The role of letters and syllables in typical and dysfluent reading in a transparent orthography

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Abstract

The role of letters and syllables in typical and dysfluent 2nd grade reading in Finnish, a transparent orthography, was assessed by lexical decision and naming tasks. Typical readers did not show reliable word length effects in lexical decision, suggesting establishment of parallel letter processing. However, there were small effects of word syllable structure in both tasks suggesting the presence of some sublexical processing also. Dysfluent readers showed large word length effects in both tasks indicating decoding at the letter-phoneme level. When lexical access was required in a lexical decision task, dyslexics additionally chunked the letters into syllables. Response duration measure revealed that dysfluent readers even sounded out the words in phoneme-by-phoneme fashion, depending on the task difficulty. This letter-by-letter decoding is enabled by the transparent orthography and promoted by Finnish reading education.

Keywords: syllables; word length; lexicality; developmental dyslexia; phonological decoding

1 Introduction

The core of reading in alphabetical writing systems involves the conversion of written to spoken language (for reviews, see Frost, 1998; Rayner, Foorman, Pesetsky, & Seidenberg, 2001), in which dyslexics are deficient (for reviews see Rayner et al., 2001; Vellutino, Fletcher, Snowling, & Scanlon, 2004). Here, we address which linguistic units impact reading in Finnish, a fully transparent orthography, by manipulating independently the lexical status, number of letters and number of syllables of words. Moreover, we explore how these stimulus effects vary as a function of reading skill and task by examining young typical and dysfluent readers in the second grade in visual word naming and lexical decision tasks.

In English, there are approximately 1,500 grapheme-phoneme connections to be mastered (Goswami, 1995) in reading. Evidence from acquired dyslexics suggesting selective impairment in reading either pseudowords or words with irregular spelling-to-sound correspondences (for a review, see Coltheart, 2004) led to the development of visual word recognition models that include options or routes for holistic word recognition and phonological decoding or simply decoding (e.g., Dual-Route Cascaded (DRC) Model; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001). The former type of processing is characterized as uninfluenced by sublexical properties of words, whereas in the phonological route, sublexical influences arise from a systematic conversion of graphemes to phonological representations. In transparent orthographies each letter may correspond to one phoneme and vice versa, as is the case in Finnish, the language of the present study (Aro, 2006; Karlson, 1999). According to the orthographic depth hypothesis (for a review see Katz & Frost, 1992), the transparency of the orthography-to-phonology mapping facilitates decoding, and therefore the entire process of reading acquisition (Aro & Wimmer, 2003; Seymour, Aro, & Erskine, 2003). A commonly used marker for decoding in transparent orthographies is word length effect, i.e. the impeding effect of the number of letters (De Luca, Di Pace, Judica, Spinelli, & Zoccolotti, 1999; Weekes, 1997), which indeed has been found to be larger in transparent than opaque orthographies (Ziegler, Perry, Jacobs, & Braun, 2001; Ziegler, Perry, Ma-Wyatt, Ladner, & Schulte-Körne, 2003) and more commonly observed in visual word naming than in the lexical decision task (Ferrand & New, 2003; Frederiksen & Kroll, 1976). However, word length effects may be absent in fluent reading in transparent orthographies (see Hawelka, Gagl, & Wimmer, 2010 for eye movement evidence in silent reading and Martens & de Jong, 2008, and Spinelli, De Luca, Di Filippo, Mancini, Martelli, & Zoccolotti, 2005, for word naming latencies), suggesting that fluent readers may be capable of holistic word recognition as well.

It is possible that larger sublexical units than letters are used for decoding (Ans, Carbonnel, & Valdois, 1998; Ferrand, 2003). Syllables are natural building blocks of all spoken words, being suitable units for orthography-to-phonology mapping (see Álvarez, Carreiras, & Perea, 2004; Spoehr & Smith, 1973) and impeding effects of the number of syllables on word recognition accuracy (Spoehr & Smith, 1973) and on pseudoword reading speed in particular have been found across orthographies (Ferrand, 2000; Ferrand & New, 2003; Jared & Seidenberg, 1990; New, Ferrand, Pallier, & Brysbaert, 2006; Stenneken, Conrad, Jacobs, 2007). Gagl, Hawelka, & Wimmer (2010) followed the development of word recognition skills from Grades 2 to 4. They found that the number of syllables had an impeding effect on reading speed only at Grade 2. Thus, it is expected that in typical readers, syllable effects may be present in both word and pseudoword reading, but are larger in the latter type of items.

The present study assesses the extent to which decoding, as indexed by word and syllable length effects, is involved in children's word and pseudoword reading in naming and lexical decision tasks. In naming tasks, a detailed phonological code is required (Frost, 1998) in order to correctly produce a spoken output, potentially increasing the phonological effects. In lexical decision tasks, only lexical access is required, which may not require detailed phonological decoding (Frost, 1998). Empirical comparisons of naming and lexical decision latencies confirm these predispositions (Baayen, Feldman, & Schreuder, 2006; Balota, Cortese, Sergent-Marshall, Spieler, & Yap, 2006).

In addition to the stimulus and task manipulations, the present study also examines how effects are modulated by reading skill by examining cohorts of fluent and dysfluent second-grade readers. The behavioral manifestation of dyslexic reading is known to reflect properties of writing systems – in transparent writing systems dyslexic reading is characterized by slow reading (Wimmer, 1993, 1996a, 1996b), whereas in opaque orthographies dyslexics also make a substantial amount of errors (for review, see Rack, Snowling, *&* Olson, 1992). Dyslexic reading in transparent orthographies is characterized by striking word and pseudoword length effects present in eye fixations (De Luca et al., 1999; De Luca, Borrelli, Judica, Spinelli, & Zoccolotti, 2002; Hutzler & Wimmer, 2004), naming response times (De Luca, Burani, Paizi, Spinelli, & Zoccolotti, 2010; De Luca, Barca, Burani, & Zoccolotti, 2008; Martens & de Jong, 2008; Ziegler et al., 2003; Zoccolotti, De Luca, Judica, & Spinelli., 2008) and in lexical decision response times (Di Filippo, De Luca, Judica, Spinelli, & Zoccolotti, 2006; Juphard, Carbonnel, & Valdois, 2004; Martens & de Jong, 2006). Slowness has been found even in naming single letters (De Luca et al., 2010). To our knowledge, the present study is the first that looks into the unique effect of the number of syllables in poor reading. As poor readers are expected to read mainly by decoding, we predict a syllable length effect both in word and pseudoword reading.

For beginning readers phonological decoding is a tool for independently learning new words and for increasing word-specific knowledge as suggested by Share (1995). Undoubtedly, poor and beginning decoding is cognitively a more complicated and effortful process than fluent decoding (Share, 1995). For dyslexics effortful decoding may be the predominant way of reading if the word recognition processes are not automatized (Pugh et al., 2008). In the naming task, fluent readers seem to start their naming response only after assembling the phonological code of the item (Rastle, Harrington, Coltheart, & Palethorpe, 2000; but see Kawamoto, Kello, Jones, & Bame, 1998). However, the response duration has been also found to be sensitive for stimulus properties independent of the response onset in some conditions – the authors inferred that this processing was related to the meaning of the words in English (Balota, Boland, & Shields, 1989). Particularly in transparent orthographies – in which the pronunciation of letters is not affected by orthographic context – the assembly of a complete phonological code before a response onset may not be necessary (Hutzler, Conrad, *&* Jacobs, 2005). This strategy may be easier for poor and early readers, allowing them to utilize their vocalization in the assembly process. If dissociations in response onset times and response durations in the naming task are found, this may suggest that children exploit such an online decoding strategy. The online decoding strategy may be a general reading strategy, therefore the interest is to study whether this strategy usage is affected by item properties.

In Finnish each letter of the alphabet corresponds to a unique phoneme and vice versa, with the exception of the grapheme 'ng', which corresponds to long quantity of the phoneme /ŋ/ (Aro, 2006; Karlsson, 1999). The syllabification in Finnish is determined by simple rules, denoting a syllable boundary before every sequence of a single consonant followed by a vowel, and a syllable boundary between vowels not constituting a diphthong (Karlsson, 1999). In addition, the syllable structure is fairly simple with only ten possible CV-structures and the number of different syllables is rather limited (~ 3,000) (Karlsson, 1999). The initial syllable of a word is always stressed (Karlsson, 1999), followed by a secondary stress on every other syllable in a word except the final syllable. As the present study utilizes only two- and three-syllable items, only the initial syllable is stressed. Being limited in number, frequently occurring, easily parsed, and prosodically distinct, syllables seem good candidates for decoding units in Finnish. Finnish has a complex agglutinative morphology, a productive derivational system and compounding (Karlsson, 1999). Agglutination leads to long words, which are not recognizable by a single fixation due to restrictions of visual acuity (Bertram & Hyönä, 2003). Studies have found that morphological decomposition is typically required to read Finnish words (Hyönä, Bertam, & Pollatsek, 2004), although constituent and compound frequency effects suggest the existence of word representations (Hyönä et al., 2004). These factors alleviate some of the sublexical processing that typically takes place even in fluent reading of Finnish.

Reading instruction in Finnish is systematically based on phonics. Nearly every child learns to decode in the first grade (Lerkkanen, 2007), and the literacy curriculum in the second grade focuses on fluency and reading comprehension. Moreover, reading and spelling skills are taught simultaneously and children usually acquire both skills confidently. Syllabification has been found to be instrumental for learning to read and especially spell, and is standardly used in early reading education and even explicitly marked in early reading materials. While learning the letter sounds in first grade, children are simultaneously practicing decoding with the letters already mastered. Typically this is carried out with syllables, and hyphenated words where they read syllable-by-syllable by slowly “sliding” from one phoneme sound to another in the hyphenated syllables (Lerkkanen, 2007).

Here, typical and dysfluent reading in the transparent Finnish orthography is studied among 8-year-old children in the second grade. The first research question examines the extent to which typical readers demonstrate phonological decoding. We take as our index of holistic word recognition a lack of number of letter or syllable length effect, particularly in lexical decision tasks (Di Filippo et al., 2006; Martens & De Jong, 2006), whereas in naming tasks such phonological effects may be present (De Luca et al., 2002, 2009; Martens & de Jong, 2008 ; Zoccolotti et al., 2005, 2008). The dysfluent readers are expected to yield large responses to lexicality and the number of letter manipulation in both the lexical decision (Di Filippo et al., 2006; Martens & de Jong, 2006) and naming tasks(De Luca et al., 2002, 2008, 2009; Martens & De Jong, 2008; Zoccolotti et al., 2005, 2008). Second, the possible role of the syllable in decoding in Finnish is studied. The influence of the number of syllables (Ferrand, 2000; New et al., 2006; Stenneken et al., 2007) is expected to be larger in pseudoword than word reading in controls. Due to their decoding-based reading style, dysfluent readers are expected to show syllable effects both in word and pseudoword reading, irrespective of the task. Finally, the separation of response onset and response duration measures in the naming task should reveal if children rely on the online decoding strategy.

2 Method

2.1 Participants

The participants were 40 children (21 girls, 19 boys) taking part in a three-year longitudinal study from Grade 1 to Grade 3. Only the results from the second grade are reported here.

2.2 Reading and cognitive skill assessment

The behavioral testing for the 40 participants consisted of assessment of general intellectual abilities (WISC-III, seven subscales), followed by testing of reading skills. The inclusion criterion of a full IQ of at least 80 led to the exclusion of one participant. Performance in three reading tasks was taken into account when dividing children into two groups, dysfluent (DYS) and typical chronological age matched (CA) readers: Time-limited reading of (1) word (Lukilasse Graded Fluency Test; Häyrinen, Serenius-Sirve, & Korkman, 1999) and (2) pseudoword lists were both scored based on the total number of correctly read items (aloud) within the space of 45 seconds and (3) text reading fluency, assessed through oral reading tasks (a meaningful story “Exciting adventures,” 124 words long) with measures of both speed (words per minute) and accuracy (number of correct words per minute) (Lyytinen et al., 2005).

The scores of all three reading tasks were z-scored using the mean and standard deviation from a normative sample of 363 second graders derived from the longitudinal First Step Study (Lerkkanen et al., 2006). A child was considered a dysfluent reader if he or she had an average score across the three tests of more than 1.25 standard deviations below the mean. Children with z-scored averages above -1.0 were included in the control group. Three subjects scored between these cutoff scores and their data was excluded from the analyses. With these criteria, 12 of the 39 children were considered dysfluent readers and 24 children constituted the typical readers as a control group. For various reasons including fatigue and technical problems, data was lost for one DYS and two CA in the naming task, and for four DYS and one CA in the lexical decision task. Therefore, a full dataset was acquired from 8 DYS and 20 CA participants. Table 1 presents means and standard deviations of demographic variables. Small group differences were observed with the size of 11 in performance IQ, *t*(32) = 2.36, p = .028, and with the size of 9 in full IQ, *t*(32) = 2.28, p = .032.

Table 1 Demographic statistics of the children belonging to dysfluent (DYS) and control (CA) groups.

	DYS	CA	*t*(33)	*p*
N	12	24		
Age (months)	105 (3)	106 (4)	.061	.952
Verbal-IQ	99 (9)	102 (13)	.-686	.443
Performance-IQ	86 (13)	97 (14)	2.36	.028
Full-IQ	91 (8)	99 (10)	2.28	.032

2.3 Stimuli

In both the naming and lexical decision tasks, there were three categories of words and pseudowords, each consisting of 25 items: bisyllabic four-letter, bisyllabic six -etter and trisyllabic six-letter items. Words were common Finnish words familiar to children and controlled for frequency (Kotimaisten kielten tutkimuskeskus, 2007; see Table 2 for frequency counts and Appendix for lists of experimental items). Pseudowords conforming to Finnish phonotactics were constructed from the words by replacing two letters. Different words and pseudowords were used in lexical decision and naming tasks. The items contained no foreign letters (b,c,d,f,q,z,w,x,å). As Finnish syllabification is simply dictated by the consonant-vowel structure of two consecutive letters (or phonemes), the manipulation of the number of syllables when the number of letters is controlled for always produces different consonant-vowel structures in bi- and trisyllabic items (a syllabified example: *ka.ra.ta* (escape), *kart.ta* (map), *kar.tat* (maps)).

Table 2 Mean surface word frequencies of the items used in the experimental tasks. Values are expressed as occurrences in a million word with standard deviations in parenthesis. L = letters, S=syllables.

	Word type		
	4L2S	6L2S	6L3S
Naming	16 (14)	15 (25)	14 (17)
Lexical decision	16 (24)	9 (15)	12 (19)

Note: Due to hundreds of inflected word forms of the same base word frequency values are lower in Finnish than what is typically seen in English. Nonetheless the words were common Finnish words familiar to children as shown by high accuracy data reported in Results -section.

2.4 Procedure

The naming and lexical decision tasks were presented using Cognitive Workshop v.1.11 software with a laptop computer. All participants received the naming task first, followed by the lexical decision task. During each trial, subjects saw a fixation cross in the center of the screen for 1000 msec, followed by an item presented in white lower-case Arial 72-point font on a black screen. The item remained on the screen until the response was completed. There was a 2000 msec blank-screen interval between the trials.

Naming. Items were blocked by a stimulus type such that all words were presented prior to pseudowords and stimuli within each block were presented in random order for each subject. Participants were asked to read the items aloud as fast and accurately as they could. The experimenter (a trained research assistant) had to decide after each trial whether the response was correct or not, providing no feedback for the participant. The subjects' utterances were recorded into audio files where voice onset and offset trigger marks were added by means of a voice key.

Lexical decision. Words and pseudowords were mixed and presented in random order in two blocks with a brief pause between blocks. The trials had the same parameters as in the naming task. WORD and PSEUDOWORD responses were indicated by pressing colored buttons on a laptop computer.

2.5 Data processing

A research assistant checked and corrected the automatic voice onset and offset triggers from the sound files as necessary. This was obligatory because the voice key cannot handle various aspects of vocal responses for example non-response sounds such as loud breathing and silent pauses at syllable boundaries consisting of stop consonants. Only valid trials and correct responses were included in response time and duration analyses. In the naming task there were 1.9% invalid trials (89), due to failure of voice onset or offset trigger. Reaction times shorter than 350 msec were excluded (11 or 0.2% of all responses).

Reaction times longer than 3 SD from each subject-pseudo/word average were excluded from the analyses (76 or 1.6% of all responses). In the lexical decision task, reaction times shorter than 600 msec (17 or 0.3% of all responses), invalid trials (20 or 0.4% of all responses), and reaction times longer than 3 SD from each subject-word/pseudoword average (83 trials or 1.7% of all responses) were excluded from the analyses.

3 Results

3.1 Data analysis

The lexicality, number of letter (NoL), and number of syllable (NoS) manipulations provide information on the recognition units. The comparison between the total response time in naming (the sum of response onset time and response duration) and the lexical decision response times reveal whether the relevance of the units is dependent on task requirements, and the comparison of response onset times and response durations in naming should reveal whether the children continue the decoding during their responses.

First, to see which of the studied effects contribute to reading fluency, we analyzed – with continuous variables and including all 39 subjects in the analysis – the partial correlations of the studied effects with reading fluency when the performance IQ was controlled for. In addition, the influence of word frequency was studied by dividing each class of words into two equal halves according to their word frequency values. Next, to examine the difference between dysfluent (n = 8) and typical readers (n = 20) in the studied effects, we administered an analysis of variance for repeated measures using group (DYS, CA) as a between-subject factor, whereas task (naming, lexical decision), measure (naming onset response time, naming response duration), lexicality (words, pseudowords) and item type (4L2S, 6L2S, 6L3S) were handled as within-subject factors. A planned repeated contrast of item type factor would reveal whether the effect resulted from manipulation of the number of letters (4L2S vs. 6L2S) or number of syllables (6L2S vs. 6L3S). The performance IQ value was added as a covariate to rule out the possible effect of the small difference between groups in overall cognitive level regarding reading speed.

The mean accuracy rates for the studied effects are reported in Table 3. Generally the accuracy was high; in the naming task the mean accuracy was 87% for DYS group and 94% for CA group, and in the lexical decision task the mean accuracy was 92% for DYS group and 95% for CA group. Because of the ceiling – particularly in CA group – and to avoid spurious results, accuracy rate analyses were omitted.

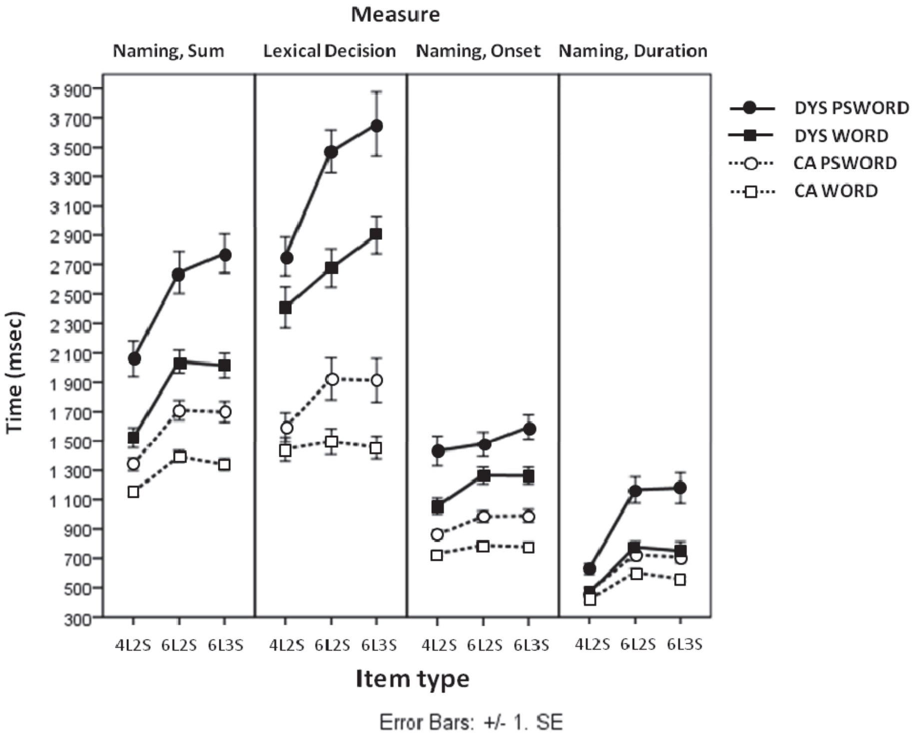
Table 3 Accuracy Percentages with Standard Deviations in Parenthesis.

		Words			Pseudowords		
	Group	4L2S	6L2S	6L3S	4L2S	6L2S	6L3S
Naming	DYS	94.1 (4.5)	86.9 (5.0)	91.6 (9.0)	85.0 (14.1)	82.1 (6.7)	81.4 (8.9)
	CA	97.3 (2.9)	96.0 (3.0)	96.7 (4.9)	94.8 (5.3)	89.5 (7.6)	91.6 (5.4)
Lexical Decision	DYS	84.8 (10.1)	87.6 (12.0)	95.9 (5.6)	92.0 (6.9)	93.3 (6.5)	96.9 (4.1)
	CA	88.5 (6.5)	95.4 (4.3)	96.5 (4.0)	96.1 (4.2)	95.7 (5.7)	95.6 (5.5)

3.2 Partial correlations of the studied effects to reading fluency

It appeared that lexicality effects both naming, *r*(31) = -.721, *p* < .001, and lexical decisions, *r*(31) = -.621, *p* < .001, and pseudoword NoL effects in lexical decision, *r*(31) = -.612, *p* = .001, word NoL effect in naming, *r*(32) = -.685, *p* < .001, and differential naming onset and duration measure, *r*(32) = -.555, *p* = .001, had highly significant correlations with reading fluency. Moreover, pseudoword NoL effect naming, *r*(31) = -.527, *p* = .002, task, *r*(28) = -.480, *p* = .007,and word frequency effect in naming, *r*(32) = -.467, *p* = .005, had intermediate correlations to reading fluency. Instead, any of the NoS effects, or word NoL and frequency effects in lexical decision did not correlate significantly with reading fluency.

Figure 1 Group averages of reaction times in the experimental tasks.



3.3 Task comparison

In the comparison of total naming response tim and lexical decision response times, the following main effects were significant or near-significant: task, *F*(1.25) = 4.05, *p* = .055, = .139, lexicality, *F*(1.25) = 6.90, *p* = .015, = .216, item type, *F*(2.24) = 7.45, *p* = .003, = .383, and group, *F*(1.25) = 57.5, *p* < .001, = .697. The main effect of the IQ covariate was not significant, *F*(1.25) = 1.54, *p* = .226, = .058, and it did not interact with any of the independent variables studied.

A highly significant Group x Item type interaction, *F*(2.24) = 21.9, *p* < .001, = .646, indicated that the NoL effect was generally larger for DYS group (503 msec) than CA group (244 msec), irrespective of the task or lexical status of the item. Group x Lexicality interaction, *F*(1.25) = 9.06, *p* = .006, = .266, showed that the influence of lexical status was greater on reading for DYS group (630 msec) than for CA group (304 msec). Group x Task interaction, *F*(1.25) = 13.07, *p* = .001, = .343, indicated that the influence of task was larger for DYS group (790 msec) than CA group (180 msec).

There was a significant three-way interaction of Group x Task x Item type, *F*(2.24) = 3.83, *p* = .036, = .242, stemming from the NoS manipulation, *F*(1.25) = 6.52, *p* = .017, = .207. The DYS group demonstrated an impeding effect of NoS with the size of 242 msec in the lexical decision task, *F*(1.7) = 8.98, *p* = .020, = .562, whereas the CA group did not show any syllable effect, *F* = .739.

In the naming task, Lexicality x Item type interaction was significant, *F*(1.30) = 24.68, *p* = .000, = .630, stemming from both NoL, *F*(1.30) = 6.55, *p* = .016, = .179, and NoS manipulations, *F*(1.30) = 8.38, *p* = .007, = .219. The number-of-letter effect was larger for pseudowords (478 msec) than for words (380 msec), and trisyllabic relative to bisyllabic words were responded to 42 msec faster, *F*(1.30) = 5.02, *p* = .032, = .139. Although the three-level interaction of Group x Lexicality x Item type was not significant, *F* = 1.42, within groups CA group showed Lexicality x NoL interaction as a sign of specialized letter processing for words, *F*(1.20) = 11.12, *p* = .003, = .358, whereas DYS group did not, *F* = .768.

In the lexical decision task, Lexicality x Item type interaction was significant, *F*(2.28) = 15.55, *p* < .000, = .526, stemming only from NoL, *F*(1.29) = 30.13, *p* < .001, = .510, not NoS manipulation, *F* = .004. CA group showed no difference (2 msec) in response times between 4L2S and 6L3S words, *F* < .003, suggesting a capacity for parallel letter processing. However, response times were 48 msec slower for 6L2S than 4L2S words, *F*(1.22) = 4.83, *p* = .039, = .187, which may indicate a presence of some structural coding of words.

3.4 Comparison of different measures in naming task

The response onset time and response duration in the naming task were significantly influenced by the following main effects: lexicality, *F*(1.29) = 6.20, *p* = .019, = .176, item type, *F*(2.28) = 4.53, *p* = .020, = .244, group, *F*(1.29) = 52.7, *p* < .001, = .645. Again, performance IQ did not produce a main or interaction effect.

The two-level Group x Item type interaction, *F*(2.28) = 19.86, *p* < .001, = .587, stemming from NoL manipulation, *F*(1.29) = 17.98, *p* < .001, = .383, reflected an overall larger NoL (546 msec) effect in DYS group than in CA group (130 msec). The two-level Group x Measure, *F*(1.29) = 17.1, *p* < .001, = .371, indicated that the difference between DYS and CA was larger in response onset time (492 msec) than in response duration (250 msec).

Most importantly, the four-level interaction of Group x Measure x Lexicality x Item type was significant, *F*(2.28) = 6.34, *p* = .005, = .313, as well the three-level interaction of Group x Measure x Item type, *F*(2.28) = 4.66, *p* = .018, = .250. Both interactions stemmed from NoL manipulation, *F*(1.29) = 8.48, *p* = .007, = .226, and *F*(1.29) = 12.28, *p* = .002, = .297, respectively. Next, this four-level interaction is explored in detail in separate partial ANOVAs for response onset and duration measures.

<u>Response onset times.</u> The three-way interaction of Group x Lexicality x Item Type was significant, *F*(2.29) = 7.96, p = .002, = .354, stemming from both NoL, *F*(1.30) = 14.42, p < .001, = 325, and NoS manipulations, *F*(1.30) = 5.61, p < .001, = .158. Figure 1A reveals the nature of these interactions: the DYS group presents a steeper word, *F*(1,30) = 13.09, p < .001, = .304, but not pseudoword NoL effect, *F* = 2.64, than CA group. Note that this counter-intuitively small pseudoword NoL effect in DYS will be compensated for by a striking

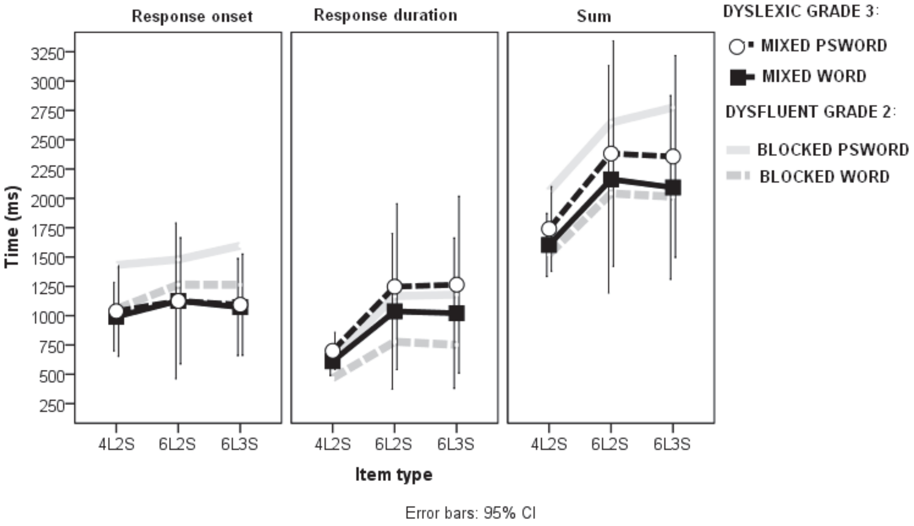
pseudoword NoL effect in response durations. The sizes of the NoL effect for CA group were 55 msec in word, F(1,20) = 6.15, p = .022, = .235, and 123 msec in pseudoword reading, F(1.20) = 16.13, p < .001, = 447. Unlike what was observed in lexical decision, those in the CA group responded more slowly (46 msec) to 6L3S than 4L2S words, F(1.20) = 7.79, p = .011, = .280. In regards to syllable manipulation, DYS responded 118 msec slower to 6L3S than 6L2S pseudowords, F(1.10) = 4.66, p = .057, = .317. The CA group did not present a response to NoS manipulation, F < 1. The influence of lexicality manipulation was on average 129 msec larger for the DYS than CA group, F(1.30) = 10.06, p = .003, = .251.

Response duration. Again, the three-way interaction of Group x Lexicality x Item Type was significant, F(2,29) = 4.85, p = .015, = .251, stemming from the NoL manipulation, F(1.30) = 6.74, p = .014, = .184, not from the NoS manipulation, F < .1. Figure 1B shows that the DYS group prolonged their responses in particular when reading six-letter pseudowords. Crucially, within-group analyses showed Lexicality x NoL interaction both in DYS, F(1.10) = 10.02, p = .010, = .501, and in CA groups, F(1.20) = 5.36, p = .031, = .211. With respect to NoS, the CA group articulated the 6L3S items 32 msec faster than 6L2S items, F(1.20) = 4.78, p = .041, = .193, whereas the DYS group articulated both type of words at equal speed, F < 1. The lexicality effect was 380 msec greater for the DYS, F(1,30) = 17.93, p < .001, = .374 than the CA group.

3.5 A Post-Hoc Study

The dynamics of phonological decoding was additionally studied with three dyslexic children (all third-grade 9-year old boys) in a local clinic serving those with learning disabilities. The children received the same naming task as specified in the Methods section, but with a mixed presentation of words and pseudowords. The general intelligence (WISC-III) of the participants was normal with performance IQs of 92, 100, and 88, and verbal IQs of 118, 97, and 96, while scoring -2, -3, and -2.3 *SDs*, respectively, in a standardized word list reading task (Lukilasse Graded Fluency Test; Häyrinen et al., 1999). The children were presented with the same naming task as specified in the Methods section, but with a mixed presentation of words and pseudowords. The average values are shown by black lines in Figure 2, along with the data of second-grade dysfluent readers presented by gray lines. The dyslexic readers began their naming responses earlier than second-grade dysfluent readers, but showed even more inflated response durations. There were no signs of manipulated effects in response onset times, but a strong length and small lexicality effect in response durations and summed onset and duration measures were observed. This small supplementary data suggests that the more severe the reading problem, the more the phonological decoding may be conducted online.

Figure 2 Naming data of three clinical third-grade dyslexics, when the presentation of words and pseudowords were mixed. For comparison, gray lines show the average values of second-grade dysfluent readers in the blocked naming task.



4 Discussion

The word reading processes of typical and dysfluent second-grade readers in the transparent Finnish orthography was assessed by studying the effects of different linguistic units (words, syllables, letters) in visual naming and lexical decision tasks. The partial correlation analysis, in which IQ was controlled for, revealed that lexicality, number of letters, naming measure, task, and word frequency effects were significantly correlated with reading fluency. All the correlations were negative, indicating that the smaller the influence of the studied effect (e.g. lexicality) the higher the reading fluency. The ANOVAs then revealed more fine-tuned information about the connection between reading fluency and studied effects.

In line with recent findings across transparent orthographies (De Luca et al., 2009, 2008; Di Filippo et al., 2006; Martens & de Jong, 2006, 2008; Zoccolotti et al., 2008), increased responses to length and lexicality manipulations were found among dysfluent readers both in naming and lexical decision tasks. The present study presents three important novel findings concerning dysfluent reading in a transparent orthography. First, dysfluent readers were slower than the control readers in the lexical decision task relative to the naming task. Second, dysfluent readers also showed a number of syllable effect in the lexical decision task, but not consistently in the naming task. Third, in the naming task both the response onset time and response duration were sensitive measures of stimulus properties. Interestingly, already in second grade at the age of eight, typical readers were not affected by the number of letters per se in a lexical decision task. There was a length effect between four-letter and bisyllabic six-letter words, but not between four-letter and trisyllabic six-letter words, the latter result indicating that a major developmental shift from letter-based serial decoding to parallel-letter processing has been achieved. As expected on the basis of more elaborate phonological decoding required in the naming task relative to the lexical decision task (Baayen et al., 2006; Balota et al., 2004; Frost, 1998), the word length effects in naming response onset times were present both when four-letter words were compared to bi- and trisyllabic six-letter words. There was a lexicality-by-length interaction in response durations, which may be due to ongoing phonological decoding during the response in a transparent orthography (Hutzler et al., 2005), or due to less fluent articulation of pseudowords than words (Seidenberg & Plaut, 1998).

Typical readers did not demonstrate the expected impeding effect of number of syllables in pseudoword reading, whereas in the word reading condition there was a facilitatory effect of number of syllables on the naming response duration. The number of syllable effect seems not to behave consistently across orthographies as suggested by our inspection of Italian naming data with adult subjects available in the web (LEXVAR: Barca, Burani, & Arduino, 2002). The Italian data shows a facilitatory effect for number of syllables when the number of letters remains constant. The magnitude of this effect was ~ 20 msec per syllable, the same size as a hindering letter effect. These finding are somewhat in contrast to other languages in which the impeding number of syllable effect have been found in pseudoword reading, including French (Ferrand, 2000; Ferrand & New, 2003), German (Stenneken et al., 2007), and English (Jared & Seidenberg, 1990) even in word reading (New et al., 2006). One explanation for this discrepancy may be that the linear number of syllable effects may be present in languages such as German, French, English and Italian (Pagliuga & Monaghan, 2010) which feature complexities in syllabification or in syllable-stress assignment. The Italian language resembles Finnish in a number of ways: Italian is an only slightly less transparent orthography than Finnish; it has strong syllable stress in speech and a rich morphology, albeit less complex than Finnish. However, in terms of syllabification and assigning syllable stress, Finnish is clearly simpler compared to Italian. Finnish syllabification is governed by two rules and the main syllable stress is denoted by a single rule (Karlsson, 1999), whereas in Italian at least four syllabification rules are required (Hall, 1974). In addition, approximately 20% of multisyllabic Italian words have an irregular syllable-stress pattern and need to be recognized via non-rule-based, lexical processing (Pagliuga & Monaghan, 2010).

It is possible that the syllable may serve some other function than serial decoding unit. Slowing initial-syllable frequency effects have been consistently reported in some regular orthographies as in Spanish (Carreiras, Ferrand, Grainger, & Perea, 2005; Carreiras & Perea, 2007) and in German (Hutzler et al., 2005). No syllable frequency effects have thus far been studied in Finnish, but recently Häikiö, Hyönä, & Bertram (2010) studied the role of the syllable boundary in reading with Finnish second -graders, in both the autumn and spring semesters. They manipulated the bigram frequency in the syllable boundary and measured eye movements during reading. A syllable boundary effect was observed in the autumn but not the spring term, suggesting that the syllable may be a relevant unit only when beginning to read in Finnish, which mirrors the results from a similar German developmental study (Gagl et al., 2010).

Finally, the number of syllable effect may not be related to syllables per se, but rather to the consonant structure of the words. According to Frost (1998), the fluent reader may first decode consonants (not necessarily in a serial fashion) to constrain the lexical search and conduct a detailed phonological coding of vowels only if necessary for lexical disambiguation or for reading aloud. The tendancy to process the trisyllabic items faster than the bisyllabics may indicate that syllabic parsing is easier for the former type of items. The Finnish syllabification rule of denoting a syllable boundary before a vowel - consonant sequence, fits most readily to short CV syllable, from which the trisyllabic six letter items typically consist of. Instead, applying the main syllabification rule to the bisyllabic six-letter items containing successive consonants requires more letters. In addition, when reading bisyllabic six-letter items, one must also apply the second syllabification rule of denoting a syllable boundary between vowels that do not constitute a diphthong.

In line with previous studies, the dysfluent reading was characterized by larger length and lexicality effects in the lexical decision task (Di Filippo et al., 2006; Martens & de Jong, 2006), and in the total naming response time(Figure 1). Compared to the results obtained from the naming tasks, dysfluent readers' response times in the lexical decision tasks were much more delayed than those from the control group. The large influence of the number of letters indicates that dysfluent readers decode even familiar words in a letter-to-phoneme manner. However, the large lexicality effect shows that if the decoding leads to activation in the phonological lexicon, the later phonological output processes are greatly facilitated. Finally, slow pseudoword reading also indicates slowness in decoding, as suggested by Bergmann & Wimmer (2008). Problems in decoding are apparent from a developmental perspective. In transparent orthographies, reading acquisition is based on decoding skills (Seymour et al., 2003) and the poor reading is initially characterized by slow decoding speed (Wimmer, 1996b).

Dysfluent children displayed a slowing influence of number of syllables in the lexical decision task, but this was not reflected on partial correlations. This discrepancy, along with individual profiles, suggests that it is only the poorest readers who, in addition to phonemic decoding, assemble the phonemes into syllables. According to Frost (1998) assembling letters into syllables may help poor readers attain lexical access. It is somewhat a mystery why the dysfluent group did not demonstrate a consistent syllable effect in naming task despite the substantial lexicality effect, indicating that lexical processing was already taking place. One explanation for this pattern of results may be that in the naming task the children were mostly engaged in producing a correct phonemic response. For this reason only partial lexical activation may have been obtained, while complete lexical recognition may have occurred even post-response. This possibility was supported also by the results of the post-hoc study, in which there was no influence of lexicality or number of letter or syllable manipulation present in naming response onset times, but a strong influence of number of letter and a small influence of lexicality manipulation in response durations.

The present results of continued decoding during the naming response in dysfluent readers suggest that the assembly and lexical processes can co-occur or even follow the naming response in a transparent orthography, in which distant letters in a word do not influence the pronunciation of early letters in the word (Hutzler et al., 2005). However, it seems that mere orthographic transparency is only a prerequisite for yielding such a reading strategy, as even severely impaired readers in Italian have not shown a reduced pseudoword length effect in naming response onset times as a sign of an online decoding strategy, despite identical methodology and task instructions (De Luca et al., 2009; Zoccolotti et al., 2008). However, possible evidence for online decoding in Italian is reported by Orsolini, Fanari, Cerrachio, & Famiglietti (2009). In their study responses read aloud were qualitatively classified as fragmented decoding or lexical recognition on the basis of pronunciation correctness. The results indicated that beginning and dyslexic readers produced more serially ordered separate pronunciations of sublexical parts of a word, whereas more advanced readers presented more holistic responses. One factor behind the pronounced online phonological decoding strategy in Finnish may be the way in which reading is taught in the first grade in Finnish schools. Children are explicitly taught to slowly articulate the word aloud according to syllables or letters. In this manner, children are able to decode every Finnish word, regardless of length. It seems plausible that when the words are not easily recognized, Finnish children return to this systematic decoding strategy that they were taught in school.

The present results suggest a limitation in number of letters for the silent assembly process, as short but not long pseudowords were silently decoded, evidenced by a growing group difference in response durations as a function of number of letters. This may be due to limitations of the phonological buffer, which can be seen as a working memory for the assembly process (Ziegler et al., 2003). By focusing on single letter-sound correspondences during articulation instead of generating full phonological code in the mind, the online decoding strategy may relieve demands on working memory. Moreover, the online decoding resembles the orthographic evaluation process suggested by Bergmann & Wimmer (2008), in which dysfluent readers check more carefully whether the initial lexical recognition they made is correct. Thus, poor readers may concentrate on single letter-sound correspondences during articulation for self-monitoring and avoiding mistakes.

Taken together, the present study shows that typical second-grade children show a capability for parallel-letter processing by age 8. However, rapid phonological coding of a word syllable or consonantal structure may still occur. Dysfluent readers seemed to decode even familiar words at a letter-phoneme level, even by sounding out the words in a phoneme-by-phoneme fashion, depending on the task difficulty. When complete lexical access was required, they additionally chunked the letters into syllables. The results indicate an incapability of parallel letter processing, slowness in decoding and additional problems in attaining lexical access for dysfluent readers in transparent orthographies.

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Appendix

List of experimental items:

Naming, words:

4L2S: lelu, pipo, naru, poro, rapu, sora, mopo, mato, kynä, lasi, sade, kala, juna, vene, kisa, mäki, susi, loma, meri, rivi, raja, veli, koti, valo, kivi, **6L2S:** koukku, munkki, nilkka, kurkku, kaivos, lautta, piippu, suihku, lamppu, kuoppa, mainos, patsas, rengas, verkko, kiekko, myrsky, puisto, kerros, leikki, vanhus, taivas, hammas, luonto, kirkko, kauppa, **6L3S:** seteli, pusero, pisara, kipinä, vasara, sipuli, peruna, kitara, veturi, meteli, kävely, puhelu, kamera, satama, kanava, ikkuna, mitali, tavara, enkeli, matala, paperi, kaveri, numero, mukava, tarina

Naming, pseudowords:

4L2S: heku, sito, salu, toso, sanu, kopa, lovo, rapo, pylä, jati, tame, jatu, tusa, seke, mila, pähi, luti, tova, sesi, lini, laha, resi, hopi, naro, pini, **6L2S:** jousku, kulkki, kiikka, sunkku, haipos, vausta, tiilpu, luisku, talppu, nuuppa, tainos, lattas, pentas, teekko, hiesko, kyysky, vuinto, pertos, reiski, nantus, malvas, jasmas, ruusto, niikko, launpa, **6L3S:** keveli, lutero, mikara, liminä, pavara, tiluri, kevuna, pikara, sepuri, hekeli, rätely, muselu, pahera, malama, japava, okkina, nirali, sapara, ankila, rakala, naseri, naveli, tupero, suhava, hapira

Lexical decision, words:

4L2S: hame, havu, latu, maha, tori, mehu, mono, muna, muru, namu, pomo, romu, räme, sumu, papu, vesi, talo, raha, kone, käsi, pora, kylä, levy, lumi, katu, **6L2S:** vaippa, veitsi, viitta, viikko, viesti, heikko, sääntö, käärme, miekka, hiekka, laukku, kaappi, toukka, keitto, kioski, kortti, kyltti, liekki, niitty, pensas, piikki, pultti, reitti, teltta, turkki, **6L3S:** kolari, lattia, ritari, tivoli, väline, salama, terävä, sokeri, sekava, kamala, ämpäri, kypärä, lokero, pipari, kotelo, hunaja, rypäle, majava, lakana, sopiva, vakava, sanoma, matala, ystävä, tarina,

Lexical decision, pseudowords:

4L2S: läte, junu, nalu, hepi, rano, lata, roje, pähi, vola, mykä, jery, ruvi, raku, pale, jatu, hapu, kaja, nosi, seku, romo, vuha, luvu, tasu, soko, kopu, **6L2S:** leisto, tooski, soltti, nyrtti, keekki, tiitta, tenpas, huikki, tuntti, leisti, kertta, sulkki, haappa, reetsi, piirta, seikko, kiesto, jeikku, läänti, täisme, vienka, leekka, sausku, taalpi, routka, **6L3S:** motero, tovake, voselo, ruhaja, kytäle, patava, sapana, rokiva, lapava, kaloma, rasala, ästivä, sapina, posari, sartia, linari, nitoli, närine, tanama, melävä, hoperi, lemava, parala, amperi, nykärä.