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Phonemic awareness is a more important predictor of orthographic processing than rapid serial naming: Evidence from Russian

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Abstract

We studied the relationship between rapid serial naming (RSN) and orthographic processing in Russian, an asymmetrically transparent orthography. Ninety-six students (mean age = 13.73) completed tests of word and pseudoword reading fluency, spelling, orthographic choice, phonological choice, PA and RSN. PA was a better predictor of orthographic skills and pseudoword reading accuracy than RSN, which accounted for more variance in word and pseudoword reading fluency. Controlling for pseudoword reading fluency washed out RSN's contribution to word reading fluency. These results extend previous findings questioning the role of RSN as an index of orthographic processing skills and support the idea that RSN taps into automaticity/efficiency of processing print-sound mappings.

Keywords

Rapid serial naming; phonological awareness; orthographic processing; phonological processing; fluency; asymmetric orthography

It has been well attested that rapid serial naming (RSN)—the speed with which one is able to name series of repeating stimuli, such as letters or digits—is related to reading performance independently of factors known to exert an important influence in literacy acquisition, such as intelligence, phonological awareness, and prior reading performance (Compton, 2003; Georgiou, Parrila, Kirby, & Stephenson, 2008; Kirby, Parrila, & Pfeiffer, 2003; Lervag & Hulme, 2009; Pennington, Cardoso-Martins, Green, & Lefly, 2001). In addition, deficits in RSN are often observed among children with specific reading disability (Bowers, 1995; Cronin, 2013; Denckla & Rudel, 1976; Katzir, Kim, Wolf, Morris, & Lovett, 2008; Landerl et al., 2013; Wimmer, Mayringer, & Landerl, 2000).

Nonetheless, there is still much controversy regarding the mechanism(s) behind the association between individual differences in RSN and literacy acquisition. In the present

study we investigated the relationship between RSN and literacy skills in Russian. We were particularly interested in evaluating the hypothesis that the relationship between RSN and literacy acquisition is mediated by orthographic processing skills (Bowers & Wolf, 1993). As argued further below, one characteristic of the Russian orthography, namely, the presence of inconsistent sound-to-spelling correspondences despite its high degree of consistency in the spelling-to-sound direction, renders it particularly well suited for addressing this question.

Orthographic Processing Skills in Literacy Acquisition

Given the importance of phonology in alphabetic orthographies, it is not surprising that knowledge of letter-sound relations and phoneme awareness (PA) are among the best predictors of success in learning to read and spell in orthographies of varying orthographic depth (Caravolas, Volin, & Hulme, 2005; Ehri et al., 2001; Mayringer, Wimmer, & Landerl, 1998; Share, Jorm, Maclean, & Matthews, 1984; Wagner & Torgesen, 1987). However, despite their fundamental role, phonological skills are clearly not sufficient for the development of fluent reading and accurate spelling.

Skilled reading, i.e., rapid and effortless recovery of the phonological form and meaning of the word without directing conscious attention to the mechanics of phonological decoding (Ehri, 2005), involves an additional set of skills, i.e., orthographic processing, a construct importance of which is widely acknowledged (Berninger, 1994, 1995; Cunningham, Perry, & Stanovich, 2001; Castles & Nation, 2006; Wagner & Barker, 1994), but precise definition of which is somewhat elusive (Castles & Nation, 2006). According to one theory-neutral definition, orthographic processing is the ability to form, store and access orthographic representations (Stanovich & West, 1989), which may include such skills as identifying illicit letter sequences, sensitivity to recurring orthographic patterns and word spellings, analyzing words into orthographic units, applying spelling rules, much of which is acquired implicitly (Ehri, 2000; Venezky, 1967). Consequently, mature readers come to possess a large fully specified orthographic lexicon (Perfetti, 1992), which includes a “dictionary” of orthographic units of various types, i.e., recurring letter combinations, morphemes and whole words, and becomes an integral part of the lexical system recruited during word recognition. This makes the process highly efficient, as words are recognized not only as comprised of phoneme/grapheme strings, but also as containing orthographic units larger than single graphemes, including morpheme-size and whole-word-size orthographic units. This facility in relying on orthographic processing during word recognition does not imply bypassing phonology or recognizing words as unanalyzable gestalts, but involves both phonological and orthographic processes, at both lexical and sub-lexical levels, all tightly interconnected.

According to one prominent view in the literature, phonological skills play a primary role in the acquisition of orthographic skills by enabling the novice reader to build an autonomous orthographic lexicon, and accounts for skilled readers’ capacity to recognize thousands of words (nearly) instantaneously and automatically, regardless of how many phonological and orthographic neighbors they may have (Ehri, 1992, 2005, 2013; Share, 1995, 2008). The reason for this is that the skill of reading by processing letter-sound relations in words

obligatorily draws readers' attention to the identity and order of the letters and how they map onto sounds in the pronunciations of words, providing a powerful mnemonic mechanism for accumulating written words bonded to their pronunciations and meanings.

The importance of PA for building orthographic skills, however, is somewhat challenged by the imperfect, albeit substantial, correlations between the former and the latter observed in both good and poor readers (Castles & Coltheart, 1993; Ehri, 2000; Manis, Seidenberg, Doi, McBrideChang, & Petersen, 1996; Peterson, Pennington, & Olson, 2013; Stanovich, Siegel, & Gottardo, 1997). Indeed, children seem to begin to learn about orthographic regularities even before they acquire letter-sound correspondences (Kessler, Pollo, Treiman, & Cardoso-Martins, 2013).

1.2. Relationship between orthographic skills and rapid serial naming

The idea of the autonomy of orthographic from phonological processing skills was boosted by the view that suggested an important role for RSN in the development of orthographic skills. Specifically, learning recurring letter patterns or even word spellings has been proposed to be related to the capacity for rapid identification of familiar symbols, as measured by RSN tasks (Bowers & Wolf, 1993). There is indeed strong evidence that RSN, in comparison with PA, accounts for more individual differences in word reading fluency, a skill that presupposes the capacity to efficiently access words' orthographic representations in long-term memory (Katzir et al., 2006; Lervag & Hulme, 2009; Vaessen & Blomert, 2010). Although the relationship between RSN and reading fluency has been clearly documented (see Kirby, Georgiou, Martinussen, & Parrila, 2010, and Norton & Wolf, 2012, for recent reviews), the idea that this relationship is mediated by orthographic processing skills has not been always supported (Georgiou et al., 2008; Moll Fussenegger, Willburger, & Landerl, 2009).

In particular, the findings on the relationship between RNS and orthographic knowledge, as indexed by spelling skills, are rather weak. Some studies found that RSN contributed to spelling after controlling for variation in PA (Caravolas, Lervåg, Mousikou, Efrim, et al., 2012; Moll, Ramus, Bartling, Bruder, et al., 2014; Moll et al., 2009; Savage, Pillay, & Melidona, 2008; Stainthorp, Powell, & Stuart, 2013) or other measures typically used to assess phonological processing, such as pseudoword spelling or pseudoword reading (e.g., Savage & Frederickson, 2006; Savage et al., 2008). However, in none of these studies was the unique contribution of RSN to spelling greater than that of PA or that of pseudoword reading/spelling, with the exception of the English-speaking sample in a study of multiple orthographies of varying orthographic depth (Moll et al., 2014). Other studies (Cardoso-Martins & Pennington, 2004; Cornwall, 1992; Pennington et al., 2001) found that RSN did not contribute to spelling performance above and beyond PA, while PA accounted for more variance in spelling skills than RSN.

One study of word and pseudoword reading fluency and spelling in three large samples of children learning to read in German (Moll et al., 2009) found no evidence that RSN accounted for more variance in spelling, but that it explained more variance in word reading fluency than PA. Furthermore, RSN also explained more variance in pseudoword reading fluency, a task typically taken as a measure of phonological, not orthographic processing.

Finally, controlling for pseudoword reading fluency washed out the correlation between RSN and word reading fluency, while controlling for spelling performance did not. Thus, this study called into question the idea of RSN being an index of orthographic processing skills, but suggested that it is related to efficiency and automaticity of word reading (linking orthography to phonology).

The absence of a strong relationship between RSN and spelling is, in fact, a rather consistent finding in orthographies more transparent than English (Babayigit & Stainthorp, 2011; Corrêa & Cardoso-Martins, 2012; Furnes & Samuelsson, 2011; Krasowicz-Kupis, Borkowska & Pietras, 2009; Landerl & Wimmer, 2008; Nikolopoulos, Gouladriss, Hulme, & Snowling, 2006; Vaessen & Blomert, 2013). In all of these studies, RSN was a better predictor of reading fluency than of spelling. In contrast, PA contributed more to spelling than to reading fluency. It is unlikely that the relatively weak relationship between RSN and spelling is simply a function of the differences in the way these skills are measured, with speed being the measure of RSN, while accuracy the measure of spelling, as speeded measures of spelling produce similar results as unspeeded measures (Vaessen & Blomert, 2013).

One may argue that it may be difficult to detect a relationship between RSN and spelling, even if the former is an index of orthographic processing skills, because spelling production tasks rely on phonological coding skills to a higher extent than such measures as orthographic choice and irregular word reading (Vaessen & Blomert, 2013). As argued by Shahar-Yarmes and Share (2008), during spelling production, even with highly familiar words and skilled performance, one is obliged to sequentially map each of the word's phonemes onto the corresponding conventional graphemes, in contrast to irregular word reading and orthographic choice tasks, which may only require recognition via the addressed route – accessing stored orthographic representations of words and/or word parts rather than assembling them piecemeal. This might explain the relatively strong correlations found between PA and spelling performance in the studies mentioned previously. In view of this, measures of orthographic pattern recognition may be more informative for investigating the cognitive underpinnings of orthographic processing skills.

While there is some evidence that irregular word reading and orthographic choice is related to RSN performance in English (Georgiou et al., 2008; Manis, Doi, & Bhadha, 2000; Manis, Seidenberg, & Doi, 1999), research in transparent/asymmetric orthographies using such measures is relatively scarce. One such study (Papadopoulos, Georgiou, & Kendeou, 2009) reported no strong relationship between deficits in RSN and orthographic choice in a sample of Greek-speaking children. Similar results were found in a study with Spanish-speaking children (Jiménez, Hernández-Valle, Rodríguez, Guzmán, et al., 2008). However, in both studies, the children were assessed at the beginning of elementary school, i.e., at a time when phonological coding skills are still predominantly used to read words (e.g., Georgiou et al., 2008).

The reason for the inconsistency between English and non-English-language studies likely lies in the English orthography with its high level of both feed-forward and feed-back inconsistency. This high degree of inconsistency is known to adversely affect the pace of

acquisition of literacy-related skills in English-speaking children in comparison to children learning to read in a transparent orthography (e.g., Seymour, Aro, & Erskine, 2003), leading to a more protracted phase of reduced accuracy in word reading, which becomes a confound in fluency measures. It also leads to the presence of phonological errors in spelling.

Unlike in English, languages with a high degree of feed-forward consistency often have a high degree of feed-back inconsistency, i.e., are asymmetric. In such languages most, if not all, words can be decoded phonologically, but phonologically similar words are often spelled differently, following various orthographic conventions (analogously to English “cell” and “sell” or “plane” and “plain”), such that phonologically-based spellings are often orthographically incorrect. The choice of spelling may be determined by the morphological unity principle, the word’s origin, or the orthographic, phonological, or morphological context, requiring one to search among multiple alternatives and drawing heavily on orthographic knowledge (Treiman & Bourassa, 2000).

It has been suggested (Moll et al., 2009) that asymmetric orthographies (i.e., those with high feed-forward but low feed-back consistency) provide a better probe for the study of the correlates of orthographic processing skills because children learning to read in such orthographies, even those with literacy difficulties, learn phonological decoding skills fairly quickly. Their difficulties are typically manifested not as inaccurate, but as slow effortful reading, as well as inaccurate, but phonologically plausible, spellings (Hautala, Aro, Eklund, Lerkkanen, & Lyytinen, 2013; Krasowicz-Kupis, Borkowska, & Pietras, 2009; Lachmann, Steinbrink, Schumacher, & van Leeuwen, 2009; Rakhlin, Kornilov, Grigorenko, in press; Tressoldi, Cornoldi, & Lucangeli, 2011; Wimmer et al., 2000). This suggests that reading fluency and spelling measures in asymmetric orthographies may be clearer indicators of orthographic processing skills than those are in English. Moreover, if RSN indeed taps more specifically into orthographic processing skills, we would expect to find a strong relationship between RSN and measures of orthographic processing, such as spelling accuracy and orthographic choice, as well as with measures of reading fluency, particularly word reading fluency.

In the present study, we investigated the relationship between RSN and measures of orthographic choice and spelling as well as reading fluency in a sample of older, middle school Russian-speaking students.

Russian Orthography

Despite one notorious feature of Russian orthography, namely encoding the palatalization feature of consonants with the following vowel letter (e.g., *Mam*, [mat] (checkmate) – *Mgn* [mʲat] (crumpled)), each written syllable has only one pronunciation (with a small number of exceptions). This regularity makes reading in Russian a straightforward process of converting a sequence of written syllables to a sequence of spoken syllables (in a nearly one-to-one relationship) and mapping this sequence onto a familiar word in the reader’s mental lexicon. On the other hand, spelling in Russian, as in other languages with a standardized orthography, involves converting the spoken form to a prescribed orthographic form (a one-to-many relationship) using various spelling rules and knowledge of permissible

orthographic patterns. These characteristics make the process of phonological decoding in Russian relatively easy, with low reading fluency but not low accuracy, and phonologically plausible, but orthographically incorrect spellings, being the most robust indicators of difficulties in literacy acquisition (Rakhlin, Kornilov, Grigorenko, 2014).

In contrast to orthography-to-phonology mapping, phonology-to-orthography mapping in Russian is complicated, making phonological spelling inadequate, by a number of pervasive phonological processes that alter sound shapes of words creating massive numbers of words with spellings unpredictable from pronunciations, including homophones, that is, words identical in pronunciation and distinct in spelling. For example, all unstressed vowels undergo phonological changes in vowel quality (Timberlake, 1993). Thus, when unstressed, the vowels /e/ and /i/ are both pronounced as a somewhat reduced [i] resulting in homophones, e.g., “lisa” (fox) and “lesa” (woods) both pronounced as “lisa”, but with their respective spellings reflecting the underlying (phonemic) rather than the surface (allophonic) form. Because Russian words are predominantly polysyllabic with only one stressed syllable, most words contain unstressed reduced vowels and require orthographic knowledge for correct spelling. Another ubiquitous phenomenon leading to neutralization of phonemic contrasts and a divergence between pronunciation and spelling is final consonant devoicing, e.g., “luk” (onion) and “lug” (meadow), both pronounced as “luk” but spelled with a different final consonant. A similar phenomenon is consonant assimilation, leading to obstruent clusters to always agree in the voicing feature, with the spelling retaining the underlying form (e.g., the word-initial consonant clusters in the words *sdelka*, “deal”, and *zdes’*, “here”, both sound as [zd] and require the knowledge of orthographic rules for correct spelling).

Thus, while feed-forward consistency in Russian is very high, its feed-back consistency is very low. Because the feed-back inconsistency results not primarily from irregular (idiosyncratic) spellings, but from the complex relationship between spelling and underlying (phonemic) rather than surface (phonetic) forms, it affects a large portion of Russian words and makes acquisition of orthographic skills quite challenging, requiring a protracted phase of explicit teaching of orthographic “rules” throughout the elementary and middle school years, with phonologically plausible but orthographically incorrect spellings (as well as slow, but relatively error-free reading) being the most typical symptoms of literacy deficits in children and adults (Kornev, Rakhlin, Grigorenko, 2010).

Current Study

In the present study, we evaluated the hypothesis that RSN is an index of orthographic processing (Bowers & Wolf, 1993). More generally, the goal of our study was to contribute to the understanding of the relationship between RSN, PA, and orthographic processing skills by looking at this relationship 1) in an under-researched asymmetric orthography, Russian; 2) a sample of children at a more advanced phase of literacy acquisition (middle school grades), with a relatively high level of phonological skills, but who are still acquiring orthographic knowledge; and 3) by using both production and recognition measures of orthographic processing, namely spelling production and orthographic choice (Olson, Forberg, Wise, & Rack, 1994), as well as reading fluency.

If RSN indeed taps into orthographic processing skills, this would predict a strong relationship between RSN and both measures of orthographic processing (spelling and orthographic choice), while PA skills are expected to be more strongly related to the measures of phonological processing, namely phonological choice. In addition, a close relationship between RSN and orthographic processing skills should manifest itself in a correlation between RSN and word reading fluency even when controlling for pseudoword fluency. On the other hand, this relationship is predicted to wash out when controlled for another measure of orthographic processing, i.e., spelling or orthographic choice.

Methods

Participants

Participants for the current study were recruited from a rural secondary school in Russia. As is typical in the Russian education system, the school combines all of the grades (1 through 11), i.e., the elementary, middle and high school levels. For this study, 98 students (64 % males) between 12.11 and 15.24 years of age ($Mean = 13.73$, $SD = .88$) were recruited. Only children with an IQ greater than 70 were included in the study. Two children with an IQ at or below 70 were excluded from the analyses. The average IQ of the remaining sample ($N = 96$), as estimated from their performance on the CFIT and UNIT tests (see below), was 108.55 ($SD = 19.02$) and ranged between 70 and 158.

Procedure

In addition to tests of phonological awareness (PA) and rapid serial naming (RSN), participants completed tests designed to assess phonological and orthographic skills (phonological and orthographic choice tasks), and tests of spelling, word and pseudoword reading. Finally, all participants were administered a test of non-verbal cognitive functioning. For the individually administered measures, all children were evaluated separately in a quiet room in their schools. The paper-and-pencil group measures were administered in the classroom during times agreed upon by the school principal and each individual classroom teacher. Informed consents were obtained from the parents and the participant in order for the child to participate in the study. The study was approved by the Yale and the Russian collaborating institution's Institutional Review Boards.

Measures—Phonological processing skills were assessed using the *Silent Phonological Choice Task* (Olson, Forberg, Wise, & Rack, 1994), a group administered untimed paper-and-pencil test adapted to Russian. Participants had to choose a printed pseudoword that would sound like a real word if pronounced (a pseudo-homophone) from a triplet of pseudowords. The pseudo-homophones were real words each containing 1 or 2 “weak positions”, i.e., segments, the spelling of which is not clearly predictable from their pronunciation, spelled with phonologically plausible, but orthographically incorrect spellings. The “weak positions” included unstressed vowels, vowels after sibilants, obstruent clusters, final obstruents, doubled consonants, consonant clusters with unpronounceable consonants, and soft and hard sign, all of which involve an uncertainty with regard to whether the segment in question must be spelled phonologically or not. Thus, an item may contain a triplet *plep*, *xlet*, *xlep*, with the former two being nonse words and the latter

corresponding to the real word “xleb” (bread). Because all obstruents undergo final devoicing, the pronunciation of this word ([xlep]) makes it ambiguous whether the final consonant should be spelled as or <p>. The two foils accompanying each target were similar to the target in the number and types of syllables (ranging between 1 and 3 syllables in length). To ensure the same degree of word-likeness across all pseudowords, they were constructed in accordance with Russian phonotactic constraints and were judged by 2 native Russian speakers as possible words of Russian. To choose the correct non-word, the student had to be able to 1) decode the word and 2) recognize its relationship to a real word, thus assessing not only phonological decoding skills, expected to be relatively high in our sample, but lexical access via phonological encoding. There were 60 test items. Accuracy scores were derived from the number of correct responses (Cronbach’s $\alpha = .88$).¹

Orthographic processing skills were assessed with the Orthographic Choice Task (Olson et al., 1994), a group-administered untimed paper-and-pencil measure adapted to Russian. Participants were given sets of three letter strings, two of which were real words and the third a pseudo-homophone, i.e., a string that did not correspond to an orthographic word, but which, if sounded out, would sound like an existing word (one of the two words in each string). Participants were asked to identify, which one was not a real word. The points of departure from the correct spelling were guided by the same principle as the pseudo-homophones in the Phonological Choice task, i.e., phonologically plausible spellings of the weak positions, including unstressed vowels, obstruent clusters, doubled consonants, soft and hard signs, etc. For example, a triplet may consist of the items *suma* (*bag*), *ssuma* (pseudo-homophone), *summa* (*sum*). The items in each triplet were similar in length and phonological composition. Although students could use phonological decoding skills to sound out each string, they had to analyze the orthographic form of each item to be able to choose the pseudo-homophones, thus assessing accessibility and quality of their lexical orthographic representations. There were 45 items ($\alpha = .92$). The number of correct responses was scored.

Word and pseudoword reading fluency: Participants were asked to read a list of 18 words and 15 pseudowords as fast as possible. Reading accuracy was very high for both lists, with the mean number of incorrect responses being .04 ($SD = .20$) and .56 ($SD = .86$) for the words and pseudowords, respectively. Given such high degree of accuracy, only the time in seconds taken to read the words and pseudowords was scored and used in the present analyses. The words varied in length (2–4 syllables) and frequency (although all were expected to be part of a middle school child’s vocabulary). The pseudowords were constructed from common Russian syllables conforming to both phonotactic and orthographic constraints of Russian, ranged from 2 to 5 syllables in length, and were judged as possible Russian words by two native Russian-speaking psycholinguists.

Spelling skills: Spelling skills (SS) were assessed by the *Developmental Spelling Test* (Joshi & Aaron, 2003), a group-administered paper-and-pencil test adapted for Russian. The participants were asked to spell words that varied in orthographic complexity (i.e., the

¹The reported reliabilities were calculated on the basis of a larger sample ($N = 150$) which, in addition to the current sample, included younger and older students.

number of positions of a potential spelling error), syllabic structure (i.e., containing simple versus complex syllable onsets and codas) and frequency. The examiner read each word in isolation and then in a sentence. The examiner then repeated the word one more time and asked the student to write it down. The number of correct spellings was scored (maximum score 56, $\alpha = .84$).

Phonological Awareness was measured using an individually administered elision task. The task consisted of eliding segments of various lengths (ranging from a syllable to a single phoneme) from the beginning, middle, or the end of a word and pronounce the word resulting from the elision. Responses were scored for accuracy (maximum score 40, $\alpha = .86$). As expected, this task was relatively easy for the older readers in a shallow orthography, whose scores were negatively skewed (see Table 1 for the *M* and *SD*). To remediate that, we included a measure of time to complete the task as an additional PA score. The time and accuracy scores showed a substantial correlation ($r = -.56$).

Rapid Serial Naming was measured with the Rapid Automatized Naming (RAN) task (Denckla & Rudel, 1976). The student was asked to name as fast as possible series of repeating familiar stimuli printed on a chart in the form of a matrix consisting of five rows and 10 columns. There were four different charts, each comprised of a different type of stimuli (letters, digits, figures of objects, and colors). In each chart, five different stimuli were presented 10 times in a random order. Responses were timed using a stopwatch. Two composite scores were derived, one for the alphanumeric stimuli (Letters and Digits; RSN:LD) and the other for the non-alphanumeric ones (Objects and Colors; RSN:OC), each corresponding to the summed correspondent z-scores divided by two. The two composite scores were highly correlated ($r = .57$) and, although the alphanumeric stimuli tended to be more reliably correlated with the various literacy measures than the non-alphanumeric ones, they both yielded a very similar pattern of results. In view of this, only the results for the alphanumeric composite score are reported below.

Non-verbal Intelligence: All participants, except for a few who were not available at the time of testing, were given the Culture-Fair Intelligence Test (CFIT), Scale 2 (Cattell & Cattell, 1973), a group administered paper-and-pencil test for ages 8 and above measuring non-verbal fluid intelligence, thought to be relatively independent of verbal ability, cultural background and educational level. We used the standardized general IQ score ($\alpha = .79$).

For those for whom CFIT was not available, we used the extended version of the Universal Non-Verbal Intelligence Test (UNIT) (Bracken & McCalum, 1998), an individually administered non-verbal test for ages 5–18 designed to be a fair assessment of non-verbal cognitive functioning in individuals from differing cultural and linguistic backgrounds. The extended battery includes six subtests: Object Memory, Spatial Memory, Symbolic Memory, Cube Design, Analogical Reasoning, and Mazes, with the first three designed to assess memory and the last two reasoning. We used standardized Full-Scale scores (FSIQ; $\alpha = .92$).

Results

Table 1 lists descriptive statistics for all of the indicators used in the study. There was a tendency for some of our indicators to be either negatively or positively skewed. Specifically, PA accuracy, Phonological Choice and Spelling were negatively skewed, whereas both reading fluency indicators were positively skewed. In view of this, these measures were log-transformed. We used Kline's (2005) formulae, namely $\text{Ln} [\text{Max.score} - \text{Score} + 1]$ for the negatively skewed measures, and $\text{Ln} [\text{Score} + 1]$ for the positively skewed ones. After these transformations, all indicators had skewness and kurtosis values within the acceptable (-1.00 – 1.00) range. All of the analyses reported below used the log-transformed scores. Because the procedure used for log transforming the variables resulted in the negatively skewed variables being reversed (i.e., participants with low scores before the transformation having high scores after the transformation and those with high scores before the transformation having low scores after the transformation), we re-inverted these variables before carrying out the analyses to preclude misunderstandings.

The correlation coefficients among the various measures appear in Table 2. Similar to what has been reported in previous studies (Swanson, Trainin, Necochea, & Hammill, 2003), the correlations between PA and RSN:LD was modest and only significant for the PA-Time measure, suggesting that RSN and PA tap into different processes. Accordingly, PA and RSN:LD contributed differentially to the various literacy measures investigated. Specifically, while RSN correlated more strongly with the reading fluency measures, PA was more strongly correlated with the measures of Spelling, and Phonological and Orthographic choice. As discussed further below, these latter results seem at odds with the hypothesis that RSN is of selective import for the acquisition of orthographic processing skills.

In the next set of analyses, a series of multiple regressions were performed to investigate the respective contributions to variance in each of the literacy skills of age, IQ and the two independent variables of interest: PA accuracy and RSN in Model 1, and PA time and RSN in Model 2. All of the independent variables were entered into the model simultaneously. The results of the two analyses are presented in Table 3, separately for each type of literacy skills.

In general, PA and RSN:LD made different contributions to the various indicators of literacy. First, as illustrated in Table 3, only PA (measured as either accuracy or speed) accounted for a statistically significant portion of individual differences in Phonological Choice performance. Secondly, the accuracy and speed indicators of PA accounted for statistically significant portions of individual differences in the performance on both measures of orthographic processing - Orthographic Choice and Spelling. In contrast, RSN:LD did not contribute to variance in the Orthographic Choice task when entered in the regression equation along with age, IQ, and either measure of PA. In addition, although RSN:LD made stronger contributions to performance on the Spelling task than on the Orthographic Choice test, its contribution to Spelling was significant only in the model that used PA accuracy. In marked contrast, RSN made a significant contribution to word and pseudoword reading fluency. As illustrated in Table 3, neither the accuracy nor the time

indicator of PA contributed to reading fluency after taking into account age, IQ and RSN:LD.

In the final set of regression analyses, following Moll et al. (2009), we investigated the contribution of RSN to word reading fluency after controlling for orthographic processing skills or, alternatively, for pseudoword reading speed, in addition to age and IQ. As illustrated in Table 4, results for the analyses controlling for differences in orthographic processing were mixed: while RSN:LD continued to account for a substantial amount of variance in word reading fluency after controlling for differences in the Orthographic Choice task (in addition to age and IQ), controlling for differences in the Spelling test washed out its effect on word reading fluency. Finally, RSN no longer explained a significant amount of variance in word reading fluency, when we controlled for differences in pseudoword reading fluency (in addition to age and IQ). The implications of these findings for our understanding of the role played by RSN in alphabetic literacy acquisition are discussed below.

Discussion

The present study investigated the respective contributions of PA and RSN to indicators of literacy skill in Russian. We were particularly interested in testing the hypothesis that variations in RSN make a stronger contribution to the acquisition of orthographic processing skills than variations in PA. Although the results of the present study confirmed that PA and RSN should be best understood not as two measures of the same underlying cognitive capacity, but as tapping into two somewhat distinct skills (Wolf & Bowers, 1999), we found no evidence that RSN is an index of orthographic processing skills. Thus, we found that it was PA and not RSN that showed a stronger relationship with the measures of phonological and orthographic processing (namely, Phonological Choice, Orthographic Choice and Spelling), while RSN and not PA was associated with reading fluency. Secondly, we found that RSN was strongly correlated with word and pseudoword reading fluency, and that the relation between RSN and word reading fluency was preserved when we controlled for one of the measures of orthographic processing, namely Orthographic Choice, but not when we controlled for pseudoword reading fluency.

The present study aims at contributing to the literature on the relationship between RSN and orthographic processing by focusing on Russian, an understudied language, using a sample of relatively advanced, middle school-aged, readers. As noted previously, the asymmetry of the Russian orthography renders it particularly well suited to examining the cognitive underpinnings of orthographic processing. Unlike in English, in Russian, as in other orthographies with high feed-forward but low feed-backward consistency, phonological decoding skills, and as a consequence, relatively high word and pseudoword reading accuracy, are acquired relatively quickly, while reading fluency continues to develop throughout elementary and middle school years and beyond, allowing us to use fluency measures without the low accuracy confound. Thus, by the end of first grade, children in Russia are already expected to demonstrate accurate whole-word reading of words with simple syllable structure and accurate syllabic reading (i.e., pronouncing words syllable-by-syllable) of words with complex syllable structure, with the reading speed of at least 35–40

words per minute (during oral text reading). The optimal reading rate in Russian is considered to be 120–150 words per minute, i.e., the average tempo of speech. This rate is achieved by the best readers already by the end of elementary school (grade 3), with average readers expected to read 70–80 words per minute at that stage. The rate of 80–90 words per minute is considered the minimum required for adequate reading comprehension, and only ~10% of students in the middle grades are reported to be reading less than 60 words per minute (although this figure may not reflect low SES rural populations) (Kuznetsov & Khromov, 1983)².

On the other hand, mastering orthographic skills is a more protracted process, possibly more so than in many other feed-forward transparent orthographies. Orthographic knowledge (i.e., spelling rules guiding the selection of correct spelling in the so-called “orthogrammas” or “weak” positions, i.e., those open to spelling errors) continues to be systematically taught until the end of grade 7, with a widely shared opinion among Russian educators that in many cases, orthographic skills are not fully formed by then and need to continue to be taught in high school (Rakhlin et al., in press). Thus, reading fluency and orthographic skills in children learning to read in Russian present an excellent probe into the contribution of RSN to orthographic processing.

Another noteworthy feature of our study was to look whether there is a differential relationship between RSN and orthographic processing as measured by production and recognition tasks (Spelling and Orthographic Choice). As discussed above, there are reasons to expect phonological skills to be important for spelling production, thus possibly masking the relationship between RSN and spelling. Using an Orthographic Choice task allows a more direct examination of the students’ orthographic representations. We found that although RSN correlated significantly with both measures of orthographic skills, after controlling for variations in age, IQ and the timed measure of PA, RSN no longer contributed significantly to performance on either the Orthographic Choice or the Spelling Production tests. When PA accuracy was used as one of the independent variables, alphanumeric RSN made a significant contribution to spelling but not to orthographic choice; however, its contribution was not greater than that of PA accuracy. Thus, the only unique contribution of RSN to orthographic skills occurred in the model that used PA accuracy, not speed, as a covariate and Spelling as the orthographic measure. These results suggest that the relationship between RSN and orthographic processing is modest at best.

Our results are consistent with the majority of previously reported findings with respect to a lack of a strong relationship between RSN and spelling, particularly in feed-forward consistent orthographies (e.g., Papadopoulos et al., 2006; Moll et al., 2009; Vaessen & Blomert, 2013). As far as the relationship between RSN and performance on Orthographic Choice, although our results are different from those reported for English (Manis et al., 2000; Sunseth & Bowers, 2002), they are consistent with the findings by Papadopoulos et al. (2009) and Jimenez et al. (2008), who reported no relationship between RSN and

²Reading rate in Russian schools is measured by text rather than word list reading. This may be one of the reasons reading rate in our sample was relatively low. Ours being a rural sample, known for an academic achievement gap relative to urban populations in Russia, could be another reason.

performance on the Orthographic Choice task in beginning readers acquiring literacy in feed-forward transparent languages. The stronger relationship between RSN and orthographic processing skills for English in comparison to transparent orthographies may be due to the well-known fact that basic literacy in the English orthography is harder to master than in more transparent orthographies (e.g., Seymour et al., 2003). It is also known that RSN is an excellent predictor of reading proficiency (even if the nature of the relationship is not yet fully understood), regardless of the transparency of the orthography (Kirk et al., 2010; Norton & Wolf, 2012). Therefore, studies with English-speaking samples, in which children may exhibit greater variation in proficiency, using the same measures would result in stronger relationships between RSN and measures of literacy, including Orthographic Choice and Spelling (e.g., Moll et al., 2014). The same is also likely true of the relationship between PA and measures of reading accuracy and fluency (e.g., Ziegler et al., 2010).

The finding demonstrating a greater role of PA compared to RSN in orthographic processing skills is consistent with the self-teaching hypothesis (Share, 1995), which maintains a key role of phonological coding skills in orthographic learning. In Russian, there is an additional compelling reason to expect orthographic skills to be strongly related to PA, namely because, as described above, certain most difficult aspects of its spelling system arise from phonological processes altering sound shapes of words leading to the existence of massive numbers of words whose spelling cannot be predicted easily from the way the words sound and homophones distinct only in spelling. In order to spell words with these phonological changes correctly, the child has to recover the underlying (phonemic) form by using strategies that must be taught explicitly and require a high level of sophistication in phonological awareness, reflected in our results that showed PA being an important concurrent predictor of performance on spelling and orthographic choice tasks.

Our next finding was that RSN was strongly related to reading fluency, in line with the results of previous studies (e.g., Moll et al., 2009; Vaessen & Blomert, 2013). However, this finding does not necessarily indicate that RSN is important for the acquisition of orthographic skills. As a matter of fact, although controlling for the effect of variations in Spelling washed out the contribution of RSN, RSN continued to contribute to word reading fluency when entered in the regression equation along with Orthographic Choice. Thus, clearly, the contribution of RSN to word reading fluency does not seem to be explained solely in terms of the acquisition of orthographic processing skills, and another explanation of this relationship is needed. Furthermore, controlling for pseudoword reading fluency washed out the contribution of RSN to word-reading fluency, suggesting that RSN and pseudoword reading fluency have a large overlap in variance, perhaps, indexing the efficiency or automaticity aspect of reading skills, namely the proficiency with which orthographic and phonological representations are linked, rather than the quality of either phonological or orthographic representations.

This conclusion is consistent with the findings of a number of studies that concluded that speed of lexical phonological retrieval from visual stimuli, as indexed by the duration of the pauses between each successive item, rather than the speed of articulation (i.e., time spent on naming each item), is the component of RSN that correlates more strongly with literacy

skills (Cobbold, Passenger, & Terrell, 2003; Georgiou, Parrila, & Kirby, 2009; Georgiou, Parrila, Kirby, & Stephenson, 2008; Lervåg and Hulme, 2009). Lervåg and Hulme proposed that RSN taps into the integrity of the neural circuits involved in object identification and naming, which get recruited during literacy acquisition for visual word recognition. This view is compatible with the idea that word reading proficiency goes beyond facility with phonological decoding. In addition to the capacity to sound out written words, it includes the ability to combine the resulting strings of sounds into coherent wholes and seamlessly map them onto a correct word. This view is in line with the observation that the product of phonological decoding is “not yet a word” (Elbro, de Jong, Houter, & Nielsen, 2012). Additional steps of 1) agglutinating the decoded sounds quickly and 2) finding the match between the resulting phonological form and the target word in the lexicon (aided by the efficiency of the former process) must take place before a phonological string becomes a word. This multistep procedure would explain the distinct contributions of PA and RSN to the accuracy and fluency measures observed in our study, with PA indexing phonological decoding skills (and orthographic processing, i.e., recognition of orthographic units larger than a single grapheme) and RSN the post-decoding steps of unit agglutination and word identification.

The existence of this gap between the output of phonological decoding and the recognized word would also explain why word reading fluency takes much longer to achieve in transparent orthographies than accurate but slow reading: simply converting letters or written syllables to sounds (an easy skill to learn in a feed-forward orthography) does not automatically result in word identification and the assembled pieces need to be combined into one whole and linked with an existing word in the mental lexicon. This also explains why beginning readers and children with reading difficulties learning to read in a transparent orthography exhibit the word length effect (Hautala et al., 2013) and the reverse lexicality effect, i.e., words are read slower than pseudowords (Lachmann et al., 2009). Finally, this can explain why children with reading disabilities in feed-forward transparent orthographies, despite being able to acquire letter-sound correspondences fairly quickly, remain dysfluent and do not progress to sight recognition of words at a developmentally appropriate rate and exhibit persistent spelling difficulties: even if they acquire adequate phonological decoding skills, they may have difficulties developing orthographic processing and efficient word recognition skills, thus remaining at a phase of reading, when most words have to be assembled piecemeal, slowly and effortfully, like a complex pseudoword.

In contrast to most investigations of the correlates of phonological and orthographic skills, participants in the present study were relatively advanced, middle school readers, which provided a unique opportunity for testing the generality of previous findings for younger, less skilled readers. On the other hand, it raises some questions. First, it is possible that alphanumeric RSN is more strongly correlated with the acquisition of orthographic skills early on, when children are still learning letter-sound correspondences and before they possess an extensive orthographic lexicon (Wagner et al., 1997). Secondly, in more advanced readers, orthographic processing may be more closely related to PA, rather than to RSN because skilled readers rely relatively more heavily on an orthographic strategy when performing phoneme deletion (or other phonological awareness) tasks, that is, by mentally representing the word’s spelling together with its phonological form, rather than only its

phonological form. Indeed, there is evidence that knowledge of the orthography of a word influences one's judgment of the number of segments it contains (see Castles & Coltheart, 2004, for a review). Notwithstanding these considerations, it is noteworthy that our findings are in concert, not in contradiction, with several studies investigating the contributions of RSN and PA to orthographic learning in younger, less mature readers (e.g., Papadopoulos et al., 2006, 2009; Pennington et al., 2001; Moll et al., 2009; Vaessen & Blomert, 2013).

Our study has certain limitations. First, because of our focus specifically on the relationship between RSN and orthographic processing and reading fluency, the study did not include a fully comprehensive set of measures, taking into consideration all relevant factors affecting literacy acquisition, such as vocabulary, general verbal ability, or print exposure. Very likely, some of these factors are even more important at more advanced reading levels. Lacking such additional explanatory factors, it is not surprising that our regression models were somewhat underspecified.

Secondly, some of the accuracy measures were easy, particularly the PA task and, to a lesser degree, the spelling task. However, even the small variation in the performance on those tasks did not prevent them to correlate with our measures. Another limitation was the relatively rough measures of time used in the study (manually measuring the total time used for completing each task). Nonetheless, despite these limitations, our results contribute to the growing evidence that PA skills are important for both reading and spelling and that RSN may index the efficiency with which orthographic and phonological representations are linked during reading, rather than orthographic processing skills.

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Table 1

Descriptive Statistics

Measure	M	SD
Age	13.73	.88
IQ	108.55	19.02
Phoneme Awareness (max. = 40)	37.84	2.74
Phoneme Awareness (time in secs.)	219.64	81.73
RSN:LD (time in secs.)	21.34	3.45
Phonological Choice (max. = 60)	48.27	7.73
Orthographic Choice (max. = 45)	38.10	4.43
Spelling (max. = 56)	50.97	3.85
Reading Fluency: Words (total time in secs.)	20.67	5.19
Reading Fluency: Pseudowords (total time in secs.)	27.59	6.89

Table 2

Correlations between measures

	1	2	3	4	5	6	7	8	9	10
1. Age	--									
2. IQ	.12	--								
3. PA: Accuracy	.16**	.32**	--							
4. PA: Time	-.27**	-.30**	-.56**	--						
5. RSN:LD	-.40**	-.09	-.11	.38**	--					
6. Phonological Choice	.12	.47**	.46**	-.41**	-.24*	--				
7. Orthographic Choice	.08	.38**	.37**	-.46**	-.18	.34**	--			
8. Spelling	.13	.26**	.48**	-.45**	-.33**	.44**	.48**	--		
9. Fluency: Words	-.22*	-.27**	-.26**	.19	.31**	-.28**	-.22**	-.30**	--	
10. Fluency: Pseudowords	-.23*	-.13	-.04	.35**	.62**	-.19*	-.21**	-.23*	.49**	--

*
p < .05;**
p < .01

Table 3

Results of the two multiple regression analyses examining the role of PA accuracy/PA speed and RSN as concurrent predictors of literacy skills

Model 1	Phonological Choice				Orthographic Choice				Spelling				Word Fluency				Pseudoword Fluency			
	B	SE	β	t	B	SE	β	t	B	SE	β	t	B	SE	β	t	B	SE	β	t
Age	.04	.06	.06	.62	.16	.52	.03	.30	-.02	.06	-.04	-.38	-.03	.03	-.13	-1.25	-.00	.02	-.01	-.06
IQ	.01	.00	.36	3.98***	.07	.02	.29	2.94**	.00	.00	.10	1.04	-.00	.00	-.22	-2.16*	-.00	.00	-.10	-1.09
PA accuracy	.24	.07	.32	3.55***	1.42	.55	.26	2.58*	.28	.06	.42	4.50***	-.04	.03	-.15	-1.47	.01	.02	.05	.60
RSN:LD	-.10	.06	-.15	-1.62	-.54	.49	-.11	-1.10	-.17	.05	-.29	-3.05***	.05	.02	.23	2.18*	.15	.02	.61	6.75***
	F (4, 91) = 12.90*** R ² = .36				F(4,91) = 6.74*** R ² = .23				F(4, 91) = 10.60*** R ² = .32				F (4, 90) = 5.67*** R ² = .20				F(4, 90) = 14.55*** R ² = .39			
Model 2	B	SE	β	t	B	SE	β	t	B	SE	β	t	B	SE	β	t	B	SE	β	t
Age	.05	.07	.08	.77	.05	.51	.01	.09	-.01	.06	-.02	-.19	-.04	.03	-.17	-1.57	.01	.02	.03	.29
IQ	.01	.00	.40	4.29***	.06	.02	.27	2.81	.00	.00	.14	1.45	-.00	.00	-.28	-2.75**	-.00	.00	-.04	-.51
PA time	-.00	.00	-.24	-2.41*	-.02	.01	-.37	-3.56***	-.00	.00	-.34	-3.22***	-.00	.00	-.03	-.27	.00	.00	.11	1.22
RSN:LD	-.05	.06	-.08	-.81	-.04	.49	-.01	-.08	-.11	.06	-.19	-1.87	.05	.03	.23	2.14*	.14	.02	.58	6.17***
	F (4, 91) = 10.57*** R ² = .32				F(4,91) = 8.57*** R ² = .27				F(4, 91) = 7.64*** R ² = .25				F (4, 91) = 5.03*** R ² = .18				F(4, 90) = 15.02*** R ² = .40			

Table 4

Results of the multiple regression analyses examining the contribution of alphanumeric RSN to word reading fluency controlling for orthographic coding (Model 1), spelling skills (Model 2), and pseudo-word reading fluency (Model 3) in addition to the contribution of variations in AGE and IQ.

Predictors	Word Reading Fluency			
Model 1	B	SE B	β	t
Age	-.04	.03	-.16	-1.49
IQ	-.00	.00	-.24	-2.34*
Orthographic Choice	-.00	.00	-.07	-.70
RSN:LD	.05	.02	.22	2.07*
$F(4, 91) = 5.16^{**}$ $R^2 = .18$				
Model 2	B	SE B	β	t
Age	-.04	.03	-.15	-1.49
IQ	-.00	.00	-.23	-2.35*
Spelling	-.07	.04	-.16	-1.60
RSN:LD	.04	.02	.18	1.66
$F(4, 91) = 5.79^{***}$ $R^2 = .20$				
Model 3	B	SE B	β	t
Age	-.04	.02	-.16	-1.66
IQ	-.00	.00	-.23	-2.59*
Pseudoword reading	.44	.11	.45	4.03***
RSN:LD	-.01	.03	-.05	-.44
$F(4, 90) = 9.83^{***}$ $R^2 = .30$				

*
p<.05;

**
p<.001