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The effects of age and sublexical automaticity on reading outcomes for students with reading disabilities

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For students with reading disabilities, reading fluency has proven difficult to remediate. The current study examined age-related effects on measures of word and text-reading outcomes, within the context of a phonologically based remedial reading program. The contribution of speeded-reading of sublexical sound–spelling patterns to fluency outcomes was also examined. The youngest group of participants showed better outcomes on measures of word and pseudoword reading. All age groups made significant and meaningful improvements on measures of reading fluency and reading comprehension. Participants' mastery of speeded, sublexical sound–spelling reading contributed variance to fluency outcomes beyond pre-intervention fluency scores. Practice with sublexical spelling patterns may be one important component of programs directed at remediating accuracy and fluency deficits for students with reading disabilities.

What is already known about this topic

- Reading fluency has proven difficult to remediate for students with reading disabilities.
- Training with sublexical sound–spelling patterns has increased recognition of the trained patterns, but transfer has been limited.
- Young children with reading difficulties appear to have an advantage at closing the reading achievement gap; however, there are some inconsistencies in the literature.

What this paper adds

- Automaticity with sublexical patterns made a unique contribution to fluency outcomes in this sample of students with reading disabilities.
- In the context of the reading program examined, all age groups made significant and meaningful standard score gains on reading fluency.
- Young children did not score higher than the two older groups on measures of oral reading fluency or reading comprehension; bringing into question conclusions drawn from prevention versus intervention studies.

Implications for theory and practice

- Findings lend support to models of reading acquisition that emphasize multilayered, sublexical spelling–sound knowledge as important to reading fluency, beyond that of sight-word reading efficiency.

- Including speeded practice of a broad range of sublexical sound–spelling patterns and training these to mastery deserves further study as one potential approach to improving fluency interventions for students with reading disabilities.
- We suggest that this sublexical training may mimic reading practice in terms of building orthographic representations that support fluent reading.

Research has demonstrated that reading fluency is an area resistant to remediation for students with reading disabilities (RDs). Even when these students do attain average reading accuracy and comprehension scores, fluency scores may remain stable and severely impaired (Torgesen et al., 2001). Accuracy and speed for reading sublexical orthographic units have been investigated toward better understanding fluency development and remediation. The current study examined the contribution of students' mastery of speeded identification for sublexical sound–spelling patterns to outcomes in reading fluency within the context of a remedial reading program. This investigation contributes to theoretical understandings of fluency development and may have implications for fluency interventions for students with RDs. A secondary goal of this study was to examine age-related effects on reading outcomes. Studies with younger students generally report more positive outcomes in terms of closing the reading–achievement gap than do studies with older readers; however, when age groups are compared within the same study, findings are not so consistent. A brief review of the literature on both sublexical automaticity and age-related reading outcomes follows.

Researchers have investigated which components of reading and reading-related skills are most strongly related to oral-reading fluency. Torgesen, Rashotte and Alexander (2001) found that concurrent sight-word reading efficiency (SWRE; i.e., speed of reading isolated words) was the greatest predictor of oral text-reading fluency across five samples from their previous work (see also O'Brien, Wolf, Miller, Lovett, and Morris, 2011). For students who continue to score poorly on standardized measures of reading fluency following interventions, it has been found that their reading rates approximate typical readers on easier passages with less difficult vocabulary, for which they are able to accurately identify the words (Torgesen, Rashotte, et al., 2001). Taken together, Torgesen (2006) proposed that substantial sight-word reading deficits cause these fluency impairments for students with RDs. Furthermore, these sight-word reading deficits are largely caused by severely limited amounts of reading over prolonged school years, explaining why fluency is resistant to reading interventions (Torgesen).

There also appears to be a role for sublexical decoding skills in fluency development. Phonemic decoding efficiency (PDE; rate of reading pseudowords) predicted unique variance in text reading fluency after that accounted for by SWRE in four of five samples examined (Torgesen, Rashotte, et al., 2001). Given that pseudowords cannot be represented as fused lexical units, this suggests that facility with sublexical units contributes to oral-reading fluency beyond one's automatic sight-word vocabulary (see also, Harn, Stoolmiller, and Chard, 2008). This finding is congruent with models of word-reading acquisition (Ehri, 2014; Seidenberg and McClelland, 1989; Share, 2008), which propose that facility with bigram, trigram, and larger orthographic patterns within words and positional grapheme information supports fluent reading (and spelling; Berninger, Abbott, Vermeulen, and Fulton, 2006; Brown and Deavers, 1999; O'Brien et al., 2011).1998 For example, in Ehri's (1998, 2014) model of word reading acquisition, children's early, letter-by-letter sounding-out strategy is critical to building sight-word recognition;

therefore, in this highly influential model, children's skill with matching sounds to graphemes and to other sublexical orthographic patterns is instrumental to building efficient word recognition.

There has been some support for this proposed causal link between sublexical automaticity and reading fluency from short-term training studies. Conrad and Levy (2011) found mixed support for more accurate recognition of novel words with trained versus untrained orthographic units in grade 1 and 2 students; however, there was no generalization to SWRE. Six- to seven year-old participants in a 12-week program focused primarily on training decoding with grapheme–phoneme correspondences and those in a training including learning rime-units showed medium to large effect sizes on measures of speeded word and pseudoword reading compared to a no-treatment control group (Kyle, Kujala, Richardson, Lyytinen, and Goswami, 2013). Students with RDs in relatively transparent orthographies (e.g., Finnish, Dutch, and German) frequently have rate deficits alongside adequate accuracy. In these transparent languages, one focus has been on speeded sublexical reading and its relation to reading fluency. Training studies have focused on identification of syllables (e.g., Heikkilä, Aro, Närhi, Westerholm, and Ahonen, 2013; Huemer, Aro, Landerl, and Lyytinen, 2010) and onset consonant-clusters (e.g., Hintikka, Landerl, Aro, and Lyytinen, 2008; Thaler, Ebner, Wimmer, and Landerl, 2004), and have examined letter cluster versus individual letter training (e.g., Marinus, de Jong, and van der Leij, 2012). Following relatively short, speeded training with these various sublexical units presented in isolation or within words, studies have generally found increased rate of reading both trained and untrained words containing these clusters (e.g., Hintikka et al., 2008; Thaler et al., 2004). There has been little or no transfer to rate of reading pseudowords with trained letter clusters, words without the letter clusters, or to text-reading fluency (e.g., Hintikka et al., 2008; Huemer et al., 2010; Thaler et al., 2004).

Initial support for this causal connection also comes from long-term, English reading interventions, which include instruction in dimensions of sublexical learning. These interventions have included teaching the most frequent rime patterns through key words, teaching frequent morphological units, and using game-like activities to increase speed of recognizing the most common onsets and rimes (e.g., Lovett, Lacerenza, and Borden, 2000; Wolf, Miller, and Donnelly, 2000; Wolf et al., 2009). For the most part, the observed increases in reading fluency have not been examined as a function of sublexical training components. One study, however, did examine this relationship with grades 1–3 students. O'Brien et al. (2011) found that mid-point measures of orthographic search latencies (but not accuracy) for trained orthographic pairs within visually confusing arrays predicted unique variance in end-point text-reading fluency (but not in SWRE). This study also revealed that visual search times improved most for the grade 1 students. These authors concluded that there was 'partial support for the contribution of sublexical orthographic recognition efficiency to reading fluency' (p. 126).

Speece and her colleagues have examined the contribution of rate of sublexical recognition to reading development using measures of letter–sound fluency (LSF). In one study, mid-grade 1 LSF and oral-reading fluency each accounted for unique variance in end of grade 1 oral-reading fluency for an at-risk sample of readers (Speece and Ritchey, 2005); however, when followed through to grade 2, LSF was no longer predictive of fluency outcomes (see also Ritchey and Speece, 2006; Speece, Mills, Ritchey, and Hillman, 2003; Stage, Sheppard, Davidson, and Browning, 2001). Although the sublexical patterns examined were restricted to individual letter–sound correspondences, it is significant that variance was shown to be related to speed of recognition rather than recognition accuracy.

In a study with a sample of second graders with normally distributed reading skills, contributions of oral phoneme-blending fluency and LSF to PDE were fully accounted for by phonogram (rime) fluency (e.g., eed, at, arp; Hudson, Torgesen, Lane, and Turner, 2012). Furthermore, each of PDE, SWRE, and comprehension had direct effects on oral-reading fluency. These authors suggested that single LSF is important in the earliest stages of learning to read, but then automaticity with larger units, such as rimes, becomes more important to reading fluency. This developmental progression is consistent with Ehri's (1998, 2005) model of word reading acquisition.

The current study examined the relationships between students' mastery of speeded sublexical sound–spelling patterns and text-reading fluency after each phase of a phonologically based remedial reading program. A component of the SpellRead™ (2012) reading remediation program that was examined in this study is on speeded practice with sublexical sound–spelling patterns. A series of flash-card packs is arranged from relatively easier to more difficult patterns, and a student needs to meet both target accuracy and rate criteria before progressing. The rationale for building this component into this program was to facilitate word recognition automaticity and oral-reading fluency (Rashotte, MacPhee, and Torgesen, 2001), although this connection has not been explicitly examined. We tested whether there was a unique contribution from students' mastery of this speeded sublexical pattern recognition to oral-reading fluency outcomes.

A second focus of this study was an examination of age-related effects on reading outcomes. For both word- and text-reading outcomes, researchers have suggested that young children might benefit more from remediation programs than might older students (e.g., for review, see Wanzek and Vaughn, 2007). Observations of age-related differences in achievement outcomes have been particularly prominent for measures of oral-reading fluency (for review see, Torgesen and Hudson, 2006). The current paper examined age by outcome interactions for measures of word and pseudoword reading accuracy, oral-reading fluency, and reading comprehension for a wide age-span of students.

Young children in kindergarten and grade 1 enrolled in prevention studies generally show mean outcome scores for both word reading accuracy and rate of reading within the average range (e.g., Vaughn et al., 2009; for review see, Al Otaiba and Torgesen, 2007). However, studies including students in grades 2 or 3 and up tend to report more moderate gains in terms of closing the achievement gap (Torgesen, 2006; Wanzek et al., 2013). Even when these 'older' students do attain average reading accuracy and comprehension scores, fluency scores tend to remain far below average (Torgesen et al., 2001), proving to be the reading component most resistant to remediation. In their review, Torgesen and Hudson (2006) found that in four samples of students with RDs in grades 2 and up, achievement outcomes in accuracy and comprehension were at or approaching average levels, whereas fluency scores remained below the 5th or 10th percentiles. For two younger prevention-study samples, mean accuracy and fluency outcome scores were solidly average even though these students had been selected as the most impaired within a given population. Similarly, Torgesen, Rashotte et al.'s (2001) cross-study analysis found that three samples of students with RDs continued to lag severely behind in fluency even as they closed the gaps in reading comprehension. Age advantages have also been proposed for students with RDs in grades 2–6 versus older students (Frijters, Lovett, Sevcik, and Morris, 2013). In a study with high school students, the remediated group outperformed a wait-listed, RD comparison group on all measures, but mean standard scores remained far below average (Lovett, Lacerenza, De Palma, and Frijters, 2012; see also, Moats, 2004; Vaughn et al., 2012).

Conclusions concerning age-related differences on reading outcomes, particularly for appreciable age spans, have frequently been based on comparisons of outcomes from different studies (e.g., Al Otaiba and Torgesen, 2007; Wanzek et al., 2013). Across studies, interventions may vary and participant groups may have been recruited and defined in different manners. Studies that have made direct age comparisons are not as clear concerning age-related effects on reading outcomes. For example, Rashotte et al. (2001) compared reading outcomes for an intensive intervention (SpellRead-PAT) across grades 1–6, recruiting all students in a similar manner. Although all students improved significantly after 31–35 hours of instruction, significant main and interaction effects of grade were largely absent for accuracy, fluency, and comprehension. Similarly, Lovett and Steinbach (1997) found equivalent achievement gains across students in grades 2–6, although fluency was not examined (see also, Moats, 2004). In a study with high school students (grades 9–12), age was a significant predictor of accuracy and comprehension (fluency was not reported); however, 73% of the treatment group were in grade 9 (Lovett et al., 2012). Research directly examining age- or grade-related effects on reading outcomes thus appears somewhat incongruent with cross-study conclusions concerning the superiority of outcomes for younger students. Appreciable age spans and fluency measures, however, do not appear to have been thoroughly examined in studies with direct age comparisons.

In the current study, one research question was whether each of our younger groups would outperform the older group(s) on word and text level reading outcomes. Based on empirical studies demonstrating the resistance of fluency to improvement in older students with RDs, and consistent with theories on the importance of reading amount to reading fluency, we expected each older group of students to have a lower standard score on the fluency measure; however, we were uncertain whether these age advantages would be seen in each of the other outcomes. Our primary research question was whether sublexical speeded pattern-recognition would contribute variance to a generalized measure of reading fluency. We hypothesized that we would find positive support for this connection between sublexical automaticity and reading fluency outcomes. This prediction is consistent with models of reading development and with a growing body of literature that ascribes a role for sublexical automaticity in fluency development.

Method

Participants

Participants were drawn from a larger sample of students whose parents or guardians had enrolled them in the SpellRead™ remedial reading program at a private clinic. Participants were entered into the study if they had word reading standardized scores at or below the 25th percentile (*Woodcock Reading Mastery Tests-Revised*) and had completed at least the first phase of the SpellRead™ intervention. Although oral-reading fluency was not a criterion, all participants had a fluency subscale standard score of 7 or below on the *Gray Oral Reading Test-4*.

Participants in the study consisted of 118 students from 6 to 18 years. To compare outcomes across age groups, we formed three age-categories with the goal of creating non-overlapping age groups with close to equal numbers of participants in each group. This resulted in a younger-group (n = 41, 29 males; M(age) = 91.7 mos (7.6 yrs); SD = 8.2);

a middle group (n = 40; 28 males; M(age) = 116.7 mos (9.7 yrs); SD = 8.2); and an older group (n = 37, 23 males, M (age) = 154.9 mos (12.7 yrs), SD = 29). These age means correspond roughly to those for grade 2, 4, and 7; however, the age span is considerably larger for the oldest age group.

Following each phase of the program, the number of students who continued the program diminished. Whereas the SpellRead™ program is intended to be delivered in its entirety to each student, decisions to continue the program are made by parents or guardians for a variety of reasons. The most frequent reasons given are that remedial goals are perceived to have been accomplished; financial and/or time commitments are too great; or new intervention opportunities have become available at the child's school. Following 90 hours of instruction, the younger, middle, and older groups each had 23, 29, and 17 remaining participants, respectively (N = 69); and following 120 hours of the intervention, there were 15, 22, and 6 participants remaining, respectively (N = 41). Univariate analyses of variance (ANOVAs) revealed that at each time point, there were no differences in the mean standardized scores on any reading measures between the 'full sample' that had just completed a phase of the intervention and the 'continuing sample' that carried on for the next phase of the program. However, the oldest group with six participants was dropped from all comparisons following the final phase of the intervention. Given the fees associated with the program, participants were primarily from middle and above SES backgrounds.

Reading intervention

There are three phases to the SpellRead™ intervention, and assessments were completed after 45, 90, and 120 hours. The program is scripted, and this standardized approach is followed in the delivery center studied. In this implementation, children typically attend two, 1.5-hour sessions per week in groups of three to five students. For each hour of instruction, about 35–40 minutes is spent on 'linguistic foundations,' using activities and games to increase phonological awareness and alphabetic knowledge/decoding accuracy. The remaining 20–25 minutes involves short pre- and post-reading recaps, round-robin reading, and about 5–6 minutes of writing in response to the reading. The texts used for these activities are ones for which the students had about a 95% accuracy level.

All students start with the first lesson of the first phase of the program and systematically progress through each lesson. The differences between the three phases reside in the linguistic foundations component and are primarily the size of the units being mastered and the primacy of pseudo- versus real words in the learning activities. Phase A teaches grapheme–phoneme connections, and instructional activities focus on simple CVC phonologically patterned pseudowords. In Phase B, vowel digraphs and consonant blends are introduced, real and pseudowords are used in learning activities, and syllabication and reading of two-syllable pseudo- and real words begin to be taught. Finally, Phase C activities are based primarily on real words, teach syllabication beyond two syllables, and teach common letter-pattern clusters or morphemes (e.g., tion, cian).

As previously mentioned, one aspect of SpellRead™ focuses on speeded practice and mastery of 'reading' sublexical letter patterns. There are a total of nine-card packs containing these sublexical patterns. Children must reach a time and an accuracy criterion before moving on to the next card pack. Each card pack uses a number of short or long vowels, and/or vowel digraphs. Card packs alternate between presenting vowel patterns in CV or

VC contexts with presenting these in CVC contexts. For example, for card packs containing the orthographic pattern of the long i sound with a silent e, the student might see *ni_e* and *_ile* in the CV/VC card pack and might see *mishe* in the CVC phonological-pattern card pack. Consonant sounds include consonant digraphs, and many of the consonant sounds used in the first card parks are easily stretched (e.g., fricatives, glides). There are 40 cards in the CV/VC card packs and 50 cards in the CVC packs. Included in these nine-card packs are two that review previously introduced patterns. Students take their current card pack home to practice each week and are tested once each week at a lesson.

Reading measures

Word recognition. Word recognition was measured using the Word Identification subtest of the *Woodcock Reading Mastery Tests-Revised* (WRMT-R; Woodcock, 1987). Participants read individual words of increasing difficulty until reaching a ceiling of six incorrect words. Standard scores were calculated for each participant on an age-normed scale with a mean of 100 and SD of 15.

Pseudoword reading. Pseudoword reading was measured using the Word Attack subtest of the WRMT-R. Participants read a list of pseudowords of increasing difficulty until a ceiling of six incorrect items was reached. Standard scores were calculated for each participant on an age-normed scale with a mean of 100 and SD of 15.

Oral-reading fluency and reading comprehension. The *Gray Oral Reading Test–4 (GORT-4; Wiederholt and Bryant,* 2001*)* was used to measure both oral-reading fluency and reading comprehension. This test requires the child to read aloud a series of stories of increasing difficulty. After each story, the student answers five multiple-choice questions. The test provides age-based norms for students 6 years and older.

The oral-reading fluency score is a composite measure across all stories read and accounts for the time taken and the number of errors for each story. The test is discontinued when the participant's time and accuracy are poor enough to meet a specified criterion. Standard scores were calculated for each participant on an age-normed scale with a mean of 10 and SD of 3.

The comprehension score is based on the total number of questions answered correctly across the stories. The test is discontinued when a student answers three of five questions incorrectly for a given story. Standard scores were calculated for each participant on an age-normed scale with a mean of 10 and SD of 3.

Speeded sublexical reading

Each week, the students completed a timed test of reading their current sublexical card pack (CP). We computed two variables to measure sublexical learning. Although there have been published studies examining the SpellRead™ intervention (e.g., Rashotte et al., 2001), the performance on sublexical automaticity has not been examined or quantified. We thus created two measures of sublexical learning to reflect three aspect of participants' performance; how students did on the timed trials each week, the weeks taken to meet the criterion time, and the fastest time the student achieved. The two measures are based on participants' performance on the first two card packs.

Sublexical average time. The first measure was the average time recorded across weeks for card packs 1 and 2 up until and including the week in which the student met criteria. Criteria were defined as 60 seconds or less with no more than two errors. For students who did not meet criteria for a CP within 5 weeks, the average was taken across 5 weeks (most complete data available for first 5 weeks with each card pack).

Sublexical weeks by fastest time. We created a measure that taps into both the number of weeks until reaching criteria and the fastest time achieved across each CP. For each card pack, the number of weeks until mastery was multiplied by the fastest time achieved for that card pack and the average for the two card packs was then calculated. For example, the computation would be {(4wks × 47 sec) + (5wks × 57 sec)} / 2, for a participant who took 4 and 5 weeks to reach criterion for CP1 and CP2, respectively, and whose fastest times were 47 and 57 seconds. These measures were based on the first 5 weeks of students' timed tests. A student who did not reach criteria in this period was given a 6 for the number of weeks to mastery, and this was multiplied by his or her fastest time achieved. The average number of weeks to mastery for CP1 and CP2 were 3.16 (*SE* = .28) and 4.65 weeks (*SE* = .26), respectively.

Results

For each word- and text-reading outcome, ANOVAs were used to compare mean-group standardized scores prior to versus following each phase of the remedial program. The number of participants at time 3 and time 4 were relatively small, and we discuss the possible effect of this on the patterns of statistical significance following each analysis. All score distributions for standardized measures were approximately normal with all absolute values of skewness and kurtosis smaller than 1.

Word reading

Word recognition gains were examined for the first 45 hours of instruction in a 2 × 3 (Time [pretest, post-45 hours] × Age [youngest. Middle, older]) mixed model ANOVA. All reported effects are significant at $p < .05$, unless otherwise stated. Results showed a main effect of time, $F(1,115) = 151.2$ and a significant interaction of Time × Age, $F(2,115) = 6.6$. Pairwise comparisons revealed that after 45 hours of the intervention, all groups had made significant gains (all reported pairwise comparisons are tests of Least Significant Difference). While there were no group differences at pre-test, the youngest group scored better than the middle group did after 45 hours of treatment (see Figure 1 concerning all analyses for word reading.)

The same mixed model ANOVA was conducted to examine improvement across the next 45 hours of instruction. This revealed a main effect of time, $F(1,66) = 88.4$. Although no interaction between time and age group reached significance, at time 3 a moderate effect size (d = .60) was observed between the younger and middle groups, and would be expected to have been statistically significant with about 30 participants in each group. As can be seen in Figure 1, all groups improved across this second phase of the program.

With only the younger and middle groups in the analysis (due to the small number of participants for older group in this last phase of the intervention), changes from 90 hours to 120 hours of instruction were examined in a mixed model ANOVA. Results showed a

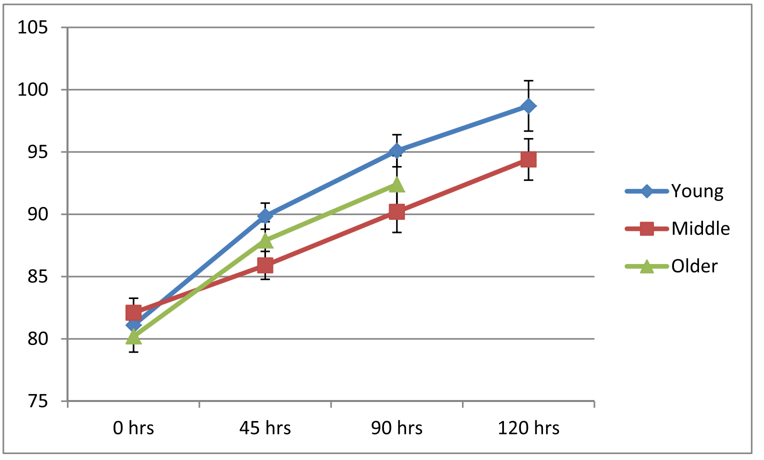

Figure 1. Word Identification standard scores following each phase of the intervention. Error bars represent standard errors of the mean. This figure is available in colour online at wileyonlinelibrary.com/journal/jrir

main effect of time, $F(1, 35) = 37.3$; the main effect of age failed to reach conventional levels of statistical significance, $F(1,35) = 3.7$, $p = .063$ and had an associated ES = .559. Both groups increased with the final 30 hours of instruction, and there was a statistical trend toward the younger group performing better than the middle group (see Figure 1).

Pseudoword reading

The same mixed model ANOVAs were conducted for the measure of pseudoword reading across each period of the intervention. Across the first 45 hours of instruction, there was only a main effect of time, $F(1,115) = 286.1$ (see Figure 2 for all outcomes for pseudoword reading). Similarly, for the second 45 hours of intervention, there was only a main effect of time $F(1,66) = 125.9$; however, the observed ES of .41 for the difference between the younger and middle groups may have been statistically significant with a larger sample. All groups improved over the first phases of the program.

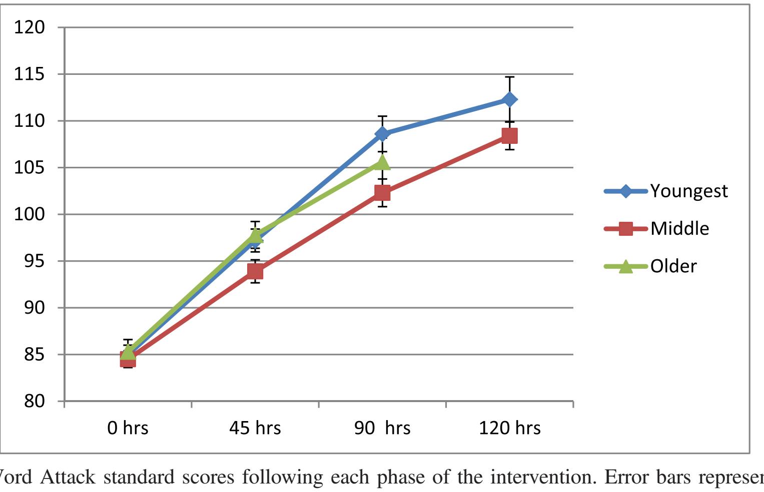

Figure 2. Word Attack standard scores following each phase of the intervention. Error bars represent standard errors of the mean. This figure is available in colour online at wileyonlinelibrary.com/journal/jrir

In the final ANOVA, with only the youngest and middle groups, there was a main effect of time, $F(1,35) = 55.2$; the main effect of age failed to reach conventional levels of statistical significance $F(1,35) = 3.4$, $p = .072$ and was associated with an ES = .67. Both groups improved across this phase of the intervention, and the young group appeared to have stronger word recognition at the outcome of the program.

Fluency

To examine gains in reading fluency with each phase of the intervention, mixed model ANOVAs were conducted in the same manner as for word-level reading skills. For each of the three ANOVAs, the main effect of time was the only significant outcome; $F(1,114) = 22.8$; $F(1,66) = 81.5$; $F(1,35) = 14.2$, for the first, second, and third phase of the intervention, respectively (for the 45-hour comparison, one of the 'youngest' participants was missing a score and was excluded from this analysis). Groups made significant improvements on fluency across each phase of the intervention (see Figure 3 for all fluency outcomes). Unlike the results for word- and pseudoword-reading analyses at time 3 and 4, sample size did not appear to limit the pattern of statistical findings; the observed ES's for the younger and two older groups across each time were small (from −.049 to .102).

Comprehension

Again, three mixed model ANOVAs were conducted to examine gains in reading comprehension. For the first 45 hours of instruction, there was a main effect of time, $F(1,113) = 17.45$ and of age $F(2,113) = 17.5$ (two participants in the youngest group were missing pretest comprehension scores and were omitted from this analysis.) Comparisons showed that all three groups improved across this phase of the intervention and that the youngest group performed more poorly overall than did the middle and older groups (see Figure 4 for all comprehension outcomes.)

Across the next two phases of the intervention, both ANOVAs revealed only a main effect of time—F(1,66) = 32.4 and $F(1,35) = 6.8$. All groups improved across these phases of

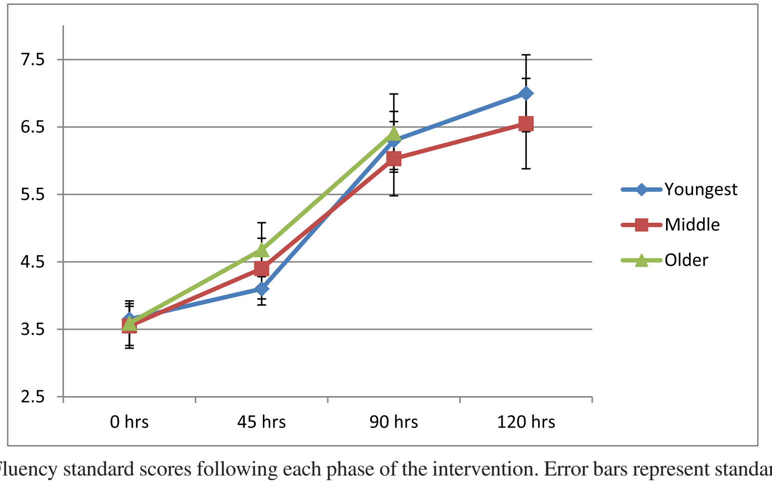

Figure 3. Fluency standard scores following each phase of the intervention. Error bars represent standard errors of the mean. This figure is available in colour online at wileyonlinelibrary.com/journal/jrir

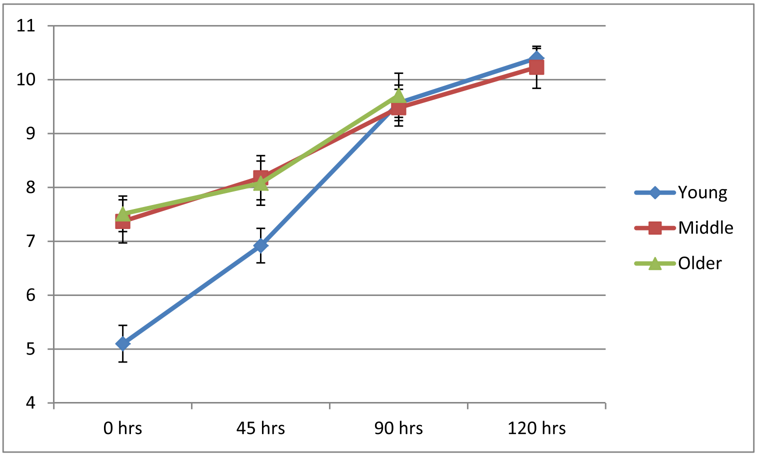

Figure 4. Comprehension standard scores following each phase of the intervention. Error bars represent standard errors of the mean. This figure is available in colour online at wileyonlinelibrary.com/journal/jrir

the intervention, with no age group differences on comprehension outcome scores. Similar to the results for the fluency comparisons, sample size at time 2 and time 3 did not appear to be limit the results; the observed ES's for the younger and two older groups across each time were small (from −.088 to .120).

Supplementary group analyses

We wanted to ensure that our pattern of results concerning age effects was not due to either having a larger age range of students in our youngest group than did most prevention studies, or to not using a stricter word recognition cutoff as was done in some studies. Therefore, we completed the above mixed model ANOVAs for all standardized measures in two ways: first, for the 45- and 90-hour outcomes with a younger group consisting of participants below 92 months of age (the group was too small for an analysis at 120 hours) and second, with participants across all age groups who were at or below the 16th percentile for word recognition. The pattern of main and interaction effects was the same for these supplementary analyses as those reported above.

Predicting fluency outcomes from speeded sublexical reading

The zero-order correlations for variables examined in the following regression analyses are presented in Table 1. To examine whether children's performance on learning sublexical sound–spelling patterns contributed unique variance to outcomes in reading fluency, separate hierarchical regression analyses were conducted for each phase of the intervention. Fluency standard scores after each phase of intervention were the dependent variables, with pretest fluency as the first step in each equation. Each of the two measures of students' sublexical speed and mastery of the sound-letter patterns were entered into separate equations as step 2. Score distributions for the two sublexical measures were approximately normal with absolute values of kurtosis smaller than 1; however, weeks by fastest time was mildly skewed, with g1 = 1.1.

Table 1. Correlations for variables in regression analyses.

Measure	1	2	3	4	5	6	7	8	9	10	11
1. T1-Word											
2. T1-Fluency	.58										
3. T1-Comprehension	.40	.41									
4. T2-Fluency	.59	.66	.35								
5. T2-Comprehension	.38	.36	.37	.69							
6. T3-Fluency	.66	.60	**.27**	.79	.57						
7. T3-Comprehension	.51	.41	.36	.56	.49	.66					
8. T4-Fluency	.62	.69	***.24***	.71	.53	.85	.51				
9. T4-Comprehension	.34	.48	.36	.52	.52	.48	.57	.40			
10. Sublexical Average	*−.13*	**−.19**	−.44	−.34	−.42	−.34	*−.18*	−.40	*−.20*		
11. Sublexical Weeksxfast	*−.12*	*−.15*	−.44	−.28	−.40	**−.27**	*−.16*	**−.38**	*−.24*	.93	

Note. T1 = Time 1 (pretest); T2 = Time 2 (post-45 hours); T3 = Time 3 (post-90 hours); T4 = Time 4 (post-120 hours). Sublexical Average = Sublexical – Average Time; Sublexical Weeksxfast = Sublexical – weeks × fastest time.
For bolded correlations $p < .05$ (two tailed); for italicized correlations, $p > .05$; all other values are significant at $p < .01$ (two tailed).

As can be seen from Table 2, the average time across the participants' trials to master CP1 and CP2 predicted significant unique variance of 5.1% and 4.6% after 45 and 90 hours of intervention, respectively, but failed to reach conventional levels of statistical significance for fluency outcomes after 120 hours (4.3%, p = .066). For the measure of the number of weeks by the fastest time achieved across CP1 and CP2, significant unique variance was predicted in fluency outcomes after 45 hours (3.2%) and after 120 hours (5.7%). This contribution did not meet levels of statistical significance following 90 hours of the intervention (3.1%, p = .09).

To begin to decipher whether the unique contribution to outcomes in reading fluency was due to participants' automaticity with sublexical patterns already established prior to the intervention, or whether learning/progression in this area asserted some effect, we ran a final regression. For Regression 3 (Table 2), pre-intervention fluency remained as the first step entered into the equation. Participants' first timed trial with CP1 was entered as the second step, and the third step was a measure of learning with sublexical automaticity, the number of weeks by the fastest time achieved. As can be seen in Regression 3, the number of weeks by the fastest time achieved predicted unique variance in Fluency outcomes at 45, 90, and 120 hours.

Discussion

This study examined the relationship between sublexical automaticity and fluency outcomes in students with RDs and compared reading outcomes for different age groups.

Table 2. Hierarchical regressions predicting fluency standard scores after 45, 90, and 120 hours of instruction.

	Fluency standard scores								
	45 hours			90 hours			120 hours		
Predictor	ΔR2	B	*Final β*	ΔR2	*B*	*Final β*	ΔR2	*B*	*Final β*
Regression 1 Step 1									
Pretest Fluency	.457**	.858		.352**	.822		.478**	.961	
Step 2									
Sublexical Average	.051**	−.022	−.230**	.046*	−.027	−.221*	.043^	−.028	−.217^
Regression 2 Step 2									
Sublexical Weeksxfast	.032*	−.001	−.180*	.031[a]	−.001	−.179[a]	.057*	−.002	−.244*
Regression 3									
Step 2									
Sublexical Trial 1	.020*	−3.53	−.140*	.003	−1.251	−.050	.001	.733	.038
Step 3									
Sublexical Weeksxfast	.030*	−.002	−.175*	.037*	−.002	−.195*	.051	−.003	−.231*

Note.
**$p \leq .01$.
*$p < .05$.
^$p < .07$.
[a]$p < .10$.
Sublexical Average = Sublexical – Average Time; Sublexical-Weeksxfast = Sublexical – weeks × fastest time; Sublexical trial 1 = Sublexical-time for first trial.

Concerning advantages for our youngest participants, we found that this group scored better than our mid-point age group did on word recognition after 45 hours, and appeared to have advantages on word and pseudoword recognition after phase 3 and 4 of the treatment. Mean standard scores were within the average range following 120 hours of instruction for both groups (at or above the 32nd and 60th percentiles for word and pseudoword reading, respectively). On text-level reading measures, there were no significant differences found to support an advantage for this youngest group. This youngest group did get off to a slower start in terms of reading comprehension, but then closed this gap following 90 hours of intervention.

Overall, these results appear consistent with similar studies that made direct age comparisons for participant groups recruited and defined in the same manner (e.g., Rashotte et al., 2001). Advantages for young participants are not found as consistently, particularly in terms of fluency outcomes, as concluded in reviews comparing outcomes across different studies (Torgesen and Hudson, 2006; Wanzek and Vaughn, 2007). Methodological differences between studies examining the prevention of reading difficulties in young at-risk children versus those used in interventions for students identified with RDs may explain the different conclusions. Prevention studies might use pre-reading skills to define risk-status; might screen participants in the general school population, rather than those with previously recognized reading difficulties; and may focus on populations placed at risk due to environmental factors (e.g., lower SES neighborhoods; Foorman, Francis, Fletcher, Schatschneider, and Mehta, 1998; Torgesen et al., 1999). Given these frequent methodological practices, which are distinct from studies with students identified with RDs, prevention studies may deem more young readers 'at risk' who would actually not go on to develop RDs.

The oldest group in the current study appeared to benefit to the same extent as the two younger groups, although comparisons were limited to the first two phases of the program. These oldest participants did show significant gains across reading outcomes, with the group's mean scores in the average range for word and pseudoword reading, and comprehension (at or above the 30th, 50th, and 37th percentiles at 90 hours, respectively). Fluency remained below average, but there were significant increases on the fluency standardized score which has not been consistently found, or not consistently examined, for older students with RDs (e.g., Lovett et al., 2012; Torgesen et al., 2001). If fluency deficits and remediation are directly related to the extent of accumulated shortfalls in reading amount (Torgesen, 2006), we might have expected significant time by group interactions, showing smaller gains for this oldest group. To understand the increases in reading fluency across all our age groups, we next discuss fluency within the context of sublexical automaticity and the SpellRead™ program.

The current study contributes to a growing body of research examining the relation of sublexical automaticity to oral text-reading fluency. We found that each of the two measures of mastery for speeded sublexical reading predicted unique variance in two of three phases of the intervention (with statistical trends for each nonsignificant contribution). Furthermore, a measure of learning for sublexical automaticity predicted fluency outcomes for each phase of the intervention, beyond that predicted by the first timed trial with sublexical patterns. This suggests that learning through the intervention, rather than already established, pre-intervention individual differences in identifying sublexical patterns, was important for gaining sublexical automaticity. A limitation of our study design, however, was that we could not determine how the amount of practice completed during the week was related to individual differences in progression in sublexical automaticity.

A link between sublexical automaticity and fluency, as found in the current study, is consistent with two frameworks that address the increasing automaticity in word reading acquisition. Essential to Ehri's (1998, 2005, 2014) phase model is the child's progression from strategically decoding words based on the application of grapheme–phoneme correspondences through to recognizing words by 'sight' or automatically, without consciously applying a decoding routine, and with simultaneous constraints from stored pronunciations and meanings. Sight-word recognition is often assumed to access whole-word or lexical-level internal orthographic-representations; however, the 'connection-forming process' (Ehri, 2005) likely reflects learning regularities between English phonology and orthography at multiple levels of mappings (e.g., grapheme-, bigram-, and trigram-connections and associated positional information along with onset, rime, syllabic, morphemic, and lexical sound-to-spelling correspondences; see for example, Brown and Deavers, 1999). Share's (1995, 2008) self-teaching framework further emphasizes that strategic left-to-right, letter-by-letter decoding affords the level of fine-grained analysis required to build the detailed, multilevel orthographic representations that support sight-word reading. Thus, individual differences in initial decoding routines and the rate of acquisition and quality of stored orthographic representations (lexical and sublexical) are all sources of possible variation in word recognition skills (Share). The current findings lend support to the causal connection between sublexical automaticity and reading fluency in these models.

Our findings, alongside these developmental frameworks, may help explain why PDE has been found to contribute unique variance to text reading fluency over that of SWRE in young readers, in students with or at-risk for RDs, and in more normally distributed samples of older readers (Harn et al., 2008; for review, see Torgesen and Hudson, 2006). Decoding efficiency for pseudowords would capture variance in sublexical automaticity beyond SWRE as the stored word pronunciations and meaning constraints are removed, as is the experienced frequency of word-level units. It takes longer to process pseudoword (vs word) stimuli, and thus there is more time for sublexical activation to affect pseudoword reading (similar to observations of increased effects of word regularity for low-frequency vs high-frequency words; Seidenberg, Waters, Barnes, and Tanenhaus, 1984). It might be expected that PDE would share considerable variance with our sublexical automaticity measures. PDE may be somewhat of a misnomer for all but the most novice readers, in so far as it suggests a phoneme-by-phoneme decoding process rather than a complex network of orthographic patterns that contribute to reading both words and pseudowords. For the same reason, the term automatic word recognition may be a better descriptor than would sight-word recognition, as the former more readily encompasses the continuing role of sublexical processes in expert word reading – rather than viewing these as a more strictly developmental or strategic route to word recognition, as sometimes suggested (e.g., Hudson et al., 2012).

There is agreement that fluent reading depends on well-established orthographic representations and that these representations are influenced by reading practice (for review, see Cunningham, Nathan, and Raher, 2011). The current study adds to several strands of previous research that supports a role for sublexical orthographic representations in fluency development (see also, O'Connor et al., 2013). These strands of previous research include: i) short-term studies that suggest a connection between training sublexical units and reading words with those units (e.g., Hintikka et al., 2008); ii) studies that show a relationship between sublexical automaticity defined as speed at individual grapheme-phoneme correspondences and/or phonogram speed and oral-reading fluency (Hudson et al., 2012;

Speece and Ritchey, 2005); and iii) multidimensional interventions that include teaching sublexical units and show improvement in standardized reading fluency scores (e.g., Morris et al., 2012).

In the SpellRead™ program, training of sublexical patterns is speeded, learned to mastery/automaticity, and includes a broad array of units in differing word positions. These aspects of training sublexical units may explain why we found a direct contribution to a generalized fluency measure, whereas studies have largely failed to find transfer effects or links to standard fluency measures (e.g., Conrad and Levy, 2011; Huemer et al., 2010). We suggest that the manner of training sublexical patterns in SpellRead™ might help build the type of skill/facility with different sound–spelling mappings that would normally be acquired through text-reading practice. Deficits in reading amount, therefore, may not only severely limit the number of words that have become 'sight-words' (i.e., stored as lexical-orthographic representations; Torgesen, 2006), but will also affect the rich connections between sublexical phonological and orthographic units. That is, sublexical automaticity is an additional source of variance in reading fluency that is negatively affected by deficits in reading amount for students with RDs. The manner of training sublexical units in SpellRead™ might explain why all reading groups in the current study, regardless of the ages involved, were able to make significant gains on a standardized fluency measure; however, this needs to be directly tested in further research. There are multiple components to the SpellRead™ program, and effects on fluency were not isolated for any one component in this study, including sublexical automaticity. That is, other aspects of the SpellRead™ program would also be expected to have a positive influence on fluency, and further research is needed to investigate the specific effect of the sublexical automaticity training. We suggest that if sublexical training can mimic the role of print exposure on building the types of connections/knowledge needed for fluent reading, this seems to us a little less daunting than does the need for students with RD's to make up the extensive amount of text reading lost over years of schooling.

Our findings and the theoretical and practical interpretations need to be further investigated. This study has obvious limitations that must be taken into account. Participant attrition following each phase of the intervention constrained age group comparisons and the data-analytic approaches used in this study. Furthermore, our oldest group had a larger age distribution than did the younger groups, and our sample was largely from middle- to upper-class SES backgrounds. Research is needed to further investigate the direct link found between the training in sublexical automaticity to reading fluency, building on the seminal work in more transparent orthographies (e.g., Thaler et al., 2004). We do think it could be informative for future research to consider the ways in which sublexical training in SpellRead™ varies from both short-term training studies and longer-term intervention studies that include aspects of instruction in sublexical knowledge. The training procedure in SpellRead™ focuses on speeded practice until accurate and automatic mastery with sublexical patterns is achieved. Furthermore, the sublexical patterns may be more varied in that they are not of one size (e.g., bigram) or in one position (e.g., rime), and there are many patterns that are introduced. Considering these variables might be helpful to understanding the effect of this training on more generalized fluency outcomes, as even near transfer has been difficult in short-term training studies (e.g., Conrad and Levy, 2011). We suggest that investigations into these factors along with broader studies concerning sublexical automaticity could be important to further current understandings and interventions for the entrenched fluency deficits in students with RDs.

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