderate among Hebrew readers in the 3rd grade ($r = .60$, $p < .01$, Canaan & Share, 2002). Abu-Rabia (2001) even failed to find any correlation between accuracy in oral reading and silent reading comprehension among adults. Also, under certain conditions, differences were obtained between oral and silent reading rates and between oral and silent reading comprehension (Canaan & Share, 2002; de Jong, Bitter, Van Setten, & Marinus, 2009; de Jong & Share, 2007; Juel & Holmes, 1981; Rowell, 1976; Salasoo, 1986). It should also be noted that in the study by Canaan and Share (2002) a small group of readers was found to be more impaired on oral reading tasks than on silent reading tasks, while another small group showed the opposite pattern. These two groups of readers also had distinguishing cognitive profiles. A series of neuro-physiological dissociations further converge to indicate that these two modes of reading only partially overlap (review by Share, 2008). These findings raise doubts concerning our understanding of the natural mode of reading. The examination of silent reading acquisition and the skills underlying it was the purpose of this study.

Out of the skills explaining the variance in the development of reading ability, phonological awareness and RAN have received much attention, as their strong relations with reading acquisition are a consistent finding in the literature on oral reading. However, their role in explaining the variance in silent reading is yet unclear. Phonological decoding was found to be involved in both oral and silent reading tasks (de Jong et al., 2009). At the same time, while oral articulation may require thorough phonological decoding of the stimuli, its silent processing may not (de Jong & Share, 2007). And indeed, in the few studies comparing the two modes of reading effects reflecting phonological processing have been more associated with oral reading than with silent reading (Canaan & Share, 2002; Schumm & Baldwin, 1989; review by Share, 2008). As phonological awareness has an important role in phonological decoding (Mody, 2003; Share, 1995, 2008), its role in reading may be stressed when pronunciation is required.

Similarly, according to one explanation of the RAN-reading relations, RAN is a phonological process, representing the ability to retrieve phonological codes from the long-term memory (Vaessen, Gerretsen, & Blomert, 2009; Wagner, Torgesen, & Rashotte, 1994; Wagner et al., 1997). If phonological processes are stressed in oral reading tasks, the role of RAN may also be emphasized. At the same time, according to a second interpretation of the RAN-reading relations, in spite of RAN's shared variance with phonological processing, it represents also a separate skill, namely, a precise timing mechanism necessary for establishing orthographic codes and linking them to their phonological codes (Bowers & Wolf, 1993; Wolf & Bowers, 1999). This timing mechanism was suggested to contribute to the creation of orthographic knowledge (Bowers & Newby-Clark, 2002)—a type of knowledge found to be related to measures of both oral and silent reading (Barker, Torgesen, & Wagner, 1992; Canaan & Share, 2002). Consequently, RAN may also explain the variance in silent reading.

The present study extends the examination of the development of silent reading and the skills underlying it by longitudinally examining the relations between a range of early verbal and visual-spatial skills (tested in K and G1) and certain aspects of silent reading (tested in G1 to G2). The verbal and visual-spatial skills tested were the ones commonly examined in the literature on oral reading acquisition.

The reading tasks addressed word identification and decoding skills, as these constitute the building blocks of skilled reading (Bowey, 2005; Bruck, 1990; Share, 1995; Stanovich, 1982; Vellutino, Fletcher, Snowling, & Scanlon, 2004). Notably, silent reading of words is usually tested by lexical decision; however, this type of task does not necessarily involve access to a word's meaning, which is the final goal of natural reading. Another task applied in research of silent reading is reading in context with or without manipulations applied on target words embedded in sentences (Barker et al., 1992; Juel & Holmes, 1981; Salasoo, 1986; Schumm & Baldwing, 1989). However, such tasks may only provide an indirect measure of single word reading ability, as aspects associated with processing in context are also involved. A semantic decision task may be a more suitable tool in examining the extraction of meaning in silent single word recognition and decoding (Van Orden, 1987; Van Orden, Johnston, & Hale, 1988). Therefore, silent semantic decision of words and pseudo-homophones was examined in the current study. The purpose of the first task was to examine word recognition skills (which can be read as familiar word patterns or decoded), and the purpose of the latter task was to examine decoding skills. Notably, although reading comprehension following silent reading is often examined in the research of reading, such a measure was included in the present study in order to obtain a wider picture on the silent reading abilities and on the processes underlying them of the sample of children examined.

The participants were children acquiring reading of the vowelized Hebrew orthography. In this form of script the phonological information is fully indicated, allowing for an almost unambiguous mapping between spelling and sound (Share & Levin, 1999). In G1 the Hebrew letters and diacritics are gradually introduced, and by the end of the year the children can usually read simple short texts. By the end of G2 children are expected to be able to read texts of growing complexity. Previous studies have shown fast mastery of decoding achieved by novice Hebrew readers as early as the end of G1 (Share & Levin, 1999). It was therefore assumed that the examination of reading in G1 and G2 should cover the stages of Hebrew reading acquisition, until reading is established.

Method

Participants

Seventy-four children (33 boys) were followed from K to G2 (mean age at K = 6 years and 1 month SD = 3.6 months). All were native speakers of Hebrew, without diagnoses of developmental difficulties at kindergarten age. Reading instruction in the schools which the children attended was based on the phonetic approach.

Materials

Silent reading tests

A standardized Israeli battery of silent reading tests (ELUL, Shatil, Nevo, & Breznitz, 2007) was administered in G1 and G2. This battery was developmentally designed, with age-appropriate versions from G1 to G9. The following sub-tests were analyzed from this battery for the purpose of this study:

Silent semantic decision of words A list of words was presented, and the children were required to circle all words signifying animal names (for example: Balloon, Nice, Dog, Drinking, Policeman, Duck). The version of test administered in G1 included 80 words, while the test administered in G2 included the same words, in addition to 20 other words presented at the end of the list. The number of letters ranged from 2 to 6 and the number of syllables ranged from 1 to 4 on both versions of the test. Examples including 24 words preceded the task.

Silent semantic decision of pseudo-homophones Pseudo-homophones were presented, and the children were asked to circle those pseudo-homophones sounding like names of food items (for example, Kandy, Focks, Soop). The same list of pseudo-homophones, including 78 items, was administered in both grades. The number of letters ranged from 3 to 6 and the number of syllables ranged from 1 to 4. Examples including 24 pseudo-homophones preceded the task.

Table 1 Descriptive statistics of the silent measures of reading and a comparison between performance in G1 and G2

	G1		G2		$t_{(73)}$
	Mean	SD	Mean	SD	
Accuracy in semantic decision of words	97.27	4.16	97.43	5.09	−.34
Accuracy in semantic decision of pseudo-homophones	93.72	6.66	94.31	5.91	−.78
Fluency in semantic decision of words	24.66	7.51	50.02	17.21	−15.52***
Fluency in semantic decision of pseudo-homophones	19.03	5.51	29.57	7.95	−13.22***
Reading comprehension	83.66	15.69	85.33	10.81	−.99

Accuracy percent of items correctly identified, *fluency* words/pseudo-homophones correctly identified in 1 min, *SD* standard deviation

* $p \leq .05$; ** $p \leq .01$; *** $p \leq .001$

One point was given for each correct answer in the two semantic decision tasks. This score was converted into percent of accuracy (Table 1). Fluency in reading has gained recognition in recent years as an important aspect of reading ability, alongside accuracy in reading (Breznitz, 2006). Fluency was suggested to reflect accuracy and automaticity achieved in the processes that underlie reading (Wolf & Katzir-Cohen, 2001), as expressed by performance time (Breznitz, 2006). Therefore, in the current study fluency was conceived as accurate and rapid reading, calculated as the words/pseudo-homophones read correctly within 1 min.

Reading comprehension Comprehension following reading of sentences, a short text and a long text, was tested. In the sentence reading sub-test 10 sentences were presented, each followed by 4 pictures. The children had to choose the picture best describing each sentence. For example: "The children are building a tower of blocks". This sentence was followed by one picture depicting the exact situation described by the sentence, and by 3 other picture distracters. The sentences in G1 ranged from 3 to 8 words in a sentence. The sentences in G2 were longer, ranging from 4 to 20 words in a sentence, and more complex than the ones presented in G1. In the text reading sub-tests the children were requested to read one short text (comprising 46 words in G1 and 95 words in G2) and another longer text (comprising 70 words in G1 and 101 words in G2). Each text was followed by 10 statements about it, and the children had to decide whether the statements were true or false. The children earned 1 point for each correct answer in the three sub-tests. A sum-score was calculated, representing comprehension in contexts of different length and complexity. This score was transformed into percent of accuracy, as presented in Table 1.

General ability

Block design (the Hebrew version of the Wechsler Preschool and Primary Scale of Intelligence, Leiblich, 1971) The children were required to recreate spatial patterns using colored cubes (red and white), according to certain visual patterns. The test comprised 10 items and the children were given 2 attempts to reproduce each item. Each attempt was restricted in time. Two points were given for each correct item reproduced in a first try, and 1 point was given for each correct item reproduced in a second try. The test was stopped if the children failed to reproduce two sequential items. The sum raw score was converted into a standardized score.

Expressive Hebrew vocabulary test (Tavor, 2008) The examiner presented 52 pictures describing nouns, verbs, and adjectives, which the children had to name (for example, the experimenter asked the children "what is she doing?" while pointing to a picture of a girl drawing. The correct answer would be "drawing"). A score of 2 points was given for each full answer, while a partial answer was scored 1 point.

Phonological awareness

Initial and final consonant isolation (phonological awareness test, Tubul, Lapidot, & Wohl, 1995) The initial consonant isolation test comprised 10 frequent words of different length (2–3 syllables, 3–6 letters). The examiner read a word aloud, and the children were required to pronounce the initial consonant of the same word (for example: the correct answer in response to the word "geshem", meaning rain in Hebrew, would be "g"). One point was given for each correct answer. Ten other frequent words were included in the final consonant isolation test (2–3 syllables, 3–4 letters). The same procedure was used, except that now the children had to pronounce the final consonant of each word. Three practice items preceded each task.

Syllabic omission (Shani, Lachman, Shalem, Bahat, & Zeiger, 2006) The children were asked to omit one syllable from the beginning, the middle or the end of a word. For example, the children were asked to say the word "matana", meaning "gift" in Hebrew, without "ta". The correct answer would be "mana". As this test was originally designed for children from G2 to G6, it was administered to the children in G1 only, including the first 8 out of the 15 items from the original test. The words were 3–5 letters in length, consisting of 2–3 syllables. The children earned one point for each correct answer.

Rapid naming (RAN)

RAN digits (Breznitz, 2005, after Denckla & Rudel, 1974) A table of 5 rows and 10 columns was presented to the children. Five different digits appeared 10 times in this table (an example of a row: 6 4 7 9 2 4 6 7 2 9). The children were asked to name each digit as fast as possible. Each correct naming of a stimulus was scored 1 point and performance time was recorded. A RAN speed measure was computed by dividing the number of stimuli correctly named by performance time.

Morphological awareness

Sentence completion: morphological inflections (Shatil, 2002) The children had to complete a missing word in a sentence read by the experimenter. Morphological inflection rules had to be applied in order to correctly complete the word according to its context. The children had to take into consideration morphological rules of number, gender and tense imposed by the context, and to apply them onto the missing word. For example, "Dad is driving now. He also *drove* yesterday". The test comprised 20 sentences altogether. A score of 2 points was given for each complete answer, and a score of 1 point for each partial answer.

Phonological memory

All memory tests were sub-tests from the AWMA battery (Alloway, 2007). This test was originally designed to be administered by computer in English. In this study a Hebrew translation of this test (Nevo & Breznitz, 2010) was administered orally. All tests were divided into blocks. Each block comprised 6 trials of identical difficulty. The blocks were arranged in a rising level of difficulty. Each trial was scored 1 point. The tests were stopped after 3 errors in one block.

Word and pseudoword recall (phonological short-term memory) The children listened to a sequence of single-syllabic words and had to recall each sequence in the correct order. In each block 1 word was added to the sequence (the first block included 1 word per trial, and the last block included 6 words per trial). For example, one word: Tooth; two words: Boy, Fun; three words: Bull, Arm, Juice. The same procedure was administered with single-syllabic pseudowords (for example, one pseudoword: Vad; two pseudowords: Nat, Tsis; three pseudowords: Kiz, Mes, Rix).

Forward digit recall (phonological short-term memory) The experimenter read out sequences of digits, of a rising number of items. The first block included 1 digit per trail, and the last included 9 digits per trial. The children were asked to recall each sequence in the correct order (for example, one digit: 4; two digits: 6, 2; three digits: 4, 8, 3).

Listening recall (phonological working memory) The children listened to a series of individual sentences read by the experimenter, and were later asked to judge whether each sentence was true or false. In each block one sentence was added to each trial, ranging from a block of 1 sentence per trial to a block of 6 sentences per trial. Memory was assessed by the child's ability to recall at the end of a trial, the final word of each sentence in the correct order. For example: "scissors cut paper". "Gold fish have fur". After the first sentence the children had to say "correct", and after the second "false", and then repeat "paper, fur".

Backwards digit recall (phonological working memory) The children listened to a sequence of digits of a rising number of items. The first block comprised 2 digits per trail and the last block comprised 7 digits per trail. The children were asked to recall each sequence in the reverse order. For example: the experimenter read out 2 digits 2, 7, and the correct response would be 7, 2.

Visual-spatial memory

Subtests from the computerized AWMA (Alloway, 2007) battery were administered. The structure and scoring of these tests were the same as in the phonological memory tests: the tests were divided into blocks arranged in a rising level of difficulty. Each block comprised 6 trials of identical difficulty. Each trial was scored 1 point and the tests were stopped after 3 errors in one block.

Dot matrix (visual-spatial short-term memory) The children were shown a red dot in a series of four by four matrices. The dot disappeared from the screen (an empty matrix remained), and the children were then asked to point to the cell in the matrix were the dot was presented. In each trial the number of dots that the children had to recall increased, ranging from blocks of 1 dot per trial to blocks of 9 dots per trial.

Block recall (visual-spatial short-term memory) The children were presented with a picture of 9 blocks. A hand appeared on the screen, tapping a series of these blocks in a rising level of difficulty. The children were then asked to reproduce the sequence in its correct order by tapping on the blocks appearing on the screen. The test began with the tapping of one block per trial, and increased to the tapping of 9 blocks per trial.

Odd-one-out (visual-spatial working memory) Three figures ordered in a row of three boxes were presented in each trial. Two of the figures were identical and one was different. The children were asked to point out the outstanding figure in the row. After the row of figures disappeared from the screen, the children had to recall the place of the odd-one-out figure in the row by pointing to its box on the screen. The blocks ranged from 1 set of figures to a block of 7 sets of figures.

Mister X (visual-spatial working memory) Pairs of pictures were presented of two figures of men: the one wore a yellow hat and the other a blue hat. While the first figure was always presented in the same position, holding a ball in the same hand, the man with the blue hat changed his position and the hand holding the ball. The children were first asked whether the two men were holding the ball in the same hand. After the pictures disappeared, the children had to recall the side the ball was held by the man with the blue hat, according to the order of the pairs of pictures presented in each trial. In each block one pair was added, ranging from 1 to 7 per trial.

Visual speed of processing (SOP)

Visual matching (Woodcock & Johnson, 1989) A sheet of 60 rows with 6 digits/numbers in a row was presented. Two digits/numbers appeared twice in each row (e.g., 8 9 5 2 9 7 and 85 32 74 90 61 61). The children were asked to locate and mark the reappearing stimuli as quickly as possible. Working time was limited to 3 min. The children earned 1 point for each row correctly marked.

Cross-out (Woodcock & Johnson, 1989) A sheet of 30 rows with 20 geometric figures in a row was presented to the children. One target figure appeared on the left side of each row, and 19 other similar figures appeared next to it. For example, one row consisted of a target rectangle enclosing a diagonal line (appearing on the left side of the row) and 19 rectangles with lines of different angles, dots or circles within them. The target figure reappeared 5 times on the same row. The children were asked to mark the reappearing target figures by drawing a line through them as fast as they could. The participants were stopped after 3 min. One point was given for each row correctly marked (only rows with all 5 reappearing forms identified earned 1 point).

Procedure

All tests were administered at the last term of each year (May–June). Tests examining verbal and visual-spatial skills were administered in K and once again in G1 (with a few exceptions, see Table S1 in the Supplemental Material). Reading was tested in G1 and G2.

While the children were tested individually on verbal and visual-spatial skills, reading was tested in groups (following the ELUL Test instructions, Shatil et al., 2007). The silent reading battery was restricted in time.

Results

Reading performance

Reading achievements in G1 and G2 are presented in Table 1. Very high accuracy rates in the semantic decision tasks were achieved as early as G1. Accordingly, no improvement from G1 to G2 was observed. A set of simple *t* tests indicated an improvement from G1 to G2 in fluency in both semantic decision tasks. The improvement in reading comprehension was insignificant, however, the standard deviation declined.

In Table S2 (Supplemental Material) descriptive statistics of the verbal and visual-spatial skills is presented. Paired sample *t* tests showed a significant improvement from K to G1 within each skill.

Skills explaining the variance in reading achievements in G1 and G2

Multiple regression analyses were carried out in order to examine which K and G1 skills explained the variance in G1 and G2 silent measures of reading (separate equations were performed for each grade). As ceiling effects were obtained in the accuracy scores of the semantic decision tasks, these were removed from the regression analyses (in order to avoid a distortion effect resulting from lack of variation in the dependent variables). The dependent reading measures were therefore fluency (a combined score of accuracy and speed) in word recognition and in decoding of pseudo-homophones, and reading comprehension.

The K and G1 skills considered to enter the equations as independent variables were the ones showing significant correlations with the measures of reading at least at one point of measurement (Tables S3 and S4 in the Supplemental Material). Principle component analyses confirmed that the skills examined with more than one test (phonological awareness, visual SOP, phonological STM, phonological WM, visual-spatial STM and visual-spatial WM) loaded on the same factors (Table

S5, also see Table S6 and Table S7 for inter-correlations of the verbal and visual-spatial skills). Therefore, these were combined into one variable representing each skill, as detailed in Table S1 (Supplemental Material). It should also be reminded that the phonological awareness tests and the morphological test were scored for both accuracy and performance time. As the accuracy scores of both skills showed generally stronger correlations with the measures of reading than the time scores, the accuracy scores only were entered into the regression equations as independent variables. The rationale for these procedures of data reduction was to create one representing variable for each skill in order to avoid possible effects of multicollinearity between the independent variables.

These procedures resulted in 10 independent variables; however, the number of independent variables entering the regression equations had to be further restricted to 7 at most (due to the sample size, $N = 74$). Each skill was represented by a single variable, apart from memory which included four sub-skills: phonological short-term memory (STM) and working memory (WM) and visual-spatial STM and WM. In order to maintain representation of all major skills in the regression equations, a series of preparatory regressions were carried out in an attempt to examine which of the memory sub-skills best predicted the variance in reading. All the variables representing the other skills were entered into the regression equations as independent variables, while one sub-skill only was entered from the memory measures.

This resulted in four regression equations for each measure of reading: the general ability skills were entered first in one block as control variables (Bowey, 2005). The scores representing phonological and morphological awareness, RAN, visual SOP and phonological STM were entered into a second block in a stepwise manner. In the following equation the phonological WM score replaced the phonological STM score. Next, the visual-spatial STM score replaced the phonological WM score, and finally the visual-spatial WM score was entered instead of the visual-spatial STM score. Neither the phonological memory scores nor the visual-spatial memory scores explained any significant amount of variance in the reading fluency measures and were therefore excluded from the final regression equations reported in Table 2. In contrast, the phonological WM score explained a significant amount of variance in G1 reading comprehension, and the visual-spatial WM score explained a significant amount of variance in G2 reading comprehension. Consequently, these were included in the reported regressions (Table 2) predicting the variance in comprehension (the K and G1 phonological WM scores were entered into the equations predicting G1 comprehension and the K and G1 visual-spatial WM scores were entered into the equations predicting G2 comprehension).

Phonological awareness, RAN and vocabulary explained a significant amount of variance in fluency in word recognition and decoding of pseudo-homophones, while visual SOP explained a notable amount of variance in fluency in word recognition only. The skills explaining the variance in reading comprehension were phonological and morphological awareness and phonological WM, while vocabulary and visual WM also contributed a small amount of variance.

Developmental differences were observed in the relations between the skills, examined in K and G1 and the measures of reading, examined in G1 and G2.

Table 2 Standardized regression coefficients (β) of the K and G1 verbal and visual-spatial skills explaining the variance in G1 and G2 silent reading

	G1		G2	
	K	G1	K	G1
Fluency in semantic decision of words				
Block 1				
Visual-spatial IQ	NS	NS	NS	NS
Vocabulary	.260*	.220*	.337**	.338***
Adjusted R^2	.149***	.149***	.195***	.195***
Block 2				
Phonological awareness acc	NS	.426***	NS	NS
RAN speed	.445***	.251**	.380***	NS
Visual SOP[a]	NS	NS	NS	.373***
Morphological awareness acc	NS	NS	NS	NS
Adjusted R^2	.310***	.405***	.310***	.303***
Fluency in semantic decision of pseudo-homophones				
Block 1				
Vocabulary	.330**	.263**	.314**	.427***
Adjusted R^2	.188***	.188***	.189***	.189***
Block 2				
Phonological awareness acc	NS	.560***	NS	NS
RAN speed	.399***	NS	.457***	.340***
Visual SOP	NS	NS	NS	NS
Morphological awareness acc	NS	NS	NS	NS
Adjusted R^2	.327***	.465***	.375***	.296***
Reading comprehension				
Block 1				
Visual-spatial IQ	NS	NS	NS	NS
Vocabulary	NS	.234*	NS	NS
Adjusted R^2	.206***	.206***	.133**	.133**
Block 2				
Phonological awareness acc	NS	.543***	NS	.251*
RAN speed	NS	NS	NS	NS
Visual SOP	NS	NS	NS	NS
Morphological awareness acc	.322**	NS	.343**	.280*
Phonological WM	.331**	NS	–	–
Visual-spatial WM	–	–	.255*	NS
Adjusted R^2	.368***	.463***	.239***	.256***

Variables in block 1 (general ability) were forced into the models. Variables in block 2 were entered in a stepwise manner. As the two general ability measures (the block design and vocabulary tests) correlated with fluency in word recognition and with comprehension (Table S3 in the Supplemental Material), both were entered into the first block in the equations predicting the variance in these measures of reading. As vocabulary only correlated with fluency in decoding, it was the sole general ability score entering the first block in the equation of this measure of reading

Acc accuracy, *WM* working memory, *RAN* rapid naming, *SOP* speed of processing. *NS* non-significant (variables not entering the models)

* $p \leq .05$; ** $p \leq .01$; *** $p \leq .001$

[a] When each of the two visual SOP measures (Visual Matching and Cross Out) was entered separately into the equation, only the Visual Matching score explained a significant amount of variance in G2 fluency in word recognition ($\beta = .402, p < .001$). Neither of the two visual SOP measures explained any significant amount of variance in the other measures of reading

Phonological awareness explained a significant amount of variance in the reading fluency measures only when both skills were tested in G1. G1 phonological awareness only also explained a significant amount of variance in comprehension, and these relations were stronger with G1 comprehension than with G2 comprehension. Phonological WM (as tested in K) explained a significant amount of variance in G1 reading comprehension alone.

In contrast, visual SOP (as tested in G1) was a significant predictor of fluency in word recognition only when reading was examined in G2. To remind, the combined visual SOP score entered into the regression equations represented the visual processing speed of both grapho-numeric and non grapho-numeric symbols. As the literature on oral reading suggests significant relations with visual processing mainly of orthographic and numeric symbols (Badian, 2005; Barker et al., 1992; Cunningham, Perry, & Stanovich, 2001), the two visual SOP measures were also entered separately as independent variables (in 2 separate equations predicting each measure of reading). The visual matching score, examining the ability to quickly process numeric symbols, proved to be the sole visual SOP measure explaining a significant amount of variance and in G2 fluency in word recognition only ($\beta = .402$, $p < 001$). Another visual skill explaining a significant amount of variance in reading only in G2 was visual WM; however, these relations were weak, and significant only in the case of comprehension.

RAN was generally a more consistent predictor of the reading fluency measures. Two exceptions were the lack of contribution of G1 RAN to G1 fluency in decoding and to G2 fluency in word recognition. These exceptions were probably a result of the shared variance between G1 RAN and G1 phonological awareness and between G1 RAN and G1 visual SOP in explaining the variance in these measures of reading. When both G1 phonological awareness and G1 visual SOP were excluded from analysis G1 RAN did explain a significant amount of variance in G1 fluency in decoding ($\beta = .275$, $p \leq 01$) and in G2 fluency in word recognition ($\beta = .238$, $p \leq 05$).

Vocabulary also explained a significant amount of variance in the reading fluency measures in both grades. In contrast, it predicted reading comprehension in G1 only (however, the relations were weak). Morphological awareness was the more consistent variable related to comprehension, and particularly when the K morphological awareness score was entered into the equations.

Discussion

This study was set out to examine silent reading acquisition and the skills underlying it. Reading performance is first discussed. Accuracy in silent word recognition and decoding examined using semantic decision tasks reached ceiling performance by the end of G1. As the silent reading tests administered were designed to be age-appropriate, this effect may in fact indicate that readers of Hebrew achieve by this stage almost perfect accuracy in these measures of reading. Although oral measures of reading allow for a closer examination of accuracy rates than silent measures of reading, high accuracy scores (although somewhat lower) were also found in studies examining early oral reading of Hebrew, as well as in studies examining early oral reading of other orthographies with transparent grapheme-phoneme relations (Aro & Wimmer, 2003; Mann & Wimmer, 2002; Seymour, Aro, & Erskine, 2003; Share & Levin, 1999; Spencer & Hanley, 2003; Wimmer, 1993). Also consistent with previous work on oral reading of transparent orthographies, fluency in reading proved to be a more sensitive index of reading proficiency than accuracy in reading. Accordingly, a significant improvement was obtained in this measure of reading from G1 to G2. Although comprehension improved from G1 to G2, the improvement did not reach significance. Nevertheless, the standard deviation declined. Therefore, although by the end of G2 reading ability is well established, comprehension has still to develop.

As far as the relations between the early verbal and visual-spatial skills and the measures of silent reading are concerned, phonological awareness was an important underlying skill of the silent measures of reading only when both skills were tested in G1. The stronger relations of phonological awareness and reading when the former is examined after the beginning of formal reading instruction is a consistent finding in the literature based mainly on oral reading; and as previously suggested, it may reflect the mutual development of the two skills (e.g. Bentin & Leshem, 1993; de Jong & van der Leij, 1999; Goswami, Ziegler, & Richardson, 2005; Share, 1995). The stronger relations between phonological awareness and G1 reading than G2 reading stand also well in line with a considerable number of developmental and cross-sectional studies on oral reading acquisition of orthographies with transparent grapheme-phoneme relations (Furnes & Samuelsson, 2010; Müller & Brady, 2001; Nikolopoulos, Goulandris, Hulme, & Snowling, 2006; Sprugevica & Høien, 2003; but see Caravolas, Volín, & Hulme, 2005). According to the functional opacity hypothesis proposed by Share (2008), phonological awareness is most active when opacity in spelling-to-sound correspondence exists. Consequently, readers of transparent orthographies would rely on phonological awareness in reading mainly early on. The results suggest that this hypothesis can be generalized to the measures of silent reading examined in this study in G1 and G2. Another phonological processing variable explaining a significant amount of variance in silent reading in G1 but not in G2 was phonological WM. However, its relations were significant only with comprehension, presumably due to higher demands imposed on memory in reading in context than in reading of isolated words or pseudo-homophones.

Turning next to the RAN-reading relations, RAN was an important predictor of the G1 and G2 silent reading fluency measures. Such long-lasting relations were also found for oral measures of reading fluency (Bowers, 1995; Torgesen, Wagner, Rashotte, Burgess, & Hecht, 1997; van den Bos, Zijlstra, & Spelberg, 2002). Also in line with the oral reading literature, the results indicated that RAN can serve as a reliable predictor of silent measures of reading when examined before the formal instruction of reading.

It should be noted, that the relations between RAN and the silent reading fluency measures were stronger when the former was tested in K than in G1. Moreover, the G1 RAN score did not explain any significant amount of variance in G1 fluency in decoding and in G2 word recognition. The data suggests that this may be a result of a shared variance between G1 RAN and G1 phonological awareness and between

G1 RAN and G1 visual SOP in explaining the variance in these measures of reading. The relations between G1 phonological awareness and G1 decoding, and between G1 visual SOP and G2 word recognition may have excluded RAN from the regression equations. This would accord with the interpretation of RAN as representing both a phonological process and a timing mechanism of processing visual codes (Bowers & Wolf, 1993; Wolf & Bowers, 1999).

Morphological awareness explained a notable amount of variance in reading comprehension, but none of the variance in the silent reading fluency measures. The lack of relations between morphological awareness and fluency in word recognition was rather surprising. The time taken to recognize a written word was found to be related to the organizational properties of the orthographic lexicon. A morphological overlap between a prime word and a target word was found to accelerate the recognition of the target in single word recognition tasks among readers of Hebrew (Deutsch, Frost, & Forster, 1998; Frost, Forster, & Deutsch, 1997; Frost, Kugler, Deutsch, & Forster, 2005). This was taken to suggest that readers of Hebrew perform morphological analysis in single word reading, and that the search for a word's lexical representation in the Hebrew orthographic lexicon is guided by morphological principals. Consequently, one would expect morphological skills to contribute to word recognition skills. One limitation of the present investigation was that morphological awareness was examined in context (inflicting nouns embedded in sentences). As a result, performance might have been influenced by the ability to extract contextual cues. Such a task may not sufficiently capture the variance in the ability to perform morphological analysis of isolated words. Consequently, possible relations between morphological awareness and single word recognition might have been underestimated.

Yet another possibility would be that the children tested in the current study were too young to rely on morphological skills in reading. The awareness to the morphological structure of Hebrew words continues to develop throughout the school years, and so is the morphological organization of the Hebrew orthographic lexicon (Ravid & Malenky, 2001; Ravid & Schiff, 2006; Schiff, Raveh, & Kahta, 2008). As the basic skills in our study were tested only until the end of G1, the children may have not yet developed sufficient morphological awareness that could have served as a reliable underlying skill of reading in the absence of contextual cuing. Notably, in the study by Canaan and Share (2002), who found significant relations between morphological knowledge and silent semantic decision, children in G3 were examined. It should also be noted that in studies on oral reading of English the relations between morphological skills and reading proficiencies was found to increase with age, with rather weak relations in the early school years (Carlisle, 1995; Deacon & Kirby, 2004; Nagy, Berninger, & Abbott, 2006; Singson, Mahony, & Mann, 2000).

Vocabulary showed significant relations mainly with the silent reading fluency measures. A semantic decision task of words and pseudo-homophones examines the access to their meaning, which is probably speeded up by good vocabulary skills (Wolf, Miller, & Donnelly, 2000). At the same time, the role of vocabulary may not be restricted to a silent semantic decision task, as a previous study by Schumm and Baldwin (1989) has shown reliance on syntactic/semantic cueing in silent reading in context. The relations between vocabulary and comprehension were weak, contrarily to models describing the components of reading comprehension (Perfetti, Landi, & Oakhill, 2005). As in the current study standardized reading comprehension tasks were administered, which were designed to be age appropriate, the children were probably well acquainted with the words in the texts. Consequently, differences in vocabulary would not explain a significant amount of variance in understanding the sentences and texts presented.

The visual non-grapho-numeric skills (cross out, visual-spatial memory and visual-spatial IQ) showed weak to insignificant relations with the measures of reading. These results stand in line with many studies failing to find strong relations between such visual skills and reading (review by Vellutino et al., 2004). The only visual measure explaining a notable amount of variance in fluency in word identification was visual SOP of grapho-numeric symbols. This result accords with findings on oral reading indicating significant relations with visual processing of orthographic units and numbers (Badian, 2005; Barker et al., 1992; Cunningham, Perry, & Stanovich, 2001). Notably, from a developmental perspective, the findings pointing to significant relations between the phonological skills (phonological awareness and phonological WM) mainly with the G1 measures of reading, and between the visual skills (visual SOP of digits and numbers, and to a lesser extent visual-spatial WM) and reading in G2 alone, may mean that while the early stages of reading acquisition pose demands of phonological processing, at the more advanced stages of acquiring silent reading visual processing (and mainly of grapho-numeric symbols) may become a more important skill. This would accord with the various theories describing the course of reading acquisition (which were based mainly on research of oral reading) as progressing from phonological decoding of small orthographic units to visual-recognition of larger and familiar orthographic units (e.g. Ehri, 2005; Frith, 1985; Marsh, Friedman, Welch, & Desberg, 1981).

In conclusion, phonological and morphological awareness, RAN, vocabulary, phonological WM and visual SOP of numeric symbols explained a notable amount of variance—each of which in certain aspects of silent reading ability and at certain time-points of testing. The relations of these skills with reading ability were consistently demonstrated in the reading literature based on oral measures of reading. Therefore, these appear to be relevant skills of reading, whether reading is examined orally or silently. The developmental data is also consistent with findings on oral reading, i.e. the decline in the relations between phonological awareness and the measures of silent reading from G1 to G2, and the rather consistent relations between RAN and the silent reading fluency measures. In addition, in line with developmental theories of reading, which were also based mainly on the oral reading literature, while the relations between phonological processes and silent reading were significant mainly at the early stage of reading acquisition, the contribution of the visual skills (and mainly of visual SOP of numeric symbols) to the measures of silent reading was significant at a later stage only. Therefore, the role of these skills in the course of reading acquisition appears not to be restricted to a certain mode of reading. These results converge to suggest that processes underlying the acquisition of silent reading skills are not substantially different from those underlying the acquisition of oral reading skills. This would be in agreement with earlier studies indicating common mechanisms involved in the acquisition of orthographic representations of newly encountered words in oral and in silent reading (Bowey & Miller, 2007; Bowey & Muller, 2005; de Jong et al., 2009; de Jong & Share, 2007).

Several important questions remain open. First, as in the present study the underlying skills of silent reading were explored, but no direct comparison between oral and silent measures of reading was carried out, the question whether there are differences in the extent of involvement of the verbal and visual skills in explaining the variance in oral and silent reading acquisition remains to be examined. Second, the present study focused on single word/pseudo-homophone reading. However, fluency in reading of texts, which would represent a more ecological measure of reading, should also be explored in trying to understand the processes involved in other aspects of silent reading. Third, the conclusions of this study are limited to the early stages of reading acquisition. Spache (1976) suggested that early on children vocalize while reading, even when asked to read silently, but as children develop more skilled reading, the processes are differentiated. Some of the few studies examining silent reading strengthen these assumptions. For instance, Schumm and Baldwin (1989) found differences in the cues used in oral and silent reading of texts only from G4. Also, Hale et al. (2011) found no differences in reading comprehension following the two modes of reading in G1 and G2, while such differences were found in children from G3 (Rowel, 1976). Therefore, future studies examining silent reading may extend the longitudinal examination of the skills underlying it to older readers. Finally, a sample representing a broad range of reading skills was examined in this study. Future studies may compare typically developing children and children at risk for dyslexia in measures of silent reading.

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