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Orthographic processing is a key predictor of reading fluency in good and poor readers in a transparent orthography

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Abstract

We used structural equation modeling to investigate sources of individual differences in oral reading fluency in a transparent orthography, Russian. Phonological processing, orthographic processing, and rapid automatized naming were used as independent variables, each derived from a combination of two scores: phonological awareness and pseudoword repetition, spelling and orthographic choice, and rapid serial naming of letters and digits, respectively. The contribution of these to oral text-reading fluency was evaluated as a direct relationship and via two mediators, decoding accuracy and unitized reading, measured with a single-word oral reading test. The participants were “good” and “poor” readers, i.e., those with reading skills above the 90^{th} and below the 10^{th} percentiles (n = 1,344, grades 2–6, St. Petersburg, Russia). In both groups, orthographic processing skills significantly contributed to fluency and unitized reading, but not to decoding accuracy. Phonological processing skills did not contribute directly to reading fluency in either group, while contributing to decoding accuracy and, to a lesser extent, to unitized reading. With respect to the roles of decoding accuracy and unitized reading, the results for good and poor readers diverged: in good readers, unitized reading, but not decoding accuracy, was significantly related to reading fluency. For poor readers, decoding accuracy (measured as pseudoword decoding) was related to reading fluency, but unitized reading was not. These results underscore the importance of orthographic skills for reading fluency even in an orthography with consistent phonology-to-orthography correspondences. They also point to a qualitative difference in the reading strategies of good and poor readers.

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Keywords

reading fluency; decoding; orthographic processing; phonological processing; word unitization; good and poor readers

1. Introduction

It is commonly assumed that achieving fluent reading is a direct by-product of mastering phonological decoding, the skill known to be related to phonological processing (Snowling, 1998; Torgesen, Wagner, & Rashotte, 1994; Wagner & Torgesen, 1987). However, there is evidence that learning letter-sound correspondences does not by itself lead to improved reading fluency in children with reading disability (Chard, Vaughn, & Tyler, 2002; Torgesen, 2005). Furthermore, unlike in English, where low reading fluency in typically developing beginning readers and children with reading disability is confounded with low reading accuracy, in transparent orthographies, disabled reading manifests itself as relatively accurate but slow and dysfluent reading (Landerl, Wimmer, & Frith, 1997; Serrano & Defior, 2008; Zoccolotti et al., 1999). Thus, in order to understand reading development and the nature of difficulties in achieving skilled reading, it is necessary to understand what skills, beyond decoding accuracy and its correlate, phonological processing, are important for developing skilled reading.

Our study investigates sources of individual differences in oral reading fluency in good and poor readers of Russian, a language with a shallow (i.e., spelling-to-sound transparent) orthography (Rakhlin, Kornilov, & Grigorenko, 2017). The term “reading fluency” currently lacks a consensual definition, which varies depending on the theoretical perspective of what the term represents (Wolf & Katzir-Cohen, 2001). In its general sense, it refers to reading efficiency and combines accuracy and speed of reading (e.g., the number of correctly read words per minute), the sense in which the term will be used throughout this article.

We used structural equation modeling (SEM) to elucidate the contribution of phonological processing, rapid serial naming, and orthographic processing to oral reading fluency, both directly and via two intermediary variables, decoding accuracy and word unitization.

Phonological processing skills are the skills used to recognize, analyze, and manipulate the sound structure of words. They involve (but are not limited to) phonological awareness and phonological short-term memory (Torgesen et al., 1994). Orthographic skills are involved in recognizing, analyzing and manipulating stable or recurring letter patterns and applying them in spelling (Rothe, Cornell, Ise, & Schulte-Körne, 2015). Rapid serial naming, a skill that arises from a number of processes (Denckla & Cutting, 1999; Georgiou, Aro, Liao, & Parrila, 2016; Wolf & Bowers, 1999), is commonly considered to be an independent source of variance in reading competence (Wimmer, Mayringer, & Landerl, 2000; Wolf & Bowers, 1999). Furthermore, research on consistent orthographies suggests that rapid serial naming, rather than phonological awareness, is a predictor of subsequent fluency deficits (Rakhlin et al., 2017; Wimmer, 1993; Wimmer, Mayringer, & Landerl, 1998; Wimmer et al., 2000).

Decoding accuracy (i. e., the skills involved in assembling phonological forms of words and pseudowords by converting individual graphemes into the sounds they represent) is the most commonly used outcome measure of reading acquisition. Our study added a relatively understudied reading indicator, word unitization, the process by which single-letter strings are consolidated into whole-word units, which is associated with increased reading efficiency (Healy, 1994). We hypothesized that unitization is not just a direct outcome of the acquisition of decoding skills, but an autonomous (albeit related to decoding) skill that relies more strongly on orthographic than phonological processing skills and is the key source of fluency in skilled reading. Below, we summarize the key issues involving the contributions of decoding and its major correlate, phonological processing skills, to reading fluency, the role of orthographic processing skills in the development of fluent reading, and the relationship between decoding and unitization, as two components of fluent reading. We then report the results of our study of reading acquisition in Russian, aimed at contributing new insights to the field's understanding of these issues.

1.1 Decoding and its key predictors: phonological skills

It has been suggested that reading acquisition and its difficulties can be reduced to two key factors: learning to use letter-sound correspondences in decoding written words (i.e., learning the alphabetic principle and mastering phonological decoding) and developing good language comprehension (Hoover & Gough, 1990). Thus, decoding, typically assessed with accuracy measures of oral reading of pseudowords and words with regular spellings (particularly those of lower frequency), is considered one of two key reading skills and has been studied extensively across many languages.

Learning to decode is widely assumed to depend on phonological awareness, the skills involved in accessing and manipulating sublexical phonological components of words (Bradley & Bryant, 1983; Stanovich, 1982; Wagner & Torgesen, 1987), and other phonological processing skills, such as phonological working memory (Gathercole & Baddeley, 1990). Rapid serial naming has also been extensively researched, with some suggesting that it should be subsumed under phonological processing (Torgesen, Wagner, Rashotte, Burgess, & Hecht, 1997; Wagner, Torgesen, & Rashotte, 1994; Wagner et al., 1997), while others view it as an independent source of variance in word reading (Georgiou, Parrila, Kirby, & Stephenson, 2008; Lervåg & Hulme, 2009; Wolf & Bowers, 1999). Phonological processing skills have become widely accepted as a fundamental causal influence in learning to decode across a wide variety of orthographies, both deep and shallow (Norton, Beach, & Gabrieli, 2015; Snowling, 1998; Vellutino, Fletcher, Snowling, & Scanlon, 2004; Wimmer et al., 1998). These skills have also been deemed a universal core deficit in developmental dyslexia in orthographically diverse languages (Paulesu et al., 2001).

Despite the wide acceptance of the view that the ability for mastering decoding and its key predictor, phonological processing skills, are the prime factors in reading acquisition and its failure, there are certain findings difficult to explain under this view. First, it has been well established that in shallow orthographies, reading difficulties are manifested not as a lack of accuracy, but a lack of reading speed (Kornev, Rakhlin, & Grigorenko, 2010; Landerl et al., 1997), suggesting that learning to accurately map letters to sounds is not sufficient for developing fluent reading. Secondly, there is evidence that phonological awareness, namely awareness of the smallest phonemic elements of words (rather than the larger phonological units, such as syllables or rhyme units), develops together with, rather than prior to, the acquisition of decoding skills, as adults who never experienced literacy learning exhibit similar patterns of phonemic awareness deficits as children who struggle to acquire it (Bertelson, Gelder, Tfouni, & Morais, 1989; Dehaene, Cohen, Morais, & Kolinsky, 2015). There is also evidence that phonemic awareness deficits may be a consequence (or a co-requisite), rather than a cause, of reading difficulties. For example, it has been argued that poor phonemic awareness skills in children who struggle to acquire literacy is due to insufficient or suboptimal reading experience in that population (Huettig, Lachmann, Reis, & Petersson, 2017).

Thus, despite substantial research demonstrating a relationship between fluent reading and decoding, and between decoding and phonological processing skills, there is evidence that fluent reading requires mastering additional skills, beyond learning to translate individual graphemes to phonemes and assemble these into recognizable words. Furthermore, there arises an important question of whether the acquisition of these additional skills is associated with phonological processing or perhaps relies on processing of another type.

An additional class of skills involved in reading acquisition is orthographic processing skills (Badian, 1995; Cunningham, Perry, & Stanovich, 2001; Stanovich, West, & Cunningham, 1991; Wagner & Barker, 1994). Orthographic processing has been extensively studied in skilled readers (Grainger, 2016; Grainger, Dufau, & Ziegler, 2016; Grainger & Hannagan, 2014). Its role in reading acquisition has been gaining interest in the reading literature focused on the development and impairment of reading (Araújo, Faísca, Bramão, Reis, & Petersson, 2015; Boros et al., 2016; Rothe et al., 2015), even though its contribution to the acquisition of fluent reading remains far less well studied than that of phonological processing skills. One reason for this may be the difficulty in conceptualizing orthographic skills as independent from phonological skills (Burt, 2006; Deacon, Benere, & Castles, 2012) or even in providing a consistent definition, the issues discussed in the next section.

1.2 Defining orthographic skills

In addition to the dominant line of research concentrating on the contribution of phonological processing to decoding, a complementary line of research focused on reading development as a process during which a system of visual representations is incorporated into one's linguistic system of lexical representations, with a profound effect on early visual processing and brain organization. Thus, research has documented the effect of reading development on the establishment of the network subserving the interface between vision and spoken language, i.e., the Visual Word Form Area (VWFA), early visual cortices, and the ventral occipito-temporal pathway connecting oral language areas of the brain with the VWFA (Dehaene et al., 2015; Pegado et al., 2014; Ventura et al., 2013). These profound effects on vision likely arise because of the demands of acquiring orthographic processing skills.

Orthographic processing skills are thought to involve the visual learning of word orthography, i.e., various spelling patterns that characterize specific words or word parts (Barker, Torgesen, & Wagner, 1992; Venezky, 1970). There is disagreement on whether the acquisition of orthographic skills is a byproduct of learning to decode, or rather constitutes an independent type of learning. Although some research showed that successful mastery of decoding is a necessary precondition for developing orthographic skills (Ehri, 2005; Share, 1995), others demonstrated that orthographic skills are not entirely parasitic on decoding ability (Cunningham et al., 2001; Cunningham, Perry, Stanovich, & Share, 2002), are important even at relatively early stages of reading acquisition, and develop in parallel with decoding skills (Pacton, Sobaco, Fayol, & Treiman, 2013). Even preschoolers and beginning readers were shown to exhibit orthographic learning (Apel, Wolter, & Masterson, 2006; Cassar & Treiman, 1997; Castles, Wilson, & Coltheart, 2011; Wright & Ehri, 2007), which solidifies with increasing exposure to print (Stanovich & West, 1989) and takes greater importance in the course of later reading development (Rau, Moeller, & Landerl, 2013).

Orthographic skills are often studied in opposition to phonological skills and in English are assessed with tasks involving irregularly spelled words and pseudowords with atypical letter combinations; such tasks are thought to reveal the reader's sensitivity to orthographic patterns as opposed to their ability to translate each letter into its corresponding sound, as is the case with decoding (measured with words and pseudowords with regular spellings).

This dichotomy is largely an artifact of the Anglocentricity of reading research and the nontransparency ("orthographic depth") of English orthography (Share, 2008). The existence of many words with irregular or inconsistent spellings in English led researchers to differentiate the skills involved in deciphering irregular words from those involved in reading regular words and pseudowords, and to think of the latter as manipulating "phonology" and the former as manipulating "orthography." This dichotomy has been questioned for English (Ehri, 2005; Sidenberg & McClelland, 1989). Whatever the validity of this dichotomy in English, it clearly becomes questionable in languages with a transparent orthography, where nearly all spellings are regular, at least in the feed-forward, grapheme-to-phoneme direction, which would then suggest that in such languages, orthographic skills would not play any role in reading acquisition.

However, research has shown that orthographic processing need not be relegated exclusively to reading irregular words and is important even in languages in which nearly all words are spelled regularly. Evidence of orthographic learning in transparent orthographies includes a decrease in the length effect on word compared to pseudoword reading (Zoccolotti, De Luca, Di Filippo, Judica, & Martelli, 2009), on familiar but not on unfamiliar word reading (Rau et al., 2013), and with advanced reading development. In addition, there is a documented advantage for reading words over pseudowords, and pseudowords derived from familiar words versus those derived from unfamiliar words (Marcolini, Burani, & Colombo, 2009; Paulesu et al., 2000; Seymour, Aro, & Erskine, 2003). Furthermore, children with reading disability in transparent orthographies are able to master accurate reading but remain slow inefficient readers and exhibit difficulties with orthographic processing and spelling (Suárez-Coalla, Ramos, Álvarez-Cañizo, & Cuetos, 2014).

In sum, there is mounting evidence that decoding and its associated phonological processing skills are not sufficient for the successful acquisition of fluent reading, and that orthographic processing skills play an important independent role in the development of skilled reading. One aspect of orthographic learning, the importance of which has been acknowledged but not sufficiently addressed in reading acquisition research, is unitization, i.e., the process of consolidating single-letter strings into whole-word units, recognized rapidly and effortlessly by skilled readers (Harn, Stoolmiller, & Chard, 2008; Healy, 1994). This construct is discussed in the next section.

1.3 Unitization and its relationship with decoding

Literature contains alternative conceptualizations of the relationship between decoding and unitization. For example, in Ehri's developmental framework (Ehri, 2005), children progress from the Pre-alphabetic to the Alphabetic Phases (Partial, Complete and Consolidated Alphabetic), as they gradually learn the alphabetic principle and the sound-letter correspondences and apply this knowledge to recover phonological forms of written words (both familiar and unfamiliar) with an increasing degree of completeness and efficiency. The progression through the three Alphabetic phases corresponds not only to a progressively more complete knowledge and automatized recognition of the individual grapheme-phoneme correspondences, but also to a gradual mastery and consolidation of recurring supra-graphemic units, i.e., continuously learning to recognize stable letter patterns corresponding to whole words, syllables, morphemes and other units larger than a single letter. Their use is facilitated with word familiarity and with reading development. In other words, with greater reading skills and experience, more and more complete word spellings are stored in long-term memory facilitating word recognition during reading (cf. also Share, 1995).

In this influential framework, unitized reading (*sight reading* in Ehri's terminology) is viewed as a direct by-product of developing a greater facility with decoding skills via learning to recognize letter-sound relations for all graphemic units of varying sizes (graphemes and grapheme sequences) in spellings, pointing to a close relationship between phonological decoding, orthographic skills, and unitization. In contrast, the Unitization Reading Model (Hadley & Healy, 1991), developed in skilled readers, maintains that the recognition of a larger unit (e.g., a whole word) terminates the processing of the smaller units it contains, as complete processing of letter-level information is rendered unnecessary. This view, if it can be extended to development, implies that there is dissociation between the processes of decoding, relied upon when unitized reading is unavailable, and unitized reading, once it has been mastered. As the two views compete, understanding the relationship between decoding, unitization and fluent reading, as well as their relationships with phonological and orthographic processing skills, remains an important question that the current study aims to address.

1.4 Present study

The main goal of the study was to evaluate the hypothesis that children's difficulties with developing reading fluency (operationalized as the number of correctly read words per minute) in a transparent orthography are best explained by difficulties in word unitization, rather than by difficulties with decoding. Our second goal was to disentangle the contribution of orthographic processing from that of phonological processing to decoding, unitization and reading fluency respectively.

We hypothesized that once the individual grapheme-phoneme mappings are learned, which in transparent orthographies normally occurs by mid-grade 1 (Lerkkanen, Rasku-Puttonen, Aunola, & Nurmi, 2004; Soodla et al., 2015), the process of reading acquisition is largely a process of orthographic learning and mastering unitized word reading. For many children acquiring reading skills in transparent orthographies, for whom the task of learning letter-sound mappings is relatively manageable, what makes reading development still a daunting task is difficulty acquiring the larger units, and thus becoming a fluent reader.

If this is correct, we would expect to find a strong relationship between reading fluency and both orthographic skills (i.e., performance on tasks such as orthographic pattern recognition and spelling) and unitized reading. On the other hand, we expect to find, at best, only a modest relationship between fluency and phonological skills (e.g., phonological awareness and repetition of pseudowords), as well as between fluency and decoding. We would also expect to find a significant relationship between reading fluency and rapid serial naming, as has been amply documented (Georgiou et al., 2008; Katzir et al., 2006; Lervåg & Hulme, 2009; Pennington, Cardoso-Martins, Green, & Lefly, 2001; Rakhlin, Cardoso-Martins, & Grigorenko, 2014; Vaessen & Blomert, 2010). Previous research documented an indirect, via orthographic skills, relationship between reading fluency and rapid serial naming in English, as well as a direct relationship in several orthographies, including Finnish, Chinese, and English (Georgiou et al., 2016), Italian (Zoccolotti, De Luca, Marinelli, & Spinelli, 2014), and Greek (Protopapas, Katopodi, Altani, & Georgiou, 2018), suggesting a direct relationship, potentially mediated by unitization, in Russian.

We tested these hypotheses using structural equation modeling (SEM) in a sample of elementary school students comprised of good and poor readers of Russian. We examined the respective contributions of decoding (measured alternatively as word and pseudoword reading accuracy) and unitized reading to oral reading fluency. We also examined the contributions of phonological processing skills (measured with the tasks of pseudoword repetition and phonological awareness), rapid serial naming (of letters and digits), and orthographic processing skills (measured with spelling and orthographic choice tasks) to reading fluency, both directly and via decoding and unitized reading.

2. Materials and Methods

2.1 Participants

The participants were 1491 Russian-speaking children (49.4% female) enrolled in grades 2nd to 6th in 30 public schools in St. Petersburg, Russia (age range = 7.26 to 14.33; *M* = 9.99, *SD* = 1.43). The children were selected from a sample of 4609 students screened for reading rate using teachers' recommendations and a standardized screening measure of reading efficiency in Russian (Screening Test for Reading Assessment; Kornev, 1995; Kornev & Ishimova, 2010). The students who performed below the 10th percentile (Poor Readers or PR) and above the 90th percentile (Good Reader or GR) were invited to participate. Written informed consent was obtained from the parents of all participants. Subsequently, 147 children with non-verbal IQs 70 or below were excluded from the analysis (104 from the PR and 43 from the GR group). Table 1 presents the demographic information for both groups.

2.2 Assessments

The dependent variable of *reading fluency* was measured with the Test of Oral Reading Fluency for Russian (SMINCH; Kornev, 1995; Kornev & Ishimova, 2010), a standardized norm-referenced assessment of paragraph reading for elementary school children. The test contains two texts appropriate for beginning-intermediate readers in grades 2–6 (with Text 2 containing somewhat more advanced vocabulary than Text 1). Each text contains ≈230 words. The children are instructed to read both texts orally as fast and as accurately as possible, while the examiner tracks decoding errors and marks the one-minute period for each passage. The standard fluency scores were derived based on the number of words read correctly in accordance with the grade-based norms reported in the test manual.

To derive the two word reading measures, *decoding and unitization*, we used an adaptation of the word reading subtest of the WRAT-3 (Wilkinson, 1993). Participants were asked to read a list of 42 words varying in length (1–6 syllables), syllabic complexity, and frequency. To isolate the skills of decoding from the skills of recognizing words as whole units, we designed a scoring technique that differentiates *decoding accuracy* from word *unitization*. This approach is similar to the one taken in previous studies, where “sounding-out behavior” (i.e., reading part-by-part) is scored separately from the accuracy of the responses (substitution errors during oral reading) in order to glean the “reading strategies” of developing readers under various conditions of instruction (Hendriks & Kolk, 1997; Trenta, Benassi, Di Filippo, Pontillo, & Zoccolotti, 2013).

To determine the word reading accuracy scores, each response was scored 1 if the word’s phonological form was read correctly and 0 if any substitution errors occur. To determine the word unitization scores, all responses were scored as 1 if pronounced seamlessly as a whole-word unit and 0 if read part-by-part (e.g., letter-by-letter or syllable-by-syllable). Thus, each word was given two scores, for accuracy and unitized reading. The number of words read correctly was used as the *word reading accuracy* index (WA) for the analyses (Cronbach’α_{PR} = .856, Cronbach’α_{GR} = .730). The number of words read as whole units was used as the word *unitization* index (WU) for the analyses (Cronbach’α_{PR} = .961, Cronbach’α_{GR} = .876).

There was only a moderate correlation between the WA and WU scores ($r = .550$, $p < .001$ for good readers; $r = .417$, $p < .001$ for poor readers), indicating that accurate reading did not always entail fluent reading. It is also possible that in some cases a child could produce a seemingly unitized but incorrect word reading (exhibiting an incorrect guess rather than a truly unitized reading). These two types of discrepancy between decoding accuracy and unitization are likely to show different distributions in good and poor readers, potentially affecting the structure of inter-correlations between the study measures in the two groups.

An alternative measure of *decoding accuracy*, namely *Pseudoword Reading Accuracy (PWA)* consisted of a task in which each participant was asked to read a list of 20 pseudowords of increasing complexity (in terms of syllabic length and syllable structure). The pseudowords were constructed from common Russian syllables conforming to the phonotactic and orthographic constraints of Russian. They ranged from two to five syllables in length and were judged as good possible words by two native speakers. The responses were scored as 2 when the child read the word correctly from the first attempt, 1 when an error was self-corrected, and 0 if the item was read incorrectly (Cronbach'α_{PR} = .843, Cronbach'α_{GR} =.664).

Orthographic processing skills were measured by Orthographic Choice (OCh), an adaptation of the Orthographic Choice Task (Olson, Forsberg, & Wise, 1994). In this group-administered untimed paper-and-pencil measure, the participants were given sets of three orthographic strings, two real words and a pseudo-homophone, and had to identify the pseudo-homophone. For example, a triplet may consist of the items *summa (sum), ssuma (*pseudo-homophone*), sama (herself*). The items in each triplet were similar in length and phonological composition. The task contained 39 items (Cronbach'α_{PR} =.859, Cronbach'α_{GR} = .863).

In addition, *orthographic processing skills* were assessed via a *Spelling Skills (SS)* task, an adaptation of the *Developmental Spelling Test* (Joshi & Aaron, 2003), a group-administered paper-and-pencil test adapted for Russian. Russian is an asymmetrically transparent language, with a number of complexities affecting feedback consistency (sound-to print correspondences) (Rakhlin et al., 2014). The participants had to spell words varying in orthographic complexity (i.e., the number of potential spelling errors), syllabic structure (i.e., containing simple versus complex syllable onsets and codas) and frequency. The test was composed of 56 items (Cronbach'α_{PR} = .870, Cronbach'α_{GR} = .824).

Phonological processing skills were measured with a *Phonological Awareness (PA)* task, an individually administered elision task. The task consisted of eliding elements (syllables and single phonemes) from a word's initial, medial, or final positions and pronouncing the word resulting from the elision. The test was composed of 42 items (Cronbach'α_{PR} = .950, Cronbach'α_{GR} = .913).

An additional *phonological skills* measure included a *Pseudoword Repetition (PWR)* task, an adaptation of the *Children's Test of Non-word Repetition* (Gathercole & Baddeley, 1990, 1996) used to measure phonological short-term memory. Each participant was individually presented with items ranging from 2 to 5 syllables with an equal number of items of each length. The complexity of the syllable structure was systematically varied, with half of the items containing consonant clusters in the onset or coda of the initial syllable, with the remaining half containing no clusters. Live presentation of the stimuli was used to make sure that the child's attention was engaged before presenting an item (Adams & Gathercole, 1995). The task was composed of 23 items (Cronbach'α_{PR} =.816, Cronbach'α_{GR} = .714).

Rapid Serial Naming (RSN) was measured with Denckla and Rudel's (1976) tasks of rapid serial naming of letters (RSN_L) and digits (RSN_D) adapted to Russian. In each task, five different stimuli of each type were presented 10 times in a random order. Responses were timed using a stopwatch.

In addition, we assessed children's non-verbal Intelligence NV-IQ) using the Culture-Fair Intelligence Test (CFIT), Scale 2 (Cattell & Cattell, 1973), a timed group-administered paper-and-pencil test of non-verbal intelligence for ages 8 and above, thought to be relatively independent of verbal ability, cultural background, and educational level (Cronbach'α_{PR} =.622, Cronbach'α_{GR} = .688).

2.3 Procedures

After the screening, the schools contacted the families of the selected students inviting them to enroll in the study. After the parental consents were obtained, children's status as good or poor readers (10^{th} and 90^{th} percentile using the oral reading fluency norms for grades 2–6) was confirmed and qualified children were enrolled in the study. Except for the three group-administered tests (orthographic choice, spelling, and non-verbal intelligence), each child was tested individually by a trained examiner at the school. The individual assessment session lasted between 40–60 minutes.

2.4 Analytical approach

Prior to the analyses, the data were examined for missing values (none were found), normality and outliers. The values for kurtosis and skewness are reported in Table 2. Some variables showed values of kurtosis and skewness outside the recommended range (Groeneveld & Meeden, 1984; Kendall & Stuart, 1958). The non-normal distributions of the variables in this study are probably due to the fact that the same tasks were administered to children selected for high and low ability levels across grades 2–6. Different strategies have been proposed to deal with the non-normal distribution of the variables (West, Finch, & Curran, 1995). After considering the advantages and disadvantages of the different methods, bootstrapping was implemented to minimize the potential violations of the assumptions of parametric statistical analyses (Finney & DiStefano, 2006). The bootstrap procedure generates random repeated samples with replacement from the original sample creating an empirical distribution from which the parameters of the models may be obtained (Enders, 2001). Two thousand samples and a 95% confidence interval were used to obtain the parameters for the group comparisons, and ten thousand samples and a 95% confidence interval for the structural equation model.

The groups were compared on IQ using a t-test, and a MANOVA was conducted to compare the groups on all of the literacy related measures. All the literacy-related scores were regressed on age and IQ[i], and the standardized residuals were used in the analyses. To test the contribution of componential skills to reading fluency in good and poor readers, two structural equation models were built using AMOS (Arbuckle, 2009). Both models included three independent variables – Rapid Serial Naming, Phonological Processing, and Orthographic Processing skills. Each was a latent factor composed of two sets of scores: rapid serial naming of letters and rapid serial naming of digits, phonological awareness and pseudoword repetition, and spelling skills and orthographic choice, respectively. The scores on word unitization and phonological decoding, the latter alternatively measured as word

[i]In our initial analyses, the models included age or grade as an independent variable, but the model fit indices were poor indicating that the model was overloaded. This is the reason we made a decision to factor out age differences.

reading accuracy in Model 1 and pseudoword reading accuracy in Model 2, were used as mediators. Oral reading fluency was used as the observed dependent variable.

Maximum likelihood estimation was used to estimate the parameters (Nevitt & Hancock, 2001). Multiple fit indices were used to evaluate model fit. The following values were used to judge the good fit of the models: $\chi 2$ and Bollen–Stine bootstrap p values of .05 or greater; chi-square/degree of freedom values < 3; Standardized Root Mean Square Residual (SRMR) ≤ .80, and Comparative Fit Index (CFI) ≥ .95; and Root Mean Square Error of Approximation (RMSEA) ≤ .06, and the Tucker-Lewis Index (TLI) ≤ .95 (Bollen & Stine, 1992; Browne & Cudeck, 1993; Byrne, 1994; Hu & Bentler, 1999).

Finally, multigroup SEM analyses were used to assess the partial invariance between the two groups (Good and Poor Readers) in both models. The baseline models were compared and the partial invariance between groups was tested using the chi-square test between the unconstrained model and the models with several parameters constrained. Given the sensitivity of the chi-square test to the sample size, the decrease in the CFI was also taken into account. A decrease in the CFI greater than .01 indicates a meaningful decrement in fit (Chen, Sousa, & West, 2005; Cheung & Rensvold, 2002). In addition, the critical ratio for pairwise comparisons was used. Direct and indirect effects were obtained separately for each group, and the mediation effects were assessed (Preacher & Hayes, 2004; Zhao, Lynch, & Chen, 2010).

3. Results

3.1 Descriptive statistics

The two groups did not differ on grade composition [$\chi^2(4) = 9.301$, $p = .054$] and age [$t(1074.87) = 1.699$, $p = .090$], but the poor readers performed significantly lower than the good readers on non-verbal intelligence [$t(1342) = 11.425$, $p < .001$, Cohen's $d = .62$]. They also underperformed on all literacy-related tasks (Cohen's $d = .708 – 2.908$). The largest differences were observed in oral reading fluency (d =2.908) and word decoding accuracy (Cohen's d =1.881), with the smallest differences in Rapid Serial Naming (d = .709 and . 782 for letters and digits, respectively). Table 2 reports the descriptive statistics for all of the measures for each group, with the effect sizes for each measure.

3.2 The results of the SEM analyses

As reported in Table 3, all of the variables were significantly, albeit modestly, inter-correlated, with the exception of the association between rapid serial naming of digits with pseudoword reading in poor readers. The strongest correlate of reading fluency for both groups of readers was word unitization (r =. 449 for PR for poor readers and .535 for good readers).

As described above, two models were built to test the contribution of the componential skills to reading fluency in good and poor readers, with phonological decoding alternatively measured as word (Model 1) or pseudoword (Model 2) reading accuracy. Figure 1 schematically depicts Model 1. Model 1 showed a good fit for both the entire sample and for each of the two groups (poor readers: $\chi^2(15)= 14.2$, p= .510; CFI= 1.000, RMSEA = .000

(CI90: .000 −.039); good readers: $\chi^2(15)$= 20,687, p =. 336; CFI= .996, RMSEA = .022 (CI90: .000 −.039). See Table 4 for the fit indices for all models.

The results indicate that orthographic skills significantly contributed to unitization in both good and poor readers (β = .35 & .42, respectively) and to word decoding accuracy in good readers (β = .24). Orthographic skills also directly contributed to reading fluency in both groups (β = .27 & .49 for good and poor readers respectively). Phonological skills were a significant predictor of word decoding for both good and poor readers (β = .31 & .46) and unitization (β = .35 & .29, respectively), but did not contribute directly to reading fluency in either group (β = .13 & −.03, good and poor respectively). Unitization significantly predicted reading fluency in good readers only (β = .23), while word decoding accuracy was not significantly related to reading fluency in either group (β = .02 & −.02 for good and poor readers respectively). Rapid serial naming was significantly negatively related to word decoding in the group of poor readers (β = −.18), to unitization in both groups (β = −.14 & −.12 for good and poor readers respectively), and directly to reading fluency in the group of good readers (β = −.12).

To explore the equivalence of the model for each group, a multigroup comparison was conducted. The baseline model showed adequate fit indicating that the model was adequate for both groups (see table 4). After that, partial invariance was explored, assessing the differences between the groups in the various paths connecting the independent variables, the mediator variables, and the dependent variable. The only significant difference observed was for the path connecting word unitization and reading fluency. Specifically, word unitization was more strongly correlated with reading fluency in the group of good readers than in the poor readers (β= .23 & .13 for good and poor readers, respectively, CR = 2.33, p < .05).

Next, we investigated the mediation effects in each group. For the group of good readers, when considered together, word unitization and word reading accuracy mediated the relationship between each of the three independent variables and reading fluency: rapid naming (β= −.029, CI95 = −.055 − −.010, p = .014), phonological processing skills (β = .086, CI95 = .001 − .095, p = .005), and orthographic processing skills (β = .085, CI95 = .045 − .140, p = .007). Mediation by word reading accuracy and word unitization for the relationship between reading fluency and both rapid naming and orthographic skills was complementary, suggesting that additional variables also mediate these relationships. The relationship between phonological skills and reading fluency was completely mediated by word reading accuracy and word unitization. Next, we evaluated the mediating effects separately for word reading accuracy and word unitization in this group. Word reading accuracy by itself did not mediate the relationship between any of the three independent variables and reading fluency. On the other hand, for word unitization, all three indirect effects (rapid serial naming, phonological processing and orthographic processing) were significant (β_{RSN} = −.027, CI95 = −.050 − −.006, p = .011; β_{PP} = .079, CI95 = .025 − .143, p = .003; β_{OP} = .084, CI95 = .025 −.139, p = .004). For rapid naming and orthographic skills, the mediation was complementary. The relationship between phonological skills and reading fluency was completely mediated by word unitization.

Finally, we evaluated the mediation effect in the group of poor readers. For this group, word reading accuracy and unitization together did not mediate the relationship between any of the independent variables and reading fluency. Only the direct path between orthographic skills and reading fluency was significant. Likewise, when assessed separately for word reading accuracy and unitization, none of the mediation effects were significant.

Next, we built Model 2 to test whether the same results would be obtained with phonological decoding skills measured as pseudoword reading accuracy (instead of word reading accuracy), as reading pseudowords is generally considered a more pure measure of decoding than reading words. Figure 2 schematically depicts Model 2.

The results obtained for Model 2 were nearly identical to those obtained for Model 1. The only difference was in the path between the decoding variable (pseudoword reading accuracy in this case) and reading fluency. While in Model 1, word decoding accuracy was not significantly related to reading fluency for either group, in Model 2, the relationship between pseudoword decoding accuracy and reading fluency was significant for the group of poor readers ($\beta = .22$).

The multigroup analysis showed that the baseline models had a good fit in both groups (see Table 4). Partial invariance was explored, assessing the differences in the various paths connecting the variables in the two groups. As in Model 1, word unitization was more strongly correlated with reading fluency in good readers than in poor readers ($\beta = .22$ & .13 respectively, CR = 2.306, $p < .05$). No other differences were significant.

The mediation analyses for the group of good readers indicated that the indirect effects of all three independent variables on reading fluency via word unitization and pseudoword decoding were significant: rapid naming ($\beta = -.035$, $p = .005$, CI95 = −.060 − −.008); phonological processing ($\beta = .109$, $p = .009$, CI95 = .040 − .200); and orthographic processing skills ($\beta_= .087$, $p = .031$, CI95 = .016 −.149). When considering the indirect effects of these on reading fluency separately via word unitization or pseudoword decoding accuracy, we found that the indirect effects via unitization were significant for all three independent variables: rapid naming: ($\beta = -.027$, $p = .017$, CI95 = −.054 − −.005), phonological processing: ($\beta = .079$, $p = .006$, CI95 = .023 − .151), and orthographic processing: $\beta_= .084$, $p = .006$, CI95 = .023 − .144). The mediation of unitization was complementary for orthographic skills and rapid naming and complete for phonological skills. The only significant indirect effect of phonological skills was via pseudoword decoding: ($\beta = .032$, $p = .015$, CI95 = .008 − .068).

Finally, for the group of poor readers, two indirect effects on reading fluency were significant: those of phonological processing skills and rapid naming via word unitization and pseudoword decoding accuracy together ($\beta_{PP} = .180$, $p = .007$, CI = .064 − .503; $\beta_{RSN} = -.045$, $p = .042$, CI95 = −.146 − −.001). In the analyses examining the indirect effects of the three independent variables separately for word unitization and pseudoword decoding accuracy, the indirect effect of phonological skills on reading fluency via pseudoword decoding accuracy was significant ($\beta = .144$, $p = .013$, CI = .041 − .497). This effect was completely mediated by pseudoword decoding accuracy.

4. Discussion

The present study aimed to evaluate the hypothesis that word unitization and related orthographic processing skills are key predictors of reading fluency. We also hypothesized that the contribution of word unitization and orthographic skills to reading fluency is not only independent from that of phonological skills, but outweighs the latter, particularly at the high ability level. This is expected, as it is these skills that allow skilled readers to recognize words rapidly and effortlessly (Ehri, 2013; Perfetti, 1985; Share, 1995). Orthographic learning reshapes one's mental lexicon making it finely tuned with respect to orthographic representations of words (Binder, Medler, Westbury, Liebenthal, & Buchanan, 2006; Castles, Davis, Cavalot, & Forster, 2007; Perfetti & Hart, 2002). Skilled readers rely strongly on their facility for "sight word reading", when an individual has acquired as orthographic representations of words are acquired to such an extent that they become fully integrated into one's mental lexicon (Acha & Carreiras, 2014; Castles et al., 2011; Ehri, 2013; Perfetti & Hart, 2002), and letter strings corresponding to familiar words are instantly matched to their corresponding phonological and semantic and grammatical features (Carr & Pollatsek, 1985; Grainger & Jacobs, 1996). These skills allow readers to develop sensitivity to recurring orthographic sequences or "graphotactics", i.e., the knowledge of which sequences of letters are permitted and which ones are not in a specific orthography (Pacton et al., 2013; Verhoeven, Schreuder, & Baayen, 2006). Efficient reading of novel or low frequency words is facilitated via the recognition of recurring orthographic sublexical chunks, i.e., orthographic units larger than single graphemes – written syllables, onset and rime units, word roots, affixes, and other orthographic stable letter sequences that comprise written words.

There is substantial evidence that mastering decoding is not sufficient for achieving high reading fluency (Chard et al., 2002; Torgesen, 2005) and that the process of reading development is a gradual progression to operating with larger, consolidated letter-sound chunks to a greater and greater extent. Moreover, unlike in English, where low reading rate in typically developing beginning readers and individuals with reading disability is confounded with low reading accuracy, in orthographies with consistent letter-sound correspondences, it manifests itself as a reading rate disorder characterized by accurate but slow and effortful reading (Landerl & Wimmer, 2008; Landerl et al., 1997; Serrano & Defior, 2008; Zoccolotti et al., 1999). It is also characterized by failure to achieve unitized reading; i.e., manifested as letter-by-letter and syllable-by syllable oral reading (Kornev et al., 2010). This view is supported by other findings regarding children with reading disability, namely their predisposition for using orthographically incorrect but phonologically plausible spellings (Bourassa & Treiman, 2003) and low sensitivity to orthographic structure (Araújo et al., 2015; Landerl & Wimmer, 2008). Our findings are consistent with these observations.

Our results also confirm the importance of orthographic skills and reveal a limited contribution of phonological processing skills to reading fluency in both good and poor readers in grades 2 to 6, i.e., grades in which children are expected to have learned the individual letter-sound correspondences and mastered basic decoding skills. In our model with word decoding accuracy and word unitization as mediators, even though phonological skills made a contribution to both decoding accuracy and unitization, they did not, either directly or indirectly, contribute to reading fluency. In the model with pseudoword decoding accuracy, we found its direct effect on reading fluency to be significant only for the poor readers. On the other hand, orthographic processing made a strong direct contribution to reading fluency in both good and poor readers. It also contributed to word unitization, a skill that in itself is an important predictor of reading fluency in good readers. Orthographic processing also contributed to word reading accuracy in this group. Thus, orthographic processing appears to be important for reading fluency for students of both ability levels and for reading accuracy in good readers.

With respect to the relative importance of decoding accuracy and word unitization to reading fluency, our results diverged in the two groups. They underscored the role of word unitization skills in skilled reading and pointed to a failure to develop strong unitization skills as an important marker of reading difficulties in a transparent orthography. We found that for good readers, word unitization, but neither word nor pseudoword decoding accuracy, contributed to reading fluency. In contrast, for poor readers, it was pseudoword decoding accuracy not word unitization (or word decoding accuracy) that made a significant contribution to reading fluency. Thus, it appears that what distinguishes more and less fluent readers among those with high skill levels is the degree to which they read words as whole units. In contrast, this characteristic is less important for children with low skill levels, among whom more fluent readers are distinguishable from less fluent ones by the number of decoding errors.

Our mediation analyses confirmed the greater importance of word unitization in comparison to decoding accuracy for good readers and the reverse pattern (greater importance of decoding accuracy relative to word unitization) for poor readers. We found that for good readers, word unitization, but not decoding, was a significant mediator for the relationship between reading fluency and all three independent variables in both models. In contrast, for poor readers, pseudoword decoding mediated the relationship between phonological skills and oral reading fluency. This again highlights the important role of word unitization in skilled reading and points to it as an important intervention target in children with reading difficulties. This also suggests that a different mode of reading is used by good and poor readers.

The reason for the lack of a significant relationship between reading fluency and the scores on the two decoding accuracy measures in good readers needs further investigation. One potential explanation for this lack of association may be related to the so-called “missing letter” phenomenon (Healy, 1994; Healy &Cunningham, 2014; Healy & Zangara, 2017). This phenomenon refers to the finding that skilled readers make a striking number of errors on a simple letter detection task (i.e., identifying every instance of a particular letter while reading a text), particularly with familiar high frequency words (e.g., “the”). The number of such letter detection errors decreases with greater text difficulty or with less familiar words, suggesting that letter detection errors arise because skilled readers, operating with whole word orthographic units, upon recognizing such large-grain units shift attention to the next unit and do not engage in deep processing of the individual graphemes. As processing demands increase (as with greater text difficulty), necessitating a greater allocation of time and attentional resources to individual graphemes, fewer letter detection errors are observed (Healy & Zangara, 2017).

This phenomenon may explain why in our group of good readers we did not find a relationship between reading accuracy on single words and the reading fluency of a text. In the case of the single word reading task, a substantial proportion of accuracy errors made by good readers may be an epiphenomenon of word unitization (i.e., decreased attention to individual graphemes) leading to occasional graphophonemic miscues (e.g., in English, reading a word “friend” as “fried”). This type of error would be minimized for good readers on the text reading task due to contextual cues, and lead to a lack of a correlation between the scores on the two measures. In poor readers, on the other hand, reading fluency was related to decoding accuracy (when measured with pseudowords) and not to word unitization, which was likely not strong enough in this group to be a predictor. Another potential explanation for the lack of a significant relationship between word unitization and reading fluency in poor readers may be that the unitization scores in this group mainly reflected not truly unitized, “sight” word readings, but miscues (guesses based on partial cues), reflective of insufficient orthographic learning. Such miscues in a text reading would lead to self-corrections and dysfluency.

In sum, the view of reading acquisition that our study supports maintains that for a novice reader or a child with reading difficulties, still in the process of mastering basic decoding skills, translating individual letters into their corresponding sounds before blending them into recognizable words is the predominant mode of reading, aside from being able to recognize a small number of highly frequent words logographically. Sufficient exposure to written words and repeated successful decoding opportunities facilitate orthographic learning, as per the self-teaching hypothesis (Share, 1995). Furthermore, readers may need to accumulate a certain critical mass of sight-reading vocabulary as a foundation for the acquisition of the graphotactics necessary for seamless reading of novel or lower frequency words, a hallmark of skilled reading. Children with reading disability, who may need greater exposure to written words (and to successful decoding opportunities) for this type of learning to take place than typically developing readers, are likely hampered in orthographic learning, as their initial difficulties with decoding skills would translate not only into fewer successfully decoded words, but also to decreased motivation, which then further limits their exposure to reading and the acquisition of the orthographic lexicon. Succesful intervention approaches to targeting fluency would have to overcome this problem and create rewarding training conditions that allow struggling readers to attain high levels of exposure to print, necessary for successful orthographic learning.

4.1. Limitations and directions for further research

Additional research is needed to investigate the sources of heterogeneity in orthographic learning, an area overshadowed by the focus on phonological processes adopted by research in the last few decades. Visual attention, proposed as a candidate for the basis of individual differences in reading (dys)ability (Vidyasagar & Pammer, 2010) is a plausible candidate. A study of developmental dyslexia in Italian (Saksida et al., 2016) found that visual attention span correlated with orthographic processing and predicted reading fluency, while reading accuracy was predicted by phonological skills, a finding consistent with our results and worth exploring further in other languages.

Another issue that the present study did not address is the role of development independently from that of reading ability. In our study, focused on reading ability, we combined readers of high and low ability levels across a wide range of developmental levels (grades 2 – 6). Further analyses are needed to investigate how the patterns of interrelationships between the phonological and orthogrpahic skills with decoding accuracy, unitization and overall reading efficiency change with age/grade in children of average ability levels (as well as tracking the developmental changes separately in good and poor readers). If our predictions are correct, the role of phonological processing should decrease and that of orthographic processing increase with development, a change likely slower to occur in children with lower reading ability levels.

Finally, further investigations are needed on the role of general intelligence in reading acquisition, as we uncovered a significant difference in non-verbal IQ between our groups of good and poor readers. The utility of IQ discrepancy in the identification of children with reading disability is a contentious issue, with recent research suggesting that IQ is not a relevant factor in predicting neural responses to print or response to reading intervention (Simos, Fletcher, Rezaie, & Papanicolaou, 2014; Stuebing, Barth, Molfese, Weiss, & Fletcher, 2009; Tanaka et al., 2011). In our preliminary analyses, we applied the SEM models reported here separately to IQ-discrepant and IQ-non-discrepant groups of poor readers (i.e., those with average versus below average IQs). We found largely similar patterns for both groups, with the exception of the direct Orthogrphic skills – Fluency path. This relationship was stronger for the IQ-discrepant than the non-discrepant group (β=.51 and β= .21respectively), and similar to what we found for good readers. We also found significant group differences between the IQ-discrepant and non-discrepant poor readers in orthographic and phonological processing measures, but not in the decoding accuracy or fluency measures. This may suggest that to the extent that there isa relationship between non-verbal intelligence and the acquisition of componential reading skills, it is insufficient for explaining difficulties in reading acquisition. Instead, sources of individual differences in reading acquisition must be specific to phonological and/or to orthographic processing skills and their neural substraits, rather than general intelligence.

5. Conclusions

In much of research, reading development has been equated with the development of reading accuracy (Wimmer, 2006). Thus, developmental reading theories, such as the influential psycholinguistic grain-size theory (Ziegler & Goswami, 2005), address the contrast in the ease of acquiring decoding accuracy between beginning readers of transparent and non-transparent orthographies. However, as noted in a commentary to Ziegler & Goswami (2005) by Wimmer (2006, p. 447), “This is a rather (time-) limited perspective… Learning to read a consistent orthography is similar to learning to play an instrument like the piano where the problem is not to learn the fully consistent notation, but to become even moderately fluent.”

One can argue that becoming “even moderately fluent” is a hurdle to overcome for readers of any orthography past the stage when the notation is learned (the stage achieved slower with languages of greater orthographic inconsistency). Therefore, to explain reading development one must explain the process of gaining fluency and what componential skills contribute to this process.

The current study adds to the growing evidence of the importance of orthographic processing and unitized reading skills for developing fluent reading in a relatively rarely studied language (Russian) with a transparent (in the direction from spelling-to-sound) orthography. We found orthographic skills to be the strongest direct predictor of reading fluency in both good and poor readers, an important finding pointing to the crucial importance of orthographic learning in promoting reading skills in developing readers of all ability levels.

Furthermore, it appears that a key substantive difference between good and poor readers is that the latter have not yet acquired sufficient unitized reading skills and continue to rely on their piecemeal (letter-by-letter) assembly of written words for fluent reading. In contrast, in good readers’ increased reading fluency primarily comes from greater word unitization skills.

Given the importance of orthographic skills and unitized reading for achieving skilled reading in a transparent orthography, it is fair to expect the role of these skills to be even more important in an orthography like English, with its high orthographic depth, both for regular and irregular words. This finding has important pedagogical implications, as it suggests that interventions, particularly for students past the initial phase of reading instruction, should include training for orthographic processing skills and unitized reading to a much greater extent than is currently done.

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Highlights

- Orthographic skills are the strongest direct predictor of reading fluency in good and poor readers in a transparent orthography (Russian).
- In good readers, orthographic skills also contribute to fluency indirectly, via unitized reading.
- Phonological skills make no direct contribution to reading fluency in good or poor readers.
- In good readers, unitized reading, but not word or pseudoword decoding accuracy, is a significant predictor of reading fluency.
- In poor readers, pseudoword decoding accuracy, but not unitized reading is a significant predictor of reading fluency.

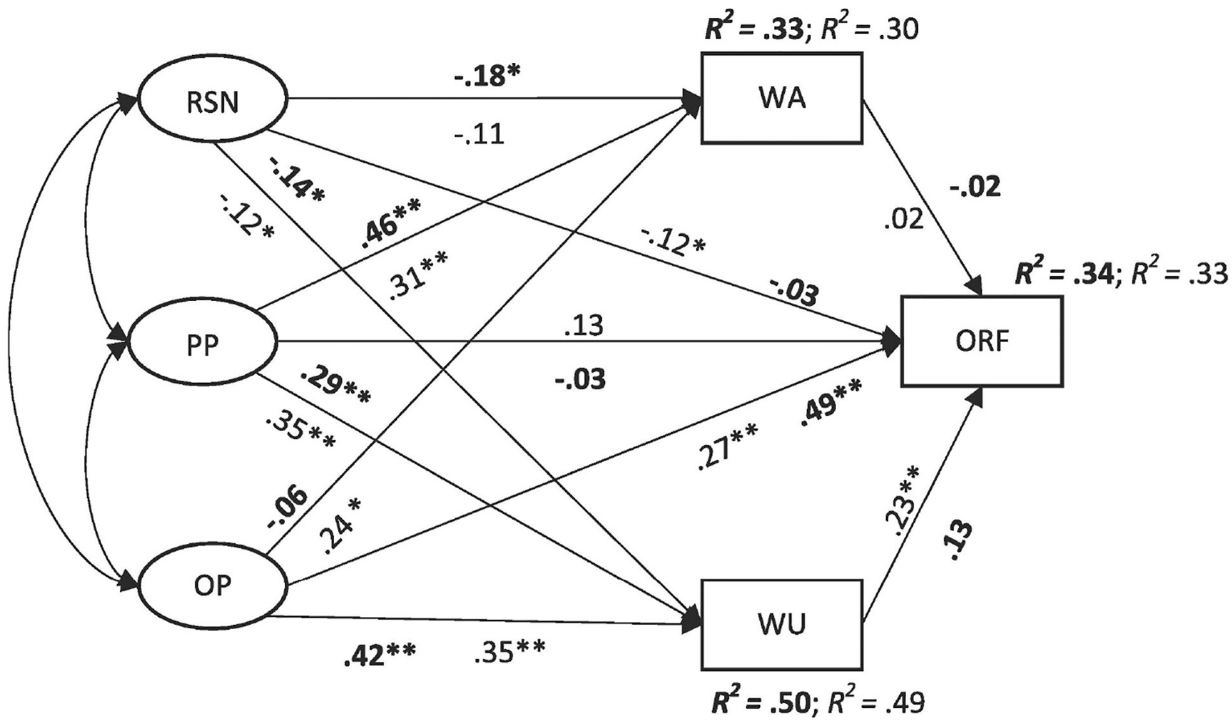

Fig. 1.

Model 1: Word reading accuracy (WA) and Word unitization (WU) as mediators of the relationship between rapid serial naming (RSN), phonological processing (PP) and orthographic processing (OP) with oral reading fluency (ORF). All the variables in the model were regressed by IQ and age. The coefficients in **bold** are for the poor readers group. $^{**}p < 0.001$, $^{*}p < 0.05$.

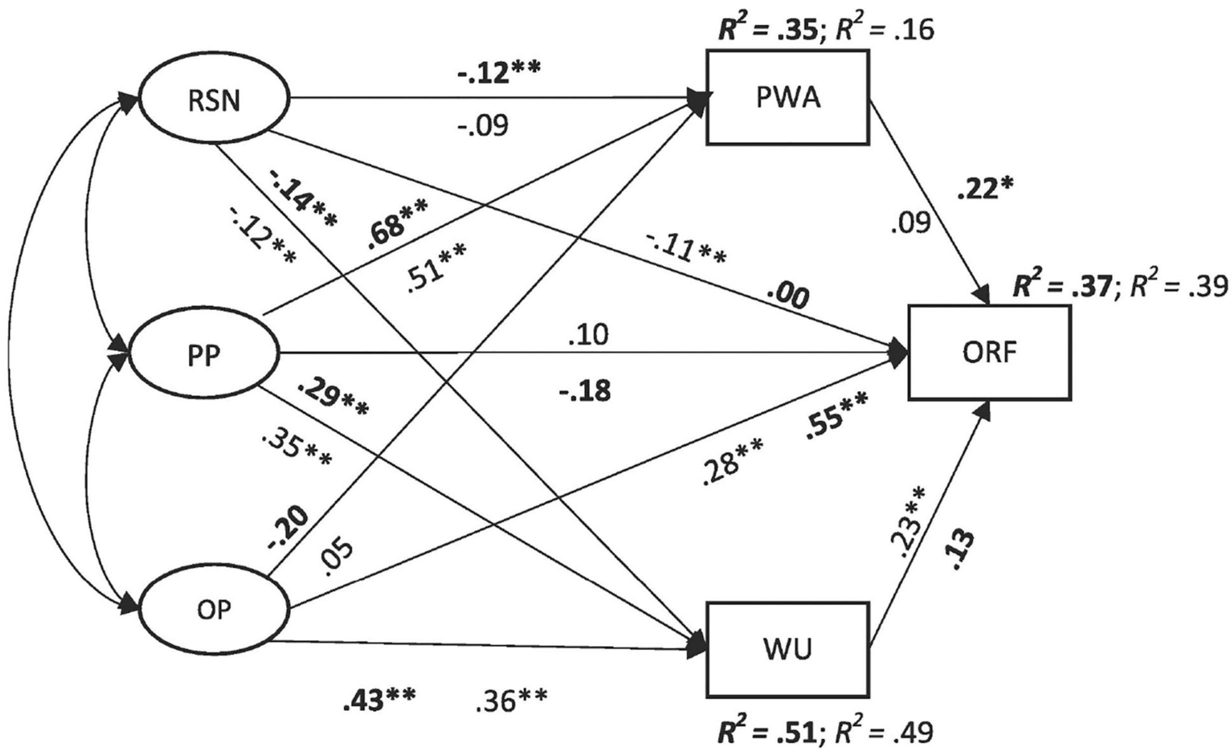

Fig. 2.

Model 2: Pseudoword decoding accuracy (PWA) and Word unitization (WU) as mediators of the relationship between rapid serial naming (R SN), phonological processing (PP) and ortho-graphic processing (OR P) and oral reading flu-ency (OR F). All the variables in the model were regressed by IQ and age. The coefficients in **bold** are for the poor readers group.

** $p < 0.001$, $p < 0.05$.

Table 1.

Sample composition for the groups of good and poor readers

	Poor Readers						Good Readers					
Grade	**N**	**%**	**Females**	**Males**	***M*** ***Age***	***SD*** ***Age***	**N**	**%**	**Females**	**Males**	***M*** ***Age***	***SD*** ***Age***
2	200	37.2	82	118	8.65	.45	272	33.7	157	115	8.65	.45
3	110	20.4	45	65	9.66	.45	194	24.1	116	78	9.66	.45
4	90	16.7	33	57	10.71	.46	170	21.1	95	75	10.71	.46
5	70	13.0	34	36	11.68	.48	91	11.3	56	35	11.68	.48
6	68	12.6	19	49	12.72	.48	79	9.8	41	38	12.72	.48
Total	538	100.0	213	325	10.11	1.51	806	100.0	465	341	9.97	1.38

Table 2.

Descriptive statistics for the groups of good and poor readers with the effect size for each task

	Poor Readers PR (n = 538)				Good Readers GR (n = 806)					
	M	***SD***	**Skewness**	**Kurtosis**	***M***	***SD***	**Skewness**	**Kurtosis**	**F (1,1342)**	**Cohen's *d***
Age	10.11	1.51	.49	−.85	9.97	1.38	.52	−.58	-	1.208
NV-IQ	104.37	13.36	−.06	−.31	113.01	13.72	−.42	.12	-	0.638
RSN_D	20.12	6.31	1.60	5.74	15.82	4.35	.97	1.64	215.156	0.782
RSN_L	33.50	12.25	1.09	2.43	26.03	8.48	.95	1.91	185.313	0.709
WU	34.97	5.76	−1.40	2.42	40.01	2.56	−3.84	30.03	382.157	1.130
WA	20.56	11.57	.12	−1.18	37.43	5.20	−2.15	6.93	1234.799	1.881
SS	38.17	7.83	−.71	.73	46.94	5.28	−1.55	6.17	554.462	1.313
PWR	17.42	4.15	−.75	.02	20.86	2.38	−1.54	2.94	265.738	1.016
PA	28.66	10.03	−.95	.25	37.87	5.51	−3.22	14.11	342.922	1.138
OP	24.58	7.00	−.39	−.15	32.03	5.92	−1.58	3.16	386.384	1.149
ORF	46.44	26.64	2.38	8.41	127.03	28.74	−.25	1.06	2802.271	2.908
PWA	28.29	7.52	−.617	.224	35.30	4.21	−1.50	3.33	348.751	1.150

Note: NV-IQ = Nonverbal Intelligence; RSN_D = Rapid Serial Naming of Digits; RSN_L = Rapid Serial Naming of letters; WA = Word Reading Accuracy; WU = Word Unitization; SS = Spelling skills; PWR = Pseudoword Repetition; PA = Phonological Awareness; OP = Orthographic Processing; ORF = Oral Reading Fluency; PWA = Pseudoword Reading Accuracy. All the differences between groups were statistically significant. The descriptive information is based on raw data; the differences between the groups were computed using the variables controlled by age and IQ. The Cohen's *d*'s for age and NV-IQ were computed using the mean of the groups. All *p's* <.001.

Table 3.

Bivariate correlations between all study variables for the groups of good and poor readers

	1	2	3	4	5	6	7	8	9	10
l. RSN _D	1	.471**	−.203**	−.250**	−.087*	−.146**	−.145**	−.141**	−.250**	−.147**
2, RSN_L	.477**	1	−.164**	−.199**	−.120*	−.117*	−.151**	−.099*	−.185**	−.127**
3. WA	−.213**	−.234**	1	.550**	.252**	.329**	.379**	.212**	.374**	.332**
4. WU	−.299**	−.258**	.417**	1	.341**	.399**	.453**	.366**	.535**	.297**
5. PWR	−.057	−.097*	.304**	.320**	1	.325**	.266**	.151**	.273**	.192**
6. PA	−.148*	−.099*	.315**	.339**	.326**	1	.354**	.227**	.321**	.256**
7. SS	−.176**	−.212**	.297**	.411**	.203**	.223**	1	.384**	.394**	.252**
8. OP	−.170**	−.149*	.157**	.341**	.184**	.159**	.324**	1	.312**	.120**
9. ORF	−.214**	−.189**	.235**	.449**	.178**	.209**	.342**	.319**	1	.309**
10. PWA	−.138**	−.146**	.336**	.298**	.317**	.336**	.172**	.386**	.102**	1

Note: The coefficients above the diagonal are for the group of good readers, and the coefficients below the diagonalare for the group of poor readers. All the variables were regressed by IQ and age. RSN_D = Rapid Serial Naming of Digits; RSN_L = Rapid Serial Naming of letters; WA = Word Reading Accuracy; WU = Word Unitization; SS =Spelling Skills; PWR = Pseudoword Repetition; PA = Phonological Awareness; OP = Orthographic Processing; ORF = Oral Reading Fluency; PWA = Pseudoword Reading Accuracy.

** p <.001,

* p <.05.

Table 4.

Fit indices for Model 1 and Model 2. Fit indices for the multigroup analyses and partial invariance.

		χ^2	*df*	*p*	χ^2/ *df*	CFI	RMSEA	LO90	HI90	TLI	Δ CFI
Model 1	Total Sample	27.857	15	.022	1.857	.998	.025	.009	.040	.994	-
	GR	20.687	15	.147	1.38	.996	.022	.000	.042	.991	-
	PR	14.2	15	.510	0.947	1.00	.000	.000	.039	1.00	-
Model 2	Total Sample	19.659	15	.185	1.311	.999	.015	.000	.032	.999	-
	GR	17.22	15	.306	1.148	.998	.014	.000	.037	.996	-
	PR	9.677	15	.840	0.645	1.00	.000	.000	.024	1.00	-
Multigroup	Baseline	34.897	30	.246	1.163	.998	.011	.000	.024	.995	-
Model 1	Loadings RSN - PP - OP	37.037	33	.288	1.122	.998	.010	.000	.023	.996	.000
	Structural Paths	78.881	41	.000	1.924	.985	.026	.017	.035	.975	.020
	Path from WA to ORF	35.211	31	.276	1.136	.998	.010	.000	.024	.996	.001
	Path from WU to ORF	40.299	31	.122	1.200	.996	.015	.000	.027	.991	.004
Multigroup	Baseline	26.896	30	.629	0.897	1.00	.000	.000	.018	1.00	-
Model 2	Loadings RSN - PP - OP	28.546	33	.689	0.865	1.00	.000	.000	.016	1.00	.000
	Structural Paths	72.166	41	.002	1.760	.996	.024	.014	.033	.975	.004
	Path from PWA to ORF	27.227	31	.658	0.880	1.00	.000	.000	.017	1.00	.000
	Path from WU to ORF	32.205	31	.407	1.039	.999	.005	.000	.021	.999	.001

Note: GR = good readers; PR = poor readers. Model 1 = rapid serial naming (RSN), phonological processing (PP), and orthographic processing (OP) as concurrent predictors of the performance on oral reading fluency (ORF)mediated by word reading accuracy (WA). Model 2: rapid serial naming (RSN), orthographic processing (OP), and phonological processing (PP) as concurrent predictors of the performance on oral reading fluency (ORF) mediated by pseudoword reading accuracy (PWA). CFI = Comparative Fit Index; RMSEA = Root Mean Square Error of Approximation and the confidence interval of 90%; TLI = Tucker-Lewis Index.