Author(s): Hautala, Jarkko; Hyönä, Jukka; Aro, Mikko; Lyytinen, Heikki

Title: Sublexical effects on eye movements during repeated reading of words and pseudowords in Finnish

Year: 2011

Version:

Please cite the original version:

Hautala, J., Hyönä, J., Aro, M. & Lyytinen, H. (2011). Sublexical effects on eye movements during repeated reading of words and pseudowords in Finnish. Psychology of Language and Communication, 15 (2), 129-149. doi:10.2478/v10057-011-0009-x

Psychology of Language and Communication 2011, Vol. 15, No. 2

VERSITA OPEN DOI: 10.2478/v10057-011-0009-x

JARKKO HAUTALA[1], JUKKA HYÖNÄ[2], MIKKO ARO[1], HEIKKI LYYTINEN[1]
[1] University of Jyväskylä
[2] University of Turku

SUBLEXICAL EFFECTS ON EYE MOVEMENTS DURING REPEATED READING OF WORDS AND PSEUDOWORDS IN FINNISH

The role of different orthographic units (letters, syllables, words) in reading of orthographically transparent Finnish language was studied by independently manipulating the number of letters (NoL) and syllables (NoS) in words and pseudowords and by recording eye movements during repeated reading aloud of these items. Fluent adult readers showed evidence for using larger orthographic units in (pseudo)word recoding, whereas dysfluent children seem to be stuck in a letter-based decoding strategy, as lexicality and item repetition decreased the NoL effect only among adult readers. The NoS manipulation produced weak repetition effects in both groups. However, dysfluent children showed evidence for word-specific knowledge by making fewer fixations on words than pseudowords; moreover, repetition effects were more noticeable for words than pseudowords, as indexed by shortened average fixation durations on words due to item repetition. The number of fixations was generally reduced by repetition among dysfluent children, suggesting familiarity-based benefits perhaps at the perceptual level of processing.

Key words: eye movements, word recognition, word length, number of syllables, reading ability

Introduction

When learning to read one first has to break the orthographic code. Languages differ in how complex the mapping is between the written and spoken language. In its simplest form each letter corresponds to a unique phoneme and vice versa. In these kinds of transparent orthographies (e.g. Finnish), learning to read is greatly facilitated when compared to more opaque orthographies such as English (Seymour, Aro, & Erskine, 2003). Naturally, even in transparent orthographies the mapping

Address for correspondence: Jarkko Hautala, Department of Psychology, Agora, POB 35, FI-40014, University of Jyväskylä, Finland. E-mail: jarkko.v.hautala@jyu.fi

must be automatized to attain a fluent reading skill (LaBerge & Samuels, 1974). This automatization is well captured by decoding speed (Ehri & Robbins, 1991; Marsh, Friedman, Desberg & Saterdahl, 1981a; Marsh, Friedman, Welsch & Desberg, 1981b; Tunmer & Hoover, 1993), i.e. the rate at which one can translate letters and words into speech when reading aloud. This efficiency in turn contributes to the experienced pleasure of reading rather than mere recognition accuracy (Leinonen et al., 2001). One strategy to improve reading fluency is to read the same words or texts several times (Laberge & Samuels, 1974), with even a few repetitions producing marked improvement in reading speed (Hyönä & Niemi, 1990; Reitsma, 1983; Share, 2004, for a review, see Ehri, 2005). Repeated reading is also used to remediate reading fluency among dyslexics (Chard, Vaughn, & Tyler, 2002). However, it is not clear which reading processes are affected by repetition and which orthographic units (e.g. syllables or words) should be repeated. The latter question is especially relevant when seeking efficient ways to promote reading fluency especially among struggling readers.

Dual-route theories (e.g. Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001) suggest that words can be recognized either by an analytic letter-to-phoneme conversion or via a whole-word route. In the former strategy, the reader breaks down the word into individual letters or groups of letters, thus allowing access to corresponding phonemic representations. Then these phonemic representations are combined and a phonological representation of the word is accessed. In order to use the latter strategy, the reader must have developed word-specific orthographic representations, and little, if any, phonological processing would be required to access the word identity. In general, sublexical factors are more important when reading pseudowords or infrequent words as compared to reading frequent words – a pattern of results supporting the dual-route view of word decoding.

The dual-route theory is mainly based on data on reading simple monosyllabic words. In many languages, long and complex words are common, containing complex consonant clusters and/or multiple syllables and morphemes. It seems plausible to assume that even in fluent reading these types of words are not recognized as whole words but via smaller units. Thus, the recognition units in reading may be viewed as a continuum from small-size letter/phonemic units via multi-letter units to complete words (Duncan, Seymour, & Hill, 2000; Thaler et al., 2009). It is known that dyslexics are highly affected by sublexical factors, possibly because they have problems in forming or retrieving larger orthographic representations and thus have to rely on a sublexical reading strategy (Zoccolotti, De Luca, Di Pace, Judica, & Spinelli, 2005). For these readers, repeated reading may thus improve reading speed by supporting the formation of larger orthographic representations.

The present study was conducted to gain more insight into fluent and dysfluent word decoding by studying the independent effects of the number of letters (NoL) and number of syllables (NoS) during repeated reading of words and pseudowords. Eye fixation patterns on words and pseudowords were used as online indices of decoding fluency during reading aloud. The reading-aloud task was selected to ensure that the readers engaged in proper decoding of the target items. The NoL effect, commonly termed as the word length effect, provides an indicator of small-unit decoding, whereas the NoS effect, or the syllabic length effect as termed by Ferrand (2000), indicates a possible contribution of larger-unit processing. Repeated reading provides a dynamic window to the use of sublexical units: sublexical effects should diminish as words or pseudowords become increasingly familiar due to repetition. It was expected that fluent adult readers are able to rapidly form new orthographic representations as indexed by a significant reduction in NoL and NoS effects in the pseudoword condition. On the other hand, as hypothesized above, dysfluent child readers may be unable to quickly acquire new orthographic representations, and thus no reduction in sublexical effects was expected.

Using the eye tracking methodology, we were in a position to obtain detailed information about how the studied effects manifest in on-line processing of words and pseudowords. During reading the eyes make stationary stops (fixations) lasting a few hundred milliseconds, during which visual information is acquired. Between fixations the eyes make rapid movements called saccades, during which vision is greatly suppressed. The number of fixations made on a word or pseudoword indicates if the lexical item is recognized instantly during a single fixation or whether recognition is spilled across several fixations (see Rayner, 1998 for a review of eye movements in reading). Hawelka, Gagl and Wimmer (2010) have recently provided an excellent account of how eye movement measures may be understood from the dual-route perspective of reading. Essentially, if several fixations are made on a single word during its initial encounter, a sublexical unit, instead of the whole word, may be recognized during each fixation. If this is the case, a connection between the number of sublexical units and the number of fixations would be found. With respect to item repetition, a reduced number of fixations due to repetition would indicate a shift to more parallel processing, whereas a decrease in average fixation duration would imply an increase in processing efficiency (Reichle, Vanyukov, Laurent, & Warren, 2008). Finally, familiar stimuli may receive fewer and shorter fixations than infrequently encountered stimuli. Nazir et al. (2004) and Maloney et al. (2009) have suggested that this kind of familiarity effect may be non-linguistic in nature and related to perceptual processes.

Letters are self-evident small-size units of reading and necessarily decoded during the course of word recognition. The amount of processing devoted to each letter in a word is captured by the word length (in letters) effect. If words are recognized solely by the whole-word strategy, no word length effect should be observed. In line with the dual-route theory, the pseudoword length effect is demonstrated to be much stronger than the word length effect, which may even be absent in the word naming latencies among adult readers (De Luca et al., 2002; Frederiksen & Kroll, 1976; Martens & De Jong, 2008; Weekes, 1997; Ziegler, Perry, Jacobs, & Braun, 2001). More commonly however, also adult readers show a small but nonetheless reliable word length effect, as reviewed by New, Ferrand, Pallier and Brysbaert (2006). The word length effect has also been apparent in readers' eye movement (Calvo & Meseguer, 2002; Bertram & Hyönä, 2003; De Luca et al., 2002; Hutzler & Wimmer, 2003; Hyönä & Olson, 1995; Just & Carpenter, 1980; Kliegl, Grabner, Rolfs, & Engbert, 2004; MacKeben et al., 2004; Rayner, Sereno, & Raney, 1996, but see Joseph, Liversedge, Blythe, White, & Rayner, 2009). The effect among fluent readers is mainly caused by increased refixations on longer words, but also to some degree by increased fixation durations on words read by a single fixation.

Developmentally, a substantial decrement in the word length effect is seen during the early school years (Martens & de Jong, 2006; 2008; Spinelli, De Luca, Mancini, Martelli, & Zoccolotti, 2005; Zoccolotti et al., 2005). On the other hand, a prolonged word length effect is the most striking behavioral manifestation of dyslexia, presumably indicating the continued use of a letter-by-letter reading strategy (De Luca et al., 1999, 2002; Hutzler & Wimmer, 2003; Zoccolotti et al., 2005; Martens & De Jong, 2006a, 2008; Thaler et al., 2009). In the aforementioned eye movement studies, the length effect among beginning and dyslexic readers is also seen in fixation frequency measures, providing strong evidence for the use of small recognition units in reading.

There is also some evidence for the role of sublexical units larger than letters in word decoding. In irregular orthographies recognition of specific letter combinations is motivated by the unique pronunciation they may code (Paap, Noel, & Johansen, 1992; Rastle & Coltheart, 1999). For example, in German there is evidence for consonant clusters working as perceptual units (Marinus & de Jong, 2008; Thaler et al., 2009). In many languages, words are formed as combinations of a relatively limited number of syllables. An effect of the number of syllables in naming and lexical decision latencies for visually presented words has been shown in English (an irregular but not syllable-stressed language; Jared & Seidenberg, 1993; New et al., 2006), in French (an irregular and syllable-stressed language; Ferrand, 2000; Ferrand & New, 2003), and in German (a regular but not syllable-stressed language; Stenneken, 2007). Additional support for the involvement of syllables in reading comes from syllable frequency studies conducted in Spanish (Álvarez, Carreiras, & Perea, 2004), German (Hutzler, Conrad, & Jacobs, 2005), and English (Macizo & Van Petten, 2007; Ashby & Rayner, 2004).

Finnish – the language of the present study – has a perfect one-to-one mapping between letters and phonemes, enabling an excellent opportunity, particularly for poorer readers, to make use of the letter-by-letter decoding strategy. In fact, there is evidence that word length effects are particularly pronounced in transparent orthographies (Ziegler et al, 2001). Also the syllable seems like a suitable sublexical unit in Finnish, as syllables are salient units in spoken Finnish, with the initial syllable of a word always being stressed (Suomi, Toivanen, & Ylitalo, 2002). Syllabification is traditionally explicitly taught in early reading education, e.g. hyphens are inserted at syllable boundaries in first-grade ABC books, and a common instructional approach is to read words aloud syllable by syllable. Finnish syllables consist of one to four letters and are only approx. 3000 in number. Because of inflectional and agglutinative morphology, words have numerous forms; word compounding is also very productive. For these reasons Finnish words are typically long. Due to restrictions of visual acuity (the foveal vision extends about 2 degrees of visual angle) Finnish words often require multiple eye fixations to be successfully identified (see e.g. Bertram & Hyönä, 2003). Thus, it seems plausible to think that even in fluent decoding of Finnish sublexical units are in use.

To date, only few studies have examined sublexical effects during repeated reading. Martens and de Jong (2008) studied the effect of repetition in a naming task with reference to word length (number of letters) and lexical status (word or non-word) in Dutch. They found that the magnitude of the lexicality effect was reliably decreased by repetition. There was a reduction in the length effect in absolute values, but the reduction was found to be proportional to the improvement in overall reading speed, and therefore it was concluded that the relative influence of the word length remained similar across repetitions. The reduction in the lexicality effect was similar for dyslexics, chronological age- and reading age-matched controls. The chronological age-matched controls, surprisingly, did not show even a pseudoword length effect, thus preventing a repetition effect from manifesting itself. Judica, de Luca, Spinelli and Zoccolotti (2002) did not find reduction in the length effect among dyslexic readers after extensive practice with rapid presentation times, while Hayes, Masterson and Roberts's (2004) case study demonstrated a reduction in the length effect in a dyslexic subject. Finally, Katz et al. (2005) showed that a sublexical regularity effect (the difference in response latency between words with regular versus irregular spelling-sound correspondences) could be cancelled by repetition in the lexical decision task but not in the naming task where pronunciation was required.

A couple of eye movement studies have examined the effects of repeated reading among adult readers. Hyönä and Niemi (1990) studied repeated reading of a single text and found a general facilitation effect due to repeated reading, which was reflected in a decrease in the summed fixation time, average fixation duration, the number of progressive and regressive fixations, as well as in an increase in average saccade length. Raney and Rayner (1995) demonstrated that rereading had a uniform effect for reading high and low frequency words, suggesting that repetition may exert a general facilitatory effect on word recognition so that few repetitions are not sufficient to cancel out the frequency effect.

A handful of studies has examined if repetition effects generalize to reading of non-repeated items containing the same sublexical parts with the practiced ones. Reitsma (1983) found that repeated articulation of words produces a transfer effect generalizing to homophone spellings, suggesting a phonological locus of the training. Berends and Reitsma (2006) demonstrated a generalization of training effect to orthographic neighbor words only when the training had an orthographic locus (a semantic task did not produce a generalized training effect). In a series of studies, Huemer and her colleagues trained children to read syllables (Huemer, Aro, Landerl, & Lyytinen, 2010) and onset consonant clusters (Huemer, Landerl, Aro, & Lyytinen, 2008) and obtained transfer to reading of words and pseudowords containing these trained units. These studies are encouraging with regard to the hypothesis that learning to recognize larger sublexical units might promote reading fluency in dysfluent readers.

The present study was conducted to investigate the extent to which different sublexical units are utilized in reading among fluent adults and dysfluent children and whether it is possible to enlarge the recognition units by repeated reading. Participants read aloud word and pseudoword lists repeatedly ten times from a computer screen while their eye movements were tracked. To study NoL effects, bisyllabic items of 4, 6 and 8 letters were used. Based on previous studies, dysfluent child readers were expected to show a NoL effect for both pseudowords and words with no effect of repetition, whereas adults were expected to show mainly a pseudoword length effect with a rapid decrement in the effect size due to repetition. To study NoS effects, 8–letter items containing 2, 3 or 4 syllables were presented. Based on previous studies (Stenneken, 2007; Ferrand, 2000; Ferrand & New, 2003), a NoS effect was expected to be found for adults, whereas dysfluent children were not likely to demonstrate NoS effects even after repeated exposure, since they seem to rely on relatively persistent letter-by-letter reading (Thaler et al., 2009).

Method

Participants

The group of fluent adult readers consisted of nineteen participants with a mean age of 29.4 years (SD = 6.6). Two adult participants were excluded from the analysis due to their slow performance in a text reading-aloud task (156 s and 143 s, when group M = 119 s and SD = 13.6) presented before the experiment. The eighteen dysfluent child readers were volunteers from a concomitant training study with a mean age of 10.5 years (SD = 11 months). The children's reading level was at least 1 z-score (M = -1.56, SD = 0.511) below their age-level norms in a standardized reading task (LUKILASSE; Häyrinen, Serenius-Sirve, & Korkman, 1999), while performing at the normal level in a general intelligence test, RAVEN M = 30.39, SD = 2.89. All the children followed the normal curriculum in regular classrooms.

Apparatus

Eye movements were recorded by a SMI HiSpeed eye tracker with a 500 Hz sampling rate. Participants were comfortably seated in a solid chair in front of a height-adjustable table, their foreheads resting on the eye tracking apparatus attached to the table. A 13-point calibration procedure was carried out before the experiment. Participants' speech during the experiment was recorded by a PC.

Materials

The stimulus materials consisted of 10 phonotactically legal pseudowords and 10 basic form words, either nouns or adjectives. Each item was repeated ten times in different locations on two text lines. There were five types of words/pseudowords matched for word and bigram frequency: CV.CV = 4L (letters) 2S (syllables), CVC.CVC = 6L2S, CVVC.CVVC = 8L2S, CV.CVC.CVC = 8L3S, CV.CV.CV.CV = 8L4S.

The set of 4L2S, 6L2S and 8L2S items was used to examine the word length effect independent of the number of syllables, which was held constant (i.e. two syllables). The set of 8L2S, 8L3S and 8L4S items was used to study the effect of the number of syllables independent of word length, which was held constant (i.e. eight letters). Pseudowords and real words were presented in separate blocks so that the pseudoword block was read before the real word block.

Procedure

The computer screen was located at a distance of 66 cm from the participant's eyes. The stimulus items were displayed on two lines in Courier New 18 pt font, in which one letter corresponded to 0.43° of visual angle. Prior to the presentation of each stimulus screen, a fixation cross appeared at the beginning of the first text line. The first word on both text lines was a filler word not included in the data analyses. The inclusion of these filler words was done to exclude noisier data in the eye movement record due to stimulus appearance (the first word of the upper text line) and return sweeps (the first word of the second text line). Participants were instructed to read aloud all the words on the screen as fast and accurately as they could. The experimenter manually controlled the appearance and disappearance of the stimulus screens contingent on the participant's gaze and reading aloud. The experiment lasted approximately 15 min.

Eye movement data handling

Raw eye data were parsed into fixations and saccades by SMI's velocity based detection algorithm using a peak velocity threshold of 30 °/s. Periods of unstable data or inaccurate calibration were coded manually and excluded from the analysis. Only fixations longer than 50 ms were included in the analysis. Each stimulus item served as an area of interest. Fixations were assigned to these areas of interest, and the eye movement measures were averaged for each stimulus category. Values deviating more than 3 SD from the condition average were replaced by the value of M + 3 SD. This correction was made separately for each dependent variable. The ten repetitions were split into two halves by averaging the first five repetitions into block 1 and the last five repetitions into block 2.

Statistical analyses

Repeated measures ANOVAs were performed on the data using a 2 (group) x 2 (block) x 2 (lexicality) x 3 (number of letters or number of syllables) design (the last three variables were within-participants variables). The following dependent variables were used: gaze duration (i.e. the time spent fixating a stimulus item during its initial encounter, i.e. first-pass reading), the number of first-pass fixations, and average fixation duration during first-pass reading. The gaze duration reflects overall processing time of the item. The fixation frequency measure reveals whether a letter string can be processed during a single fixation or whether a refixation is needed to complete its recognition. Average fixation duration indexes the relative ease of processing during individual fixations.

Results

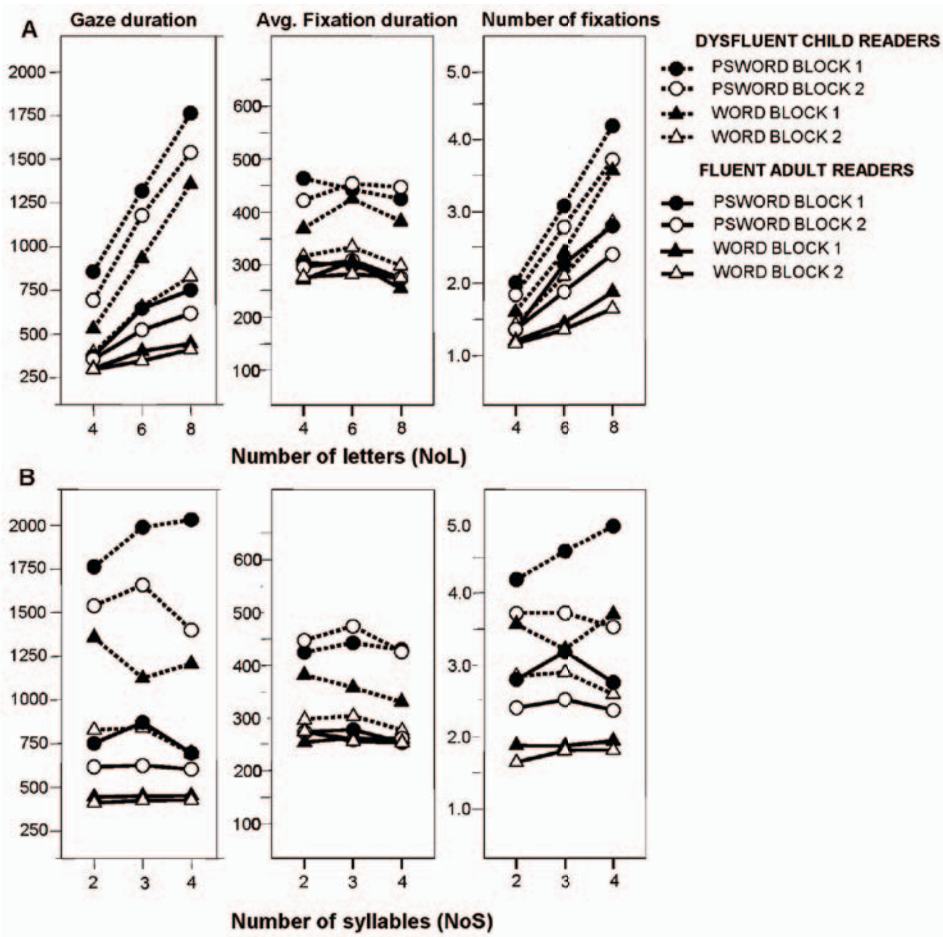
To attain equal variances between groups and to prevent proportionally equal effect sizes from producing artificial interactions in both between- and within-group analyses, logarithmically transformed values were analyzed (Salthouse & Hedden, 2002). For producing a significant interaction in logarithmically transformed values, the studied effects are likely to differ also in proportional values (Martens & de Jong, 2008). For example, if the magnitude of the word length effect in absolute values is 200 ms in pseudoword reading and 100 ms in word reading, the word length effect is 100 ms greater for pseudowords. However, if the average reading time for words is 500 ms and for pseudowords 1000 ms, the proportional magnitude of the length effect is the same for words (100 / 500 = 0.2) and pseudowords (200 / 1000 = 0.2).

The results are reported separately for the NoL and NoS manipulation. A separate section is also devoted to the lexicality effects. As lexicality was a common factor in both manipulations, all pseudowords and words were included in this analysis. The repetition effects, if not interacting with NoL and NoS, are reported in the lexicality section. For the sake of simplicity, only the highest-level interactions involving NoL, NoS, lexicality and repetition are reported in the Results section, and the more redundant main effects and interactions are listed in the Appendix. The means for the NoL and NoS manipulations are reported in Figure 1 and the means for the lexicality effects are reported in Figure 2.

NoL analyses

Gaze duration. A Lexicality x NoL x Group interaction, $F(2,30) = 4.86$, $p = 0.013$, $\eta_p^2 = 0.136$, resulted from only adults showing a steeper pseudoword than word length effect, as revealed by a significant Lexicality x NoL interaction for adults, $F(2,15) = 13.25$, $p = 0.000$, $\eta_p^2 = 0.453$. In children, the Lexicality x NoL interaction was not significant, $F < 1$. The Group x NoL interaction was significant only in word reading, $F(2,30) = 7.30$, $p = 0.006$, $\eta_p^2 = 0.186$, but not in the pseudoword condition, $F = 1.53$,

Figure 1. Results of the first-pass variables including gaze duration (left), average fixation duration (middle) and number of fixations (right). The upper panels (A) show the results of the number of letters manipulation and the lower panels (B) the results of the number of syllables manipulation. For both groups, data are plotted separately for pseudowords and words in block 1 and 2



indicating that the length effect was proportionally steeper for children only in word reading. Moreover, the Block x NoL interaction was also significant, $F(2,30) = 4.00$, $p = 0.023$, $\eta_p^2 = 0.114$, suggesting that the NoL effect was generally reduced by repetition. Although the three-way interaction of Group x Block x NoL was not significant, $F < 1$, Figure 1 raises doubts whether the length effect is really reduced by repetition within the dysfluent child group. An ANOVA computed separately for the two groups revealed that the reduction of the length effect by repetition was present in the adult group, $F(2,15) = 6.67$, $p = 0.008$, $\eta_p^2 = 0.471$, but not in children, $F = 1.34$.

Number of first-pass fixations. In the number of first-pass fixations, a three-way interaction of Lexicality x NoL x Group was significant, $F(2,30) = 8.94$, $p < 0.001$, $\eta_p^2 = 0.224$, as only adults showed a steeper pseudoword than word length effect: Children did not show a Lexicality x NoL interaction, $F < 1$, but adults did, $F(2,15) = 26.13$, $p < 0.001$, $\eta_p^2 = 0.777$. The Group x NoL interaction, indicating a steeper length effect for children, was significant in word reading, $F(2,30) = 10.07$, $p < 0.001$, $\eta_p^2 = 0.240$, but not in the pseudoword condition, $F < 1$. The Block x NoL interaction, $F(2,30) = 5.26$, $p = 0.008$, $\eta_p^2 = 0.145$, suggests that the NoL effect was generally reduced by repetition. Despite the absence of a three-way interaction of Group x Block x NoL, $F = 1.68$, the groups showed a somewhat different pattern of results: A reduction in the length effect due to repetition was present in the adult group, $F(2,15) = 7.22$, $p = 0.003$, $\eta_p^2 = 0.311$, but not in children, $F < 1$.

Average fixation duration. A Block x NoL interaction, $F(2,30) = 3.18$, $p = 0.048$, $\eta_p^2 = 0.093$, resulted from 6-letter items receiving slightly longer fixations than 4-letter items in block 1.

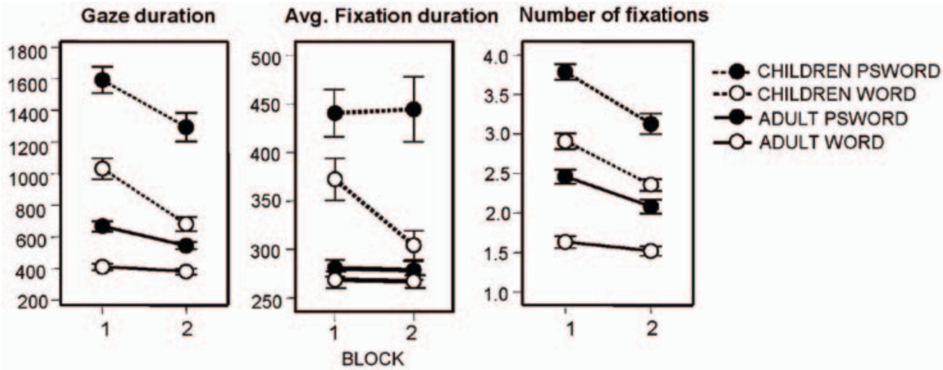
Summary. The most prominent finding was that adults consistently showed a stronger pseudoword than word NoL effect in gaze duration and fixation frequency, whereas in children the NoL effect was equally strong for pseudowords and words. The word, but not the pseudoword length effect was proportionally steeper for children than adults. Item repetition reduced the NoL effect in gaze duration and number of fixations for adults but not for children in these measures.

NoS analyses

Gaze duration. Gaze duration showed an almost significant four-way interaction of Group x Block x Lexicality x NoS, $F(2,30) = 3.12$, $p = 0.052$, $\eta_p^2 = 0.092$. The nature of this interaction is clear: Adults, but not children, $F = 2.5$, showed a three-way interaction of Block x Lexicality x NoS, $F(2,15) = 7.62$, $p = 0.002$, $\eta_p^2 = 0.323$. In adults there was a significant Lexicality x NoS interaction for block 1, $F(2,15) = 7.33$, $p = 0.002$, $\eta_p^2 = 0.314$, but not for block 2, $F < 1$. Trisyllabic pseudowords received longer gaze durations during block 1, as revealed by a contrast between bi- and trisyllabic pseudowords, $F(2,15) = 5.46$, $p = 0.033$, $\eta_p^2 = 0.254$. Children showed a significant interaction of Lexicality x NoS, $F(2,14) = 3.83$, $p = 0.047$, $\eta_p^2 = 0.354$, as the number of syllables had a slightly impeding impact on pseudoword reading and a slightly facilitating effect on word reading. However, when tested separately there was no effect of NoS either in the pseudoword or word condition, $Fs <= 1.5$. Children also showed a Block x NoS interaction, $F(2,14) = 4.69$, $p = 0.017$, $\eta_p^2 = 0.238$, as reading of four-syllabic items was facilitated the most by repetition, $F(2,14) = 9.44$, $p = 0.008$, $\eta_p^2 = 0.386$.

Number of first-pass fixations. The Block x NoS x Group interaction, $F(2,30) = 4.68$, $p = 0.013$, $\eta_p^2 = 0.131$, originates from the children demonstrating a greater reduction due to repetition in the number of fixations on four-syllable items, $F(2,14) = 4.57$, $p = 0.018$, $\eta_p^2 = 0.234$, whereas adults did not show the interaction, $F < 1$. The significant Block x Lexicality x NoS interaction, $F(2,30) = 3.99$,

Figure 2. Results for the lexicality effects. The dotted lines represent the dysfluent child readers and solid lines the fluent adult readers. Error bars of ±1 standard error are also shown



$p = 0.023$, $\eta_p^2 = 0.114$, indicates that slightly more fixations were made on trisyllabic pseudowords during block 1, $F(2,32) = 5.49$, $p = 0.007$, $\eta_p^2 = 0.143$, but not anymore during block 2, $F < 1$.

Average fixation duration. The main effect of NoS indicates that the shortest fixations were made on the four-syllable items, $F(2,30) = 4.79$, $p = 0.012$, $\eta_p^2 = 0.134$.

Summary. For adults the trisyllabic pseudowords were the most difficult items, as indicated by gaze duration, but this effect was reduced by repetition. Children did not show consistent effects of NoS across measures, except that repetition facilitated the reading of four-syllable items the most.

Lexicality and repetition effects

Gaze duration. The three-way interaction of Block x Lexicality x Group was significant, $F(1,31) = 15.35$, $p = 0.000$, $\eta_p^2 = 0.331$. In children word reading was more facilitated by repetition than pseudoword reading, $F(1,15) = 9.52$, $p = 0.008$, $\eta_p^2 = 0.338$, whereas in adults pseudoword reading was slightly more facilitated than word reading, $F(1,15) = 5.55$, $p = 0.032$, $\eta_p^2 = 0.258$. Both groups showed a robust lexicality effect during block 1 and 2 ($p < 0.001$). Repetition had a larger overall effect in children than in adults in word reading, as indicated by a Block x Group interaction, $F(1,31) = 30.60$, $p < 0.001$, $\eta_p^2 = 0.497$, but not in pseudoword reading, $F < 1$. Finally, the lexicality effect was greater for children than adults during block 2 only, $F(1,31) = 12.58$, $p = 0.001$, $\eta_p^2 = 0.289$.

Number of first-pass fixations. The Group x Lexicality interaction, $F(1,31) = 7.08$, $p = 0.012$, $\eta_p^2 = 0.186$, suggests a proportionally larger lexicality effect for adult readers, $F(1,31) = 6.89$, $p = 0.013$, $\eta_p^2 = 0.177$; yet also children showed a robust lexicality effect, $F(1,15) = 58.19$, $p < 0.001$, $\eta_p^2 = 0.784$. The Group x Block interaction,

$F(1,31) = 6.00$, $p = 0.020$, $\eta_p^2 = 0.162$, indicates that reduction due to repetition was larger for children, $F(1,15) = 7.08$, $p = 0.012$, $\eta_p^2 = 0.186$, than adults.

Average fixation duration. The three-way interaction of Block x Lexicality x Group interaction was significant, $F(1,31) = 5.05$, $p = 0.032$, $\eta_p^2 = 0.140$. Children showed a Block x Lexicality interaction, $F(1,15) = 8.43$, $p = 0.011$, $\eta_p^2 = 0.360$, whereas adults did not, $F < 1$. In word reading children greatly reduced their average fixation duration as a function of repetition, $F(1,15) = 17.24$, $p = 0.001$, $\eta_p^2 = 0.535$, whereas in pseudoword reading no significant reduction was present, $F < 1$. Adults did not show a reduction in average fixation duration due to repetition either in pseudoword or word reading, $Fs < 1$. The lexicality effect was greater for children both in block 1, $F(1,15) = 5.00$, $p = 0.032$, $\eta_p^2 = 0.135$, and in block 2, $F(1,15) = 12.58$, $p = 0.001$, $\eta_p^2 = 0.289$. Only children showed a lexicality effect in average fixation duration, $F(1,15) = 14.02$, $p = 0.002$, $\eta_p^2 = 0.467$ for block 1, and $F(1,15) = 29.59$, $p = 0.001$, $\eta_p^2 = 0.660$, for block 2.

Summary. Although children did not show a reduction in the word length effect (see previous analyses), they could reduce their overall number of fixations as a function of stimulus repetition and lexicality. Repetition also substantially shortened their average fixation durations on words, but not on pseudowords. Across all measures, the repetition effect tended to be slightly larger for children than for adults. Lexicality effects were robust for both groups in gaze duration and the number of fixations, whereas only children showed a lexicality effect in average fixation duration.

Discussion

To study to what extent words, letters and syllables are used as units in fluent and dysfluent decoding of transparent Finnish orthography and how relevant these units remain when the items become more familiar due to repetition, we measured eye movements during reading aloud of words and pseudowords, for which the number of letters and syllables were independently varied. In line with previous studies (summarized in the Introduction), we found a stronger pseudoword than word length effect in the number of fixations among fluent adult readers, whereas dysfluent children showed equally strong word and pseudoword length effects. A more novel finding was that stimulus repetition reduced the length effect especially in adults by decreasing the number of fixations, whereas children continued to be affected relatively similarly across repetitions by stimulus length. Interestingly, compared to dysfluent child readers, adults showed a proportionally weaker length effect in word, but not in pseudoword reading. The number-of-syllable manipulation produced only negligible effects. Oddly, adults fixated longest on the trisyllabic pseudowords, but this effect was reduced by repetition, whereas children reduced their number of fixations on four-syllabic items. Finally, compared to adults, children showed larger overall benefits of stimulus familiarity in terms of lexicality and repetition effects, particularly in word reading.

As argued in the Introduction, the number of fixations measure reflects the degree of lexical versus sublexical processing in word decoding, whereas the average fixation duration measure reflects the efficiency of word processing (Reichle et al., 2008; Hawelka et al., 2010). The number of fixations made on the target items seems to be determined by several factors. First, both groups showed the main effects of lexicality and repetition in the number of fixations. Both effects can be understood as reflections of stimulus familiarity and possibly sharing, at least partially, the same cognitive mechanism, perhaps at the visuo-orthographic level of processing (Risko, Stolz & Besner, 2010, Nazir et al., 2004), as will be discussed later. On the other hand, the magnitude of the word length effect in the number of fixations may be a more genuine measure of the quality of orthographic processing. However, the absolute magnitude of the word length effect is partially dependent on overall reading time, so proportional values should be analyzed (Di Filippo et al., 2006; Martens & de Jong, 2008), as was done in the present study. If the proportional length effect in the number of fixations is reduced by familiarity (i.e. words versus pseudowords), it is relatively safe to conclude that words are recognized more holistically than pseudowords. In the present study this was found only among fluent adult readers, but not among dysfluent children, suggesting a specific problem among young dysfluent readers in forming larger orthographic representations. This interpretation is further supported by the finding that dysfluent readers showed no reduction in the length effect due to repetition, whereas adult readers did.

According to the prevalent view, the word length effect stems from sublexical orthographic and phonological processing (Ziegler et al, 2003; Coltheart et al., 2001; Weekes, 1997). According to Share's (1995; 1999; 2004) self-teaching hypothesis, repeated reading produces word-level orthographic and phonological representations that bypass sublexical processing, thus relieving the word length effect. In Martens and de Jong's (2008) naming study repeated reading did not alter sublexical processing among beginning and dyslexic readers, with the exception that their fluent readers did not show a length effect at all. The authors discuss a variety of possibilities for repetition not reducing the length effect, including also the possibility that a reduction in the word length effect could be partly due to gradual development of an entire reading system and not primarily emerging from developing specific word representations. As regards fluent adult readers, Maloney et al. (2009) showed that even few repetitions are sufficient to reduce the pseudoword length effect. A similar reduction in the word and pseudoword length effect among fluent readers was observed in the present study. These findings may be taken to support the view of rapid formation of new orthographic representations among skilled readers (Ehri & Saltmarsh, 1995; Reitsma, 1983; Share, 1995; 1999; Maloney et al., 2009). Finally, it may be possible, as Martens and de Jong (2008) note, that repeated reading facilitates reading via priming. Priming should have quite a general influence on both word and pseudoword reading, contributing perhaps more to the main effect of repetition rather than to changes in processing style. Also, even in the priming account one has to assume that access to holistic representation is improved.

The number-of-syllables manipulation had only modest and not very straightforward effects in both groups, suggesting that the syllable plays at the most a subtle role in reading Finnish. These weak effects were affected by repetition – a result in line with Katz et al. (2001) who demonstrated a rapid fading of a large-unit regularity effect in lexical decision tasks, but not in naming. In the current study, adults fixated the trisyllabic pseudowords the longest, which suggests that some other factor than NoS may be responsible for the effect. However, adults overcame this difficulty by stimulus repetition suggesting again an ability to rapidly reduce sublexical processing and form new orthographic representations. Children showed a weak trend of initially fixating longer on the four-syllabic pseudowords than words, the effect being reduced by repetition, which may be taken as evidence for the ability for large-unit processing also among dysfluent readers, in addition to the dominant small-unit decoding.

As also our dysfluent children showed robust repetition and lexicality effects in the number of fixations, it seems that they have no deficit in taking advantage of stimulus familiarity. Assuming that their orthographic processing style remained letter-based, it may be that familiarity produces some sort of perceptual facilitation. Generally, perceptual learning is known to be specific to the trained stimuli and the retinal location, as reviewed by Gilbert, Sigman, and Crist (2001). Nazir et al. (2004) suggest that perceptual learning may affect early stages of visual processing during word recognition. In their lexical decision experiment, performance of briefly presented words was degraded as a function of horizontal displacement from fixation point, whereas pseudowords differing from the words only by the final letter did not show this sensitivity to horizontal displacement. Risko et al. (2010) showed that repeated words require less spatial attention and suggest that repetition may improve orthographic feature and letter-level processing. Dykes and Pascal (1981) even found that the repetition of the letter C improved the recognition of the visually similar letter G but not that of the dissimilar letter F. In our study, repetition may have activated visual representations of words and pseudowords, and these visual representations may have provided a beneficial context for feature and letter extraction.

Even when expected, it is surprising that the dysfluent children could not use their lexical knowledge to make the laborious sublexical reading procedure easier. As a very limited set of words was used, one could have adopted a strategy of guessing the word based on its initial letters.

However, the length effect in the number of fixations was not affected by the familiarity of lexical items. On the other hand, average fixation duration on words, but not on pseudowords, was clearly shortened (effect size was $\eta_p^2 = 0.54$) among children; this finding was also reflected in the gaze duration measure. Similarly to the present study, Judica et al. (2002) demonstrated shortened fixation durations as a response to a speeded word recognition training in normal and dyslexic Italian children. This was interpreted to suggest that speeded training increased the amount of visual information gathered by each fixation. An alternative account for these results would be a more strategic explanation – the dysfluent children may resort to a sublexical reading strategy even when they have quite a good idea what the word is. One apparent motive for this strategy would be to avoid mistakes.

In conclusion, the fixation frequency and duration data may be interpreted as suggesting that dysfluent child readers use a sublexical route even when reading aloud highly familiar words; an increase in familiarity facilitates perceptual and visuo-orthographic processing, but does not introduce a change in the processing strategy. This may be taken to suggest that dysfluent children seem to have a deficit in rapidly forming larger orthographic representations as a result of item repetition. Further studies of repeated reading with a more extensive repetition procedure are needed to find out to what extent the word length effect could be reduced in dysfluent reading.

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Appendix

Significant interactions and main effects redundant to higher-level interactions, not reported in the Results section.

NoL analyses

Gaze duration. Group, $F(1,31) = 78.81$, $p < 0.001$, $\eta_p^2 = 0.718$, Block, $F(1,31) = 57.79$, $p < 0.001$, $\eta_p^2 = 0.651$, Lexicality $F(1,31) = 169.47$, $p < 0.001$, $\eta_p^2 = 0.845$, NoL, $F(2,30) = 145.00$, $p < 0.001$, $\eta_p^2 = 0.824$, Block x Lexicality, $F(1,31) = 5.00$, $p = 0.033$, $\eta_p^2 = 0.139$.

Number of first-pass fixations. Group, $F(1,31) = 78.81$, $p < 0.001$, $\eta_p^2 = 0.718$, Lexicality $F(1,31) = 186.32$, $p < 0.001$, $\eta_p^2 = 0.857$, NoL, $F(2,30) = 215.13$, $p < 0.001$, $\eta_p^2 = 0.874$, Lexicality x Group, $F(1,31) = 7.65$, $p = 0.009$, $\eta_p^2 = 0.198$, Lexicality x NoL, $F(2,30) = 8.19$, $p < 0.001$, $\eta_p^2 = 0.209$.

Average fixation duration. Group, $F(1,31) = 18.39$, $p < 0.001$, $\eta_p^2 = 0.372$, Block, $F(1,31) = 9.38$, $p = 0.005$, $\eta_p^2 = 0.232$, Lexicality $F(1,31) = 28.80$, $p < 0.001$, $\eta_p^2 = 0.482$, NoL, $F(2,30) = 6.14$, $p = 0.004$, $\eta_p^2 = 0.165$, Block x Group, $F(1,31) = 9.17$, $p = 0.005$, $\eta_p^2 = 0.228$, Lexicality x Group, $F(1,31) = 9.69$, $p = 0.004$, $\eta_p^2 = 0.238$, Block x Lexicality, $F(1,31) = 5.86$, $p = 0.022$, $\eta_p^2 = 0.159$.

NoS analyses

Gaze duration. Group, $F(1,31) = 93.91$, $p = 0.000$, $\eta_p^2 = 0.752$, Block, $F(1,31) = 75.64$, $p = 0.000$, $\eta_p^2 = 0.709$, Lexicality $F(1,31) = 159.43$, $p = 0.000$, $\eta_p^2 = 0.837$, NoS, $F(2,30) = 3.22$, $p = 0.047$, $\eta_p^2 = 0.094$ Block x Lexicality x Group, $F(1,31) = 10.31$, $p = 0.003$, $\eta_p^2 = 0.250$, Block x Syllables x Group, $F(2,30) = 4.02$, $p = 0.023$, $\eta_p^2 = 0.115$, Lexicality x Syllables x Group, $F(2,30) = 4.39$, $p = 0.016$, $\eta_p^2 = 0.124$, Block x Lexicality x Syllables, $F(2,30) = 4313$, $p = 0.019$, $\eta_p^2 = 0.122$.

Number of first-pass fixations. Group, $F(1,31) = 62.64$, $p = 0.000$, $\eta_p^2 = 0.669$, Block, $F(1,31) = 125.00$, $p = 0.000$, $\eta_p^2 = 0.801$, Lexicality $F(1,31) = 120.39$, $p = 0.000$, $\eta_p^2 = 0.669$, Block x Group, $F(1,31) = 6.37$, $p = 0.017$, $\eta_p^2 = 0.171$, $\eta_p^2 = 0.795$, Lexicality x Group, $F(1,31) = 7.63$, $p = 0.010$, $\eta_p^2 = 0.198$.

Average fixation duration. Group, $F(1,31) = 25.40$, $p = 0.000$, $\eta_p^2 = 0.450$, Block, $F(1,31) = 5.10$, $p = 0.031$, $\eta_p^2 = 0.14$, Lexicality $F(1,31) = 28.08$, $p = 0.000$, $\eta_p^2 = 0.475$, Lexicality x Group, $F(1,31) = 17.28$, $p = 0.000$, $\eta_p^2 = 0.358$, Block x Group, $F(1,31) = 5.08$, $p = 0.031$, $\eta_p^2 = 0.141$.

Lexicality and Repetition analyses

Gaze duration. Group, $F(1,31) = 88.57$, $p < 0.001$, $\eta_p^2 = 0.741$, Block, $F(1,31) = 172.21$, $p < 0.001$, $\eta_p^2 = 0.847$, Lexicality $F(1,31) = 93.03$, $p < 0.001$, $\eta_p^2 = 0.750$, Lexicality x Group, $F(1,31) = 14.82$, $p < = 0.001$, $\eta_p^2 = 0.323$.

Number of first-pass fixations. Group, $F(1,31) = 78.81$, $p < 0.001$, $\eta_p^2 = 0.718$, Lexicality $F(1,31) = 129.42$, $p < 0.001$, $\eta_p^2 = 0.807$, Block, $F(1,31) = 162.66$, $p < 0.001$, $\eta_p^2 = 0.840$.

Average fixation duration. Group, $F(1,31) = 23.26$, $p < 0.001$, $\eta_p^2 = 0.429$, Block, $F(1,31) = 32.98$, $p < 0.001$, $\eta_p^2 = 0.515$, Lexicality $F(1,31) = 10.02$, $p = 0.003$, $\eta_p^2 = 0.244$, Block x Group, $F(1,31) = 16.21$, $p < 0.001$, $\eta_p^2 = 0.343$, Lexicality x Group, $F(1,31) = 6.89$, $p = 0.013$, $\eta_p^2 = 0.182$, Block x Lexicality, $F(1,31) = 5.59$, $p = 0.024$, $\eta_p^2 = 0.153$.