1. Introduction

In isolated word recognition studies, O’Regan and colleagues (O’Regan, 1992; O’Regan & Lévy-Schoen, 1987; O’Regan, Lévy-Schoen, Pynte, & Brugalière, 1984) have demonstrated that: (1) words are identified more quickly and (2) less refixations are needed on words, when the first eye fixation is close to the word center. These findings demonstrate that positioning the eyes on the word center is the optimal viewing position (OVP) for word recognition. Vitu, McConkie, Kerr and O’Regan (2001) established these effects in reading and refer to the former effect as the Gaze Duration OVP effect and to the latter as the Refixation OVP effect. Subsequent reading studies have replicated both the Refixation OVP effect (McConkie, Kerr, Reddix, Zola, & Jacobs, 1989; Nuthmann, Engbert, & Kliegl, 2005; Rayner, Sereno, & Raney, 1996; Vitu et al., 2001; Vitu et al., 1990) and the Gaze Duration OVP effect (Nuthmann et al., 2005; Vitu et al., 1990).

These OVP effects are assumed to result from a rapid programming of a refixation (O’Regan & Lévy-Schoen, 1987) when the eyes land non-optimally, far away from the OVP, which in turn is reflected in a higher refixation probability and longer gaze duration. On the other hand, less refixations are needed when the eyes initially land on the word center. It is assumed that the mechanism responsible for guiding the eyes through a text is tuned to respond quickly when the eyes land on a bad spot in a word by sending them toward the other end of the word. Such a mechanism is functional, because visual acuity drops off rapidly with retinal eccentricity. In other words, most letters of a word (when it is not very long) can be seen in a single glance when fixating on the word center (likely to result in a single fixation that is relatively long, see below for more), but the farther away a fixation is from the word center, the more difficult it becomes to recognize the word in a single fixation, which in turn increases the likelihood for a refixation. Vitu, Lancelin and d’Unienville (2007) offer a somewhat different explanation for the Refixation OVP effect. Landing on a non-optimal spot in a word automatically triggers a saccade. As short-amplitude saccades are likely to follow a short fixation, the probability of refixating a word is increased. Thus, in this explanation word recognition difficulties are ascribed only a secondary role.

There are two additional OVP effects introduced by O’Regan, Vitu and colleagues as the Fixation Duration Trade-off effect and the Fixation Duration Inverted-OVP (IOVP) effect. These effects reflect position effects at the level of individual fixation durations. The trade-off effect applies to cases when two fixations are made on a word. It is characterized by a short initial fixation made on a non-optimal word region, subsequently compensated by lengthening the duration of second fixation made on the word. Or conversely, a relatively longer first fixation close to the OVP is followed by a shorter second fixation elsewhere in the word. In other words, the duration of second fixation on the word depends on how optimally the first fixation is positioned. That the trade-off effect may generalize from isolated word recognition to reading was first demonstrated by Vitu et al. (2001) in English and subsequently replicated by McDonald, Carpenter, and Shillcock (2005) in English and Nuthmann et al. (2005) in German. Finally, the Fixation Duration Inverted-OVP effect obtained for the single fixation made on a word (Kliegl, Nuthmann, & Engbert, 2005)
As regards the single-fixation IOVP effect, our aim was twofold. First, we wanted to examine whether the effect generalizes to a structurally different language and to longer words. Nuthmann et al. (2005) showed that in German the IOVP effect in fact increases as a function of word length. Thus, we expected to replicate the effect with our long stimuli. Second, provided that it indeed does replicate, we wanted to analyze the eye behavior leading to and following a single fixation on the target word. According to the mislocated fixation account (Nuthmann et al., 2005, 2007), a subset of fixations landing on non-optimal spots in words is mislocated due to either a saccadic overshoot or undershoot. Specifically, a single fixation positioned on the beginning of the target word (Word N) may be a result of a saccadic overshoot due to the reader intending to land on Word N – 1 but unintentionally skipping over it. If the overshoot explanation is applicable to the present data, we should find that a single fixation positioned on the beginning of the target word is more likely to be preceded by a skip over Word N – 1, followed by a regression to Word N – 1, than a single fixation positioned in the word center.

To test OVP and IOVP effects in Finnish, we reanalyzed the data of Bertram and Hyönä (2003), Experiment 2 of Hyönä and Pollatsek (1998), and Experiment 2 of Pollatsek, Hyönä, and Bertram (2000). In these studies, the target words were embedded in single-sentence contexts, and readers were instructed to read the sentences silently for comprehension, while their eye movements were tracked.

2. Method

2.1. Participants

The number of participants contributing to the data for long compounds comprised 108 university students, who participated in four different experiments (24 in Experiment 2 of Hyönä & Pollatsek, 1998; 24 in Experiment 2 of Pollatsek et al., 2000; 30 in Experiment 1 of Bertram & Hyönä, 2003; and 30 in Experiment 2 of Bertram & Hyönä, 2003). As indicated above, the participants contributing to the short compound word data set also contributed to the long compound word data set. All participants took part in only one experiment. All participants spoke Finnish as their native language.

2.2. Apparatus

Eye movements were collected by the EyeLink 1 eyetracker manufactured by SR Research Ltd. (Canada). The eyetracker is an infra-red video-based tracking system combined with hyperacuity image processing. Registration is monocular and is performed for the selected eye. The sampling rate was 250 Hz. The spatial accuracy is better than 0.5°.

2.3. Materials

All target words were two-noun compound words. Either whole-word frequency or first-constituent frequency was manipulated. The short target word set consisted of 76 short compound words (7–8 characters; mean length 7.6 characters; mean length of the first constituent 3.9 characters, range 2–5 letters). Thirty-nine short compound words were included in the first-constituent frequency manipulation (mean first-constituent frequency was 25 words per million for the low-frequency condition and 468 words per million for the high-frequency condition) and 37 short compounds in the whole-word frequency manipulation (mean word

2006; McDonald et al., 2005; Nuthmann, Engbert, & Kliegl, 2007; Nuthmann et al., 2005; Vitu et al., 2007; Vitu et al., 2001) is such that a single fixation at OVP is clearly longer than a single fixation away from the word center. Radach and Heller (2000) report a similar pattern, but they do not differentiate between one-fixation and multiple-fixation trials. Note, however, that an IOVP effect has not always been observed (see Rayner et al., 1996). The effect is inconsistent with the other OVP effects, as the visuomotor explanation offered above for the other OVP effects is not applicable to the IOVP effect. Specifically, it is inconsistent with the trade-off effect in that the single fixation made on a non-optimal location is not compensated by a reflexion positioned in another word location. Moreover, it is not in line with the Gaze Duration OVP effect in that for single fixations, gaze duration on words is longest, not shortest, when the one and only fixation is positioned in the word center. Three competing, but not necessarily mutually exclusive accounts have been proposed for the single-fixation IOVP effect, the perceptual-economy (Vitu et al., 2007; Vitu, McConkie, Kerr, & O’Regan, 2001; see also O’Regan & Lévy-Schoen, 1987), the split fovea (McDonald et al., 2005) and the mislocated fixation (Nuthmann et al., 2005, 2007) account. We will go over them in some detail in the Discussion.

To date, previous research on OVP effects in reading has been conducted in three related European languages, English, French and German. The present study aimed to replicate the OVP effects reviewed above in a structurally different language, Finnish, which belongs to the Finno-Ugric family. Finnish is a morphologically rich alphabetic language that makes heavy use of inflections attached to the end of words. Moreover, word compounding is also very productive. Finally, Finnish lacks articles. As a consequence of these features, Finnish words are on average quite long.

In the present study, we examined OVP effects in reading Finnish compound words (7–14 letters). Two sets of target words were included in the analyses, shorter (7–9 letters) and longer (11–15 letters) compound words. As regards the Fixation OVP, the Gaze Duration OVP effect and the Fixation Duration Trade-off effect, two opposing predictions may be made for Finnish. First, the penalty for initially fixating on a non-optimal spot in a word will be stronger when words are long. This is because several letters lie outside the foveal area, leading to increased need to make a reflexion on the word. This would strengthen the Fixation, Gaze Duration, and the trade-off OVP effects for long compound words. Alternatively, when words are sufficiently long, readers may not aim to recognize them holistically, but may instead apply a piecemeal recognition strategy. In fact, Bertram and Hyönä (2003) have reported evidence demonstrating that Finnish readers recognize long, two-noun compound words via their components by first recognizing the initial constituent followed by the recognition of the second constituent and the whole word. If so, fixating first toward the beginning of the word may not be as detrimental for long than short compound words (the latter type of compound words are assumed to be more often processed holistically, see Bertram & Hyönä, 2003). This prediction assumes that OVP effects are partly determined by lexical processing. This assumption would be further supported by data demonstrating that the OVP effects are modulated by word frequency, as word frequency effects are considered to be the litmus test of lexical processing. In the present study, we tested these predictions by examining whether the effect of the initial landing position in a word is modulated by compound word length and/or the frequency of the whole word or the first constituent of the compound word. Note, however, that prior research has not found evidence for the Fixation OVP effect or the Single-Fixation IOVP effect to be modulated by word frequency (Nuthmann et al., 2005; O’Regan & Lévy-Schoen, 1987; Vitu et al., 2007; Vitu et al., 2001).

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frequency was 2.3 words per million for the low-frequency condition and 22 words per million for the high-frequency condition). Four words were excluded from the original word set of Bertram and Hyönä (2003), one 6-letter and three 9-letter words. The long compound word set comprised 168 words (11–14 characters; mean length 12.6 characters; mean length of the first constituent 6.8 characters, range 4–9 letters; for more details, see Bertram & Hyönä, 2003; Experiment 2 of Hyönä & Pollatsek, 1998; Experiment 2 of Pollatsek et al., 2000), of which 92 were included in the first-constituent frequency manipulation (mean first-constituent frequency was 16 words per million for the low-frequency condition and 511 word per million in the high-frequency condition) and 76 in the whole-word frequency manipulation (mean word frequency was 1.4 words per million for the low-frequency condition and 32 words per million for the high-frequency condition). Eight 15-letter words of the original word sets were excluded. Each target word appeared only once.

The target words were embedded in sentences with each target word appearing in a separate sentence. The target word never appeared as the first or last word on a text line; typically it was the third or fourth word in the sentence.1 The target sentences were mixed with filler sentences and were presented in two blocks.

2.4. Procedure

Prior to the experiment, the eyetracker was calibrated using a 9-point calibration grid that extended over the entire computer screen. Prior to each sentence, the calibration was checked by presenting a fixation point in a center-left position of the screen; if needed, calibration was automatically corrected, after which a sentence was presented to the right of the fixation point.

Participants were instructed to read the sentences for comprehension at their own pace. They were further told that periodically they would be asked to paraphrase the last sentence they had read to make sure that they attended to what they read. It was emphasized that the task was to comprehend, not to memorize the sentences. With a viewing distance of about 65 cm, one character space subtended approximately 0.5° of visual angle.

3. Results

Separate analyses of first-pass fixations were performed for short and long target words.2 Fixations shorter than 50 ms were excluded from the analyses. Five regions were delineated for long compounds and four regions for short compounds. First, a center region (C) at the physical center of each word was determined so that for short words two regions (C – 2, C – 1) of the same size were delineated toward the word’s beginning and one region was delineated toward the right (C + 1) of the word’s center (very few fixations landed there). An analogous procedure was done for long words in order to delineate three regions toward word beginning (C – 3, C – 2, C – 1) and one region to the right of the center region. This was done separately for each word length (7-letter words, 8-letter words, etc.), which means that the regions are not identical in size between the different word lengths (see Fig. 1, for examples). Note that we also computed the analyses using equal-sized word regions. The results were essentially the same, so they are not reported here.

We first analyzed the data using two independent factors, initial landing position and frequency (either whole-word or constituent frequency). However, as the Position × Frequency interaction remained non-significant for all eye movement measures, we pooled the data over the two frequency conditions.

3.1. Distribution of initial landing position

Before reporting the position-dependent eye fixation effects, we first present the data on the distribution of the initial landing position for the short and long compound words (see Fig. 2). The plots display typical initial landing position curves; the preferred landing position (Rayner, 1979) is in the word center (short words) or slightly left of it (long words).

3.2. Probability of refixation

Fig. 3 presents the refixation probability as a function of initial landing position for the long and short target words. For long compounds, the position effect (with four positions, C + 1 excluded) was highly significant ($F(3, 246) = 19.20$, $MSe = 0.038, p < .001$) and was both linear ($F(1, 82) = 20.27, p < .001$) and quadratic ($F(1, 82) = 28.01, p < .001$) in nature. The strong quadratic effect is due to the fact that the probability of refixation decreased notably for C (and C + 1, see Fig. 3), while the difference between the other regions was negligible. This is understandable given the length of the words (long words typically need a refixation to be identified).

For short compounds, there was a significant position effect ($F(3, 99) = 11.82, MSe = 0.060, p < .001$), that was both linear and cubic (linear: $F(1, 33) = 13.91, p < .001$; cubic: $F(1, 33) = 16.60, p < .001$). The cubic trend is due to the refixation probability being greater for C – 2 and C – 1 than for C and C + 1 (see Fig. 3).

3.3. Gaze duration

We then analyzed gaze durations (i.e., the summed fixation time spent on the target word prior to exiting it) as a function of the initial landing position, to examine whether we could replicate the Gaze Duration OVP effect for Finnish. Fig. 4 shows that indeed there is a downward trend in gaze duration as a function of initial fixation location for both long and short compounds. As most participants did not make any initial fixations on Region C + 1, we computed the analysis using four positions (C – 3, C – 2, C – 1, and C). This yielded a highly significant main effect of position for long compounds ($F(3, 246) = 10.70, MSe = 6529, p < .001$). Only the linear trend proved significant ($F(1, 82) = 23.03, p < .001$). When five positions were used with fewer participants ($N = 23$), the position effect was still significant ($F(4, 88) = 12.58, MSe = 3009, p < .001$). Now both the linear trend ($F(1, 22) = 24.20, p < .001$) and the quadratic trend ($F(1, 22) = 5.23, p < .05$) proved significant. The quadratic trend is due to the fact that, with less data and thus less reliable condition means, Regions C – 3 and C – 2 displayed gaze durations of about equal size (gaze duration is in fact slightly longer for C – 2 than C – 3).

For short compounds, the main effect of position (with four positions) was highly significant ($F(3, 99) = 13.11, MSe = 4145, p < .001$). Only the linear trend proved significant ($F(1, 33) = 50.15, p < .001$).

3.4. Testing the Fixation Duration Trade-off effect for two-fixation trials

We next examined the Fixation Duration Trade-off effect: When exactly two fixations are made on a word, a short initial fixation landing on a non-optimal spot is compensated by making a longer second fixation elsewhere in the word. The probability of reading

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1 In the long compound word set, in 32 sentences the target word was the second word in the sentence. In those sentences, the initial word was long, so that it at a rule attracted two fixations. In the short compound word set, the target word never appeared as the second word.

2 Note that in the original experiments frequency manipulation was always a within-participant variable. In the only study involving short compounds (Bertram & Hyönä, 2003), also word length was a within-participants variable.
the target word with exactly two fixations was 46% for the long compounds and 33% for the short compounds.

The analysis of the duration of first fixation demonstrated that the initial fixation varied as a function of its position (see Fig. 5). For short compounds (with three positions: C - 2, C - 1, C), there was a solid main effect of position (F(2, 38) = 7.95, MSe = 1136, p = .001), which was linear in nature (F(1, 19) = 12.53, p < .01). A similar pattern emerged for long compounds (four positions: C - 3, C - 2, C - 1, C); the main effect of position was highly significant (F(3, 90) = 13.14, MSe = 763, p < .001); only the linear trend proved significant (F(1, 30) = 48.09, p < .001). Note that Fig. 5 depicts a dip in fixation duration from Region C to C + 1, suggesting a quadratic trend. However, this trend could not be statistically tested due to only few participants having data for Region C + 1. Yet, the apparent quadratic trend is consistent with what has been found previously.

The data on the second fixation duration (when exactly two fixations were made) lent support to the trade-off hypothesis. The duration of second fixation showed a general downward trend from C to C as a function of the initial fixation position (see Fig. 6). For short compounds (with three positions: C - 2, C - 1, C), the main effect of position was significant (F(2, 38) = 12.05,
the main effect of position \((F(1, 19) = 24.87, p < .001)\). For long compounds (four positions: \(C - 3, C - 2, C - 1, C\)), there was a significant main effect of position \((F(3, 93) = 12.66, MSE = 766, p < .001)\), which proved to be linear in nature \((F(1, 31) = 23.56, p < .001)\), with a marginally significant cubic component \((F(1, 31) = 3.92, p < .06)\). The linear trend was also significant when positions \(C - 2, C - 1, C\), and \(C + 1\) were entered in the analysis \((F(1, 7) = 13.64, p < .01)\).

### 3.5. Single-fixation IOVP effect

The final set of analyses concerned the trials when a single fixation was made on the target word. The probability of reading the target word with a single fixation was 19% for the long compounds and 56% for the short compounds. An IOVP effect was observed; the single fixation was longest when positioned in the word center and shortest when positioned in the word beginning (see Fig. 7).

For short compounds, there were only eight participants who had data for all four word regions. Nevertheless, the main effect of position proved significant \((F(3, 21) = 9.65, MSE = 1085, p < .001)\); both the linear \((F(1, 7) = 12.08, p < .01)\) and the cubic component \((F(1, 7) = 11.42, p < .01)\) were significant, while the quadratic effect was marginally significant \((F(1, 7) = 4.70, p < .07)\). To examine these two components in more detail and more reliably (i.e., to have more participants contribute to the condition means), we computed two sets of analyses with three positions, one for positions \(C - 2, C - 1, C\), and another for positions \(C - 1, C\), and \(C + 1\). In the first analysis, the main effect of position \((F(2, 32) = 16.63, MSE = 1532, p < .001)\) was linear in nature \((F(1, 16) = 22.68, p < .001)\). In the latter analyses \((C - 1, C, C + 1)\), the main effect of position \((F(2, 26) = 7.87, MSE = 797, p < .01)\) was quadratic in nature \((F(1, 13) = 18.22, p < .001)\).

For long compounds, there was only one participant with a full data set for all five positions (and only seven participants with data for four positions). With three positions \((C - 2, C - 1, C, C + 1)\) participants), the linear trend of position proved significant \((F(1, 13) = 5.92, p = .03)\).

In the post hoc analyses we examined the eye behavior before and after a single fixation was made on the target word.

### 3.6. Eye behavior prior to making a single fixation on the target word

In the first set of post hoc analyses of the single-fixation trials we examined the probability of skipping over Word N - 1 as a function of the location of the single fixation on Word N. The probabilities of skipping Word N - 1 as a function of the location of the single fixation on Word N - 1 before a single fixation on the target word, as a function of its landing position, separately for long and short compound words.

![Fig. 6](image-url) Duration of second fixation (in ms) when exactly two fixations were made, as a function of initial landing position, separately for long and short compound words.

![Fig. 7](image-url) Single fixation duration as a function of its location, separately for long and short compound words.

![Fig. 8](image-url) Probability of skipping Word N - 1 before a single fixation on the target word, as a function of its landing position, separately for long and short compound words.

We next analyzed the probability of making a regression back to Word N - 1 as a function of the location of the single fixation on Word N. These data are shown in Fig. 9. For short compounds with four positions (19 participants), a highly reliable position effect \((F(3, 54) = 24.97, p < .001)\) was observed. Both the linear \((F(1, 18) = 43.99, p < .001)\) and the quadratic \((F(1, 18) = 8.66, p < .01)\) trends were significant. The results were similar for long compounds (eight participants, five positions); the main effect of position was significant \((F(4, 28) = 7.33, p < .001)\), reflecting a significant linear \((F(1, 7) = 17.79, p < .01)\) and a marginally significant quadratic \((F(1, 7) = 5.09, p = .06)\) trend. These data indicate that a regression to the previous word is much more regularly launched...
The means (in ms) were 190, 199, and 189 for C words (24 participants; three positions: C - 1, C, C + 1) and long (F(2, 46) = 4.57, \(M_S = 1256, p < .05\)) words (24 participants; three positions: C - 2, C - 1, C). For short words, the quadratic trend proved significant (F(1, 28) = 20.43, \(p < .001\)) and for long words the linear trend was significant (F(1, 23) = 9.80, \(p < .01\)).

Next, we analyzed the duration of fixation on Word N + 1 after a single fixation on Word N. Specifically, we examined whether the IOVP effect remains even after excluding the trials in which the single fixation was followed by a forward saccade to Word N + 1. As is evident from Fig. 10, the duration of single fixation continued to display an IOVP effect. The main effect of position proved significant for both short (\(F(2, 56) = 5.78, M_S = 1484, p < .01\); 29 participants, three positions: C - 1, C, C + 1) and long (\(F(2, 46) = 4.57, M_S = 1256, p < .05\)) words (24 participants; three positions: C - 2, C - 1, C). For short words, the quadratic trend proved significant (F(1, 28) = 20.43, \(p < .001\)) and for long words the linear trend was significant (F(1, 23) = 9.80, \(p < .01\)).

Finally, we examined the probability of making a regression back to Word N after a fixation on Word N + 1, as a function of the location of the single fixation on Word N. An immediate regression from Word N + 1 back to the target word was rarely made. In the data set, there were only 40 such trials; the frequency range of such regressions was 0–3 per participant. Most regressions from Word N + 1 were made after a single fixation at the center of Word N (24 out of 40; in the remaining cases the single fixation was positioned to the left of the word center).

4. Discussion

Previous eye movement research has established lawful relationships between locations and durations of fixations on words during reading. When a fixation lands near the word’s center, its duration is longer than when it is located toward the word beginning or end. It makes sense for the reader to stay fixating for a longer time on the word center, as it is the optimal spot for word recognition, because it maximizes the chances of having all or most letters of the word (depending on length) in the foveal region. Analogously, when the eyes land on a non-optimal spot for word recognition (word beginning or end), it makes sense to exit early the non-optimal spot and program a saccade to a more optimal location in the word.

It the present study, we observed evidence for such eye behavior during reading of Finnish compound words of variable length (7–14 letters). The probability of making a refixation in the target word was increased when the initial fixation landed in the word beginning, rather than in the word center. This has been named the Refixation OVP effect (Vitu et al., 2001). This effect translated also into an analogous effect in gaze duration (i.e., the summed fixation time spent on the word when it is first fixated), coined the Gaze Duration OVP effect. When exactly two fixations were made on the target words, we observed a trade-off in the durations of these two fixations (this pattern of results is known as the Fixation-Duration Trade-off effect): If the first fixation landed on a non-optimal spot (word beginning), it was short and it was compensated by a longer second fixation positioned elsewhere in the word. In contrast, if the first fixation landed on the word center, its duration was long and it was followed by a relatively short second fixation. Finally, we also replicated the single-fixation IOVP effect: When the single fixation fell at the word center it was longer than when it was positioned toward the word beginning (i.e., a non-optimal spot for word perception). In what follows, we first discuss the three OVP effects, followed by a discussion of the IOVP effect.

Previously, a Refixation OVP effect has been obtained in English (McConkie et al., 1989; Rayner et al., 1996; Vitu et al., 2001) and German (Nuthmann et al., 2005); the Gaze Duration OVP effect has been established for French (Vitu, O’Regan, & Mittau, 1990) and German (Nuthmann et al., 2005). However, it is noteworthy that in the French study the Gaze Duration OVP effect was observed during the recognition of isolated words but the effect was weaker in sentence reading. The Fixation Duration Trade-off effect has previously been observed in French for isolated words (O’Regan, 1992; O’Regan & Lévy-Schoen, 1987; O’Regan et al., 1984) the effect has been replicated in reading of German (Nuthmann et al., 2005) and English (McDonald et al., 2005; Vitu et al., 2001). The present study extended these three OVP effects to reading long words in Finnish – a language completely unrelated to English, French, or German. Thus, it can be fairly safely concluded that the effects generalize across structurally different alphabetic languages.

A Gaze Duration OVP effect has even been observed for the Japanese script (Sainio, Hyönä, Bingushi, & Bertram, 2007). However, the effect differs from the one obtained for alphabetic scripts in
two respects. First, the initial fixation typically lands in the word beginning, despite the fact that it is a non-optimal spot for word recognition even in Japanese (indexed by an increase in gaze duration). Second, no increase in gaze duration was observed for trials where the initial fixation was positioned in the word end. One possibility for accommodating these two somewhat contradictory findings in Japanese is in terms of the relative magnitude of parafoveal processing done prior to fixating the target word (see Sainio et al., for further details). A similar conclusion was reached by Yan, Kliegl, Richter, Nuthmann, and Shu (2010) for reading Chinese. They concluded that Chinese readers dynamically select the beginning or center of words as a saccade target depending on the failure or success with segmentation of parafoveal word boundaries. It is noteworthy that, similarly to Japanese, no processing penalty ensued by initially fixating the word end.

In the present study, the magnitude of the Refixation and Gaze Duration OVP effects was numerically clearly greater for long than short compound words. This was particularly the case for refixation. Duration OVP effects was numerically clearly greater for long than short compound words. This was particularly the case for refixations (see Fig. 2), for which the size of the landing position effect is noteworthy that, similarly to Japanese, no processing penalty ensued by initially fixating the word end.

In the present study, the magnitude of the Refixation and Gaze Duration OVP effects was numerically clearly greater for long than short compound words. This was particularly the case for refixations (see Fig. 2), for which the size of the landing position effect (i.e., the difference between the largest and smallest value) is nearly three times bigger for long than short words (in gaze duration, the effect is nearly doubled for long words). In the Introduction we envisioned two opposing predictions related to word length. According to the first alternative, OVP effects will be strengthened for long words, as initially fixating on a non-optimal spot in a long word has a more detrimental influence in word processing when several letters fall outside the fovea. The numerically stronger OVP effect for long than short words is in line with the visual acuity account, according to which these OVP effects reflect limitations of the foveal vision. According to the alternative hypothesis, as long compound words are identified piecemaly via their components (Bertram & Hyönä, 2003), initially fixating on the beginning of the word will facilitate identification of long compound words. However, as detailed below, we found no evidence in support of this alternative.

The finding that word (or constituent) frequency did not interact with initial landing position in the word lends support for the view that the OVP effects are not driven by ongoing lexical processing. A similar finding has been obtained for English (Rayner et al., 1996) and German (Nuthmann et al., 2005). Also the finding that an initial fixation on the word beginning was more rather than less detrimental for long than short compound words is inconsistent with the lexical account. This finding was evident in refixation probability and also in gaze duration, but not in single fixation or first fixation duration. If the OVP effects were lexically driven, it would have been less detrimental for word identification to initially fixate toward the beginning of a long word, as long compound words are processed piecemealy by first recognizing the left component, followed by the recognition of the second constituent and the whole compound word (Bertram & Hyönä, 2003). The lack of an interaction between frequency and initial landing position (see also Nuthmann et al., 2005; O’Regan & Lévy-Schoen, 1987; Vitu et al., 2007; Vitu et al., 2001, for additional evidence against frequency modulation of the OVP effect) is also partly consistent with O’Regan’s strategy-tactics theory (O’Regan, 1992; O’Regan & Lévy-Schoen, 1987). According to their theorizing, when a word is fixated twice and the initial fixation lands on a non-optimal spot, the duration of the initial fixation will not be influenced by lexical processing, indexed by the word frequency effect (neither will the probability of refixation be affected), whereas the duration of the second fixation positioned more optimally is affected by ongoing lexical processing. The former prediction is consistent with the present results, whereas the latter prediction is not.

The present study replicated the IOVP effect previously observed for single fixations made on the word during reading of French (Vitu et al., 2007), German (Kliegl et al., 2006; Nuthmann et al., 2005, 2007) and English (McDonald et al., 2005; Vitu et al., 2001). It is noteworthy that we obtained the IOVP effect even with relatively long words (7–14 characters). This is an intriguing finding, since for long words a single fixation positioned in the word beginning results in the word-final letters being outside the letter (and word) identification span, which in Finnish is estimated to be nine letters to the right of fixation (Häikiö, Bertram, Hyönä, & Niemi, 2009). A short fixtion in the word beginning not followed by a second fixation elsewhere in the word (cf. the Fixation Duration Trade-off effect) is unlikely to secure successful word identification. This in turn suggests that the single fixations located in the word beginning may be mishandled due to saccadic overshoot. This possibility was examined by post hoc analyses. These analyses revealed that the probability of skipping over Word N – 1 was significantly greater for trials for which the single fixation was located in the beginning than in the center of Word N. Related to this, the probability of immediately regressing back to Word N – 1 after a single fixation on Word N was significantly greater when the single fixation on Word N was located in the beginning than in the center of the word. This pattern of results is consistent with the view that the fixation falling on the beginning of Word N was in fact often intended to land on Word N – 1.

An explanation for the combination of skips and subsequent regressions is offered by Vitu, McConkie, and Zola (1998), Vitu and McConkie (2000) and Vitu (2005), who have reported data similar to our post hoc analyses. Their corpus studies demonstrate that an inter-word regression is more likely to occur to a word that was skipped to a non-skipped word. These and other data were interpreted to support the view that inter-word regressions are triggered in the service of word identification (i.e., the skipped word is not identified prior to skipping, which triggers a regression to it). This account may also explain the present results mentioned above.

The final observation made in the present study regarding the IOVP effect was that the effect remained after excluding the trials where the single fixation on Word N was followed by a regression to Word N – 1. In other words, the effect is not confined to cases where a possible saccadic overshoot is immediately corrected by a regression, but is also present for trials where the single fixation is followed by a progressive saccade to Word N + 1. It is noteworthy that the non-optimal viewing position was not compensated by lengthening the following fixation on Word N + 1, as is the case in the Fixation Duration Trade-off effect obtained for two skipped subsequent fixations made on the same word. Note also that the aforementioned account making recourse to incomplete word identification cannot readily explain the IOVP effect obtained in the absence of skipping of and regressing to Word N – 1.

How do the present data on the Single-Fixation IOVP effect relate to the existing accounts of the IOVP? As mentioned in the Introduction, there are three competing, but not necessarily mutually exclusive accounts of the effect. According to the mislocated fixation account, based on the SWIFT model of eye movement control in reading (Engbert, Nuthmann, Richter, & Kliegl, 2005), a subset of single fixations landing on either end of a word are mislocated fixations due to either a saccadic overshoot or undershoot of the word center, resulting from the assumed modulation of saccadic latency by the intended saccade length. Being on an unintended spot, their duration is short, followed by a saccade to a word that has the highest degree of lexical activation.3 It can be the currently fixated word (i.e., resulting in the Fixation Duration Trade-off Effect rather than Single Fixation IOVP effect), a previous

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3 Feng (2009) has provided evidence suggesting that saccadic error correction is not done using an efference copy, as assumed by the SWIFT model, but is instead triggered by the visual input.
word, or the following word. Finally, it should be noted that the mislocated fixation account does not claim that mislocated fixations are the only source of the IOVP effect.

The perceptual-economy account (Vitu et al., 2001, 2007) holds that the oculomotor system is programmed so that the more information the reader is anticipating to glean around the fixation position, the longer the fixation duration. Since most information relevant to word recognition can be extracted at the word center, the account predicts the longest fixation in a word to be at the center, regardless of whether it is followed by a second fixation or not (i.e., it is also offered as an explanation for the Fixation Duration Trade-off Effect). This is so for short words; with longer words, the longest fixations are assumed to be found at a position slightly left of the word center (Vitu et al., 2007). In order to assess the optimality of fixation locations the visual system only needs to estimate how far the eyes are located from a space separating the word from other words. The further away from the space the fixation is located, the longer its duration (see also Pollatsek, Reitman, & Rayner, 2006).

The split fovea account (McDonald et al., 2005) is based on the view that stimuli present at the right side of the fovea are projected to the left hemisphere, whereas stimuli in the left side of the fovea are projected to the right hemisphere. According to this account, prolonged fixations at the word center reflect the fact that the information content projected to the two sides of the fovea is similar in magnitude, which results in prolonged neural competition (a saccade may be triggered by either hemisphere) and subsequently in a longer fixation, in comparison to the case when the fixation lands on either end of the word, in which case competition will be soon over due to unbalanced competitors (see Vitu et al., 2007, for arguments against the model's ability to explain the IOVP effect under certain conditions).

A previous finding favoring the mislocated account over the perceptual-economy and the split-fovea accounts is that the IOVP effect is even stronger when scanning strings of z's than reading normal text (Nuthmann & Engbert, 2009; Nuthmann et al., 2007). The mislocated fixation account can explain the increased IOVP effect in mindless z-string reading, whereas the other two accounts predict smaller IOVP effects in z-string scanning (due to the to-be processed information being minimal) than in normal reading. On the other hand, Vitu et al. (2007) demonstrated IOVP effects in the absence of mislocated fixations arising from inaccurate saccade programming. Thus, even if accepted as a valid account, the mislocated fixation account cannot be the only explanation of the IOVP effect (and it is not offered as such).

Although we are not in the position to directly test the alternative accounts of the IOVP effect, it may be noted that the mislocated fixation account offers a viable mechanism that can account for the pattern of fixations appearing prior to and after a single fixation on a target word. However, this does not necessarily mean the other two accounts are faulty. Moreover, as the mislocated fixation account is stochastic in nature, a simulation would be needed to determine whether it can indeed account for the present data.

By running model simulations of eye behavior during reading of German sentences, Engbert, Nuthmann, and Kleigl (2007) have estimated that longer words are less likely to receive a mislocated fixation than shorter words (for example, only about 6% of 8-letter words are estimated to receive a mislocated fixation). Moreover, unintended skipping is estimated to constitute only about 10% of the mislocated fixations. The skipping estimate is considerably lower than what was observed in the present study for single fixations positioned at the word beginning (over 60%, see Fig. 7). It is also noteworthy that according to SWIFT failed skipings and unintended refixations constitute the most important saccadic error types (Engbert & Nuthmann, 2008). Failed skipings represent the most prominent type of mislocated fixations on short words, while unintended refixations typically fall on long words. These targeting errors result from the eyes' general tendency to undershoot the center of target words. The fact that our primary evidence in support of the mislocated fixation account stems from saccadic overshoots appears to be inconsistent with the model simulations. However, it is important to keep in mind that these observations cannot be by any means interpreted as a disconfirmation of the model, as the simulations were performed using a very different data set (e.g., the words were generally much shorter than in the present study).

In conclusion, the present Finnish study replicated previous studies conducted in French, German and English on the effects of the initial landing position on eye behavior during word perception in reading. Thus, the OVP and IOVP effects generalize across structurally different alphabetic scripts. Finally, the landing position effects appear at the prelexical stage of word processing.

References


