The Role of Hyphens at the Constituent Boundary in Compound Word Identification
Facilitative for Long, Detrimental for Short Compound Words

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Abstract. The current eye-movement study investigated whether a salient segmentation cue like the hyphen facilitates the identification of long and short compound words. The study was conducted in Finnish, where compound words exist in great abundance. The results showed that long hyphenated compounds (musiikki-ilta) are identified faster than concatenated ones (yllätystulos), but short hyphenated compounds (ilta-asu) are identified slower than their concatenated counterparts (kesäsa). This pattern of results is explained by the visual acuity principle (Bertram & Hyönä, 2003): A long compound word does not fully fit in the foveal area, where visual acuity is at its best. Therefore, its identification begins with the access of the initial constituent and this sequential processing is facilitated by the hyphen. However, a short compound word fits in the foveal area, and consequently the hyphen slows down processing by encouraging sequential processing in cases where it is possible to extract and use information of the second constituent as well.

Keywords: reading, eye movements, Finnish, compound words, word identification, morphological processing, segmentation, hyphen

When writing an e-mail to a friend to ask her to get in contact with you via cell phone, should you write in your e-mail message “cell phone,” “cellphone,” or perhaps “cell-phone?” The Associated Press recently announced (Freeman, 2011) it should be written as cellphone. Moreover, they decreed that e-mail should henceforth be written as email. The AP’s recommendations are stylistic in nature, so it is unlikely they have considered the implications of the written format of these compound words for the reader. In the present study we examined what consequences writing conventions may have on compound word identification during reading. We particularly focus on the role of the hyphen in compound word identification.

In English, there are three alternative ways to write a compound word comprising two constituents. It may be written in concatenated format as in backyard, in spaced format (i.e., as two separate words) as in front yard, or in hyphenated format (e.g., line-up). There are no clear rules dictating how English compound words should be written. However, certain word characteristics seem to affect in which format a compound word typically appears. For instance, frequent words tend to be written in concatenated format, long words tend to be written in spaced format (computer science), and words with double or triple identical letters around the constituent boundary are typically written in hyphenated format (e.g., sea-adder or still-life; Kuperman & Bertram, in press; Sepp, 2006).

In this study we investigated whether the printed format of compound words affects their recognition speed. There appears to be a trade-off between combining two components into a single visual unit versus visually marking the boundary between the two components. A benefit of the concatenated form is that the reader is cued to allocate attention to all letters simultaneously, allowing for quick activation of the compound word. Some theories hold that the whole-word representation of compound words is always activated via the constituents (Fiorentino & Poeppel, 2007; Taft & Nguyen-Hoan, 2010), while others claim that they are activated both via the constituents and via direct mapping of the letters onto a whole-word representation (Grainger & Ziegler, 2011; Pollatsek, Bertram, & Hyönä, 2011). Regardless of the theoretical position, when the compound word is sufficiently long, parallel processing of all letters ceases to be an option (Bertram & Hyönä, 2003). This is because the span of foveal vision is highly constrained, about two degrees of visual angle around the center of the fixation point. Thus, a relatively long compound word (gingerbread) extends beyond foveal vision, where visual...
acuity is at its best. Consequently, it is likely that its identification proceeds serially by first recognizing the first constituent (ginger) followed by the recognition of the second constituent (bread) and/or the whole word (Pollatsek, Hyöna, & Bertram, 2000).

Sequential processing of constituents in long compound words may become problematic when there is no clear cue signaling where one constituent ends and another begins. That is, when the constituent boundary is not visually marked (by a space or hyphen), the identification of the constituents may require additional effort in comparison to a situation where the boundary is clearly marked. Bertram, Pollatsek, and Hyöna (2004) showed that long Finnish compounds with clear segmentation cues are processed faster than compounds without such cues. As segmentation cues, they used infrequent bigrams around the morpheme boundary by making use of certain vowel properties of the Finnish language.

In English, the majority of existing compounds are in spaced format (see Kuperman & Bertram, in press). A potential problem in using the space as a segmentation cue is that with spaced compound words the reader cannot be always sure whether a constituent is part of a compound or whether it belongs to another phrase. Consider a sentence like “He saw the university teacher in front of the shop,” where the first constituent of the spaced compound (university) may be initially interpreted as the syntactic object of the preceding verb (i.e., He saw the university). In fact, Staub, Rayner, Pollatsek, Hyöna, and Majewski (2007) showed that spaced compound words are often misinterpreted in this way and therefore require reanalysis, which takes up additional time.

Juhasz, Inhoff, and Rayner (2005) found early facilitation in compound processing due to spacing (bookcase vs. book case), but later disruption in processing. They concluded that the space is a good segmentation cue in that it allows for fast recognition of the first constituent of the compound word, but at the same time it slows down the processing of the whole compound, presumably because it encourages sequential processing of constituents and/or introduces uncertainty about the grammatical status of the first constituent (whether it is a part of a compound word or an independent phrase).

A hyphen at the constituent boundary is an attractive alternative to the space, as it – similarly to concatenation – indicates that the two constituents belong together. At the same time, it saliently separates out the two meaning units. Thus, hyphenation in compounds may be a better alternative than spacing, which may – as described above – sometimes lead to misinterpretation, and better than concatenation, as it more clearly signals where the constituent boundary is located. A potential downside of both the hyphen and the space is that they may encourage readers to limit their visual attention predominantly to one visually separated constituent, even when they would be capable of simultaneously extracting and using information of the second constituent. This is more likely to be the case with short than long compounds, as in the former but not in the latter case the letters comprising the second constituent fall – already on the first fixation – into foveal vision.

In the present eye-movement study we examined how visual marking of the constituent boundary by a hyphen influences the reading of long and short compound words.1 The study was conducted in Finnish, where word compounding is highly productive, providing an ideal testbed to address this question. Moreover, Finnish spelling regulations prescribe that hyphens should be inserted in compounds, whose first constituent ends with the same vowel as the second constituent begins with (e.g., musiikki-ilta “music evening”). In our database comprising about 1.5 million word types, more than 50% are compound words and about 5% of these compounds (38940 in number) include one or more hyphens. Hyphens are needed in order to indicate the correct phonological form. That is, in Finnish double vowels without interruption by a hyphen represent long vowels and hence a word like musiikki-ilta would be pronounced differently than musiikkilta, the former containing five syllables and the latter only four. In other words, inclusion of the hyphen prevents from giving the reader a misleading phonological cue.

In Experiment 1, we pitted long (on average 12 characters) hyphenated compounds against long concatenated ones and in Experiment 2 we pitted short (on average eight characters) hyphenated compounds against short concatenated ones. We predict that hyphenation will yield processing benefits for long compounds that need to be recognized sequentially due to visual acuity reasons. In contrast, we predict that inserting a hyphen at the constituent boundary is detrimental to the recognition of short compound words, as the hyphen may encourage sequential processing in case where simultaneous constituent processing and with that rapid access to whole-word representations is a viable option.

Experiment 1

Method

Participants

Twenty-four Turku university students took part in the experiment. All were native speakers of Finnish.

Apparatus

Data were collected by an EyeLink 2 eyetracker manufactured by SR Research Ltd. The eyetracker is an infrared video-based tracking system combined with hyperacuity image processing. There are two cameras mounted on a headband, which sample pupil location and pupil size at

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1 Inhoff and Radach (2002) showed that the initial landing position shifts to the left when inserting hyphens into German compounds. However, they did not address the implications of hyphenation on compound processing times.
the rate of 500 Hz. The spatial accuracy is better than 0.5 degrees.

Materials

Twenty-two hyphenated compounds with the same vowel around the constituent boundary and twenty-two concatenated long Finnish compounds with different letters around the constituent boundary were selected as target words from a computerized newspaper corpus. The conditions were matched for whole-word, first and second constituent frequency, bigram frequency, word and constituent length, and initial and final trigram frequency. Table 1 lists the lexical-statistical properties of the target words in both experiments.

Each hyphenated compound was paired with a concatenated compound, and a sentence frame was constructed for the pair that was identical up to the word following the target word. To match for semantic plausibility of the target sentences, a rating study was conducted, in which six participants who did not participate in the experiments proper indicated whether there was a difference in naturalness between the paired sentences. If at least three out of six rated one sentence to be more natural than the other, a new sentence frame was constructed and retested with three participants. This was the case for five sentence pairs in Experiment 1 and four sentence pairs in Experiment 2. An example of a sentence pair is shown below (the target word is shown in bold).

| Table 1. Lexical-statistical properties of the long compounds in Experiment 1 and the short compounds in Experiment 2 |
|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|
|                                           | Long concatenated compounds (e.g., potilashuone) | Long hyphenated compounds (e.g., vaihto-ohjelma) | Short concatenated compounds (e.g., kesästä) |
| Mean 1st constituent frequency | 224.0 | 219.0 | 248.0 |
| Mean 2nd constituent frequency | 307.0 | 285.0 | 312.0 |
| Mean whole-word frequency | 1.3 | 1.2 | 1.2 |
| Mean 1st constituent length | 6.8 | 6.8 | 3.8 |
| Mean word length | 12.1 | 12.2 | 7.2 |
| Mean bigram frequency | 6.6 | 7.5 | 6.3 |

Notes: aAll values scaled to one million. bWord length in characters. cWhen the hyphen is counted as one character, the respective constituent and word lengths are 7.8 and 13.2 for the long and 4.9 and 8.3 for the short words. dScaled to one thousand.

Concatenated compound: Viime viikon yllätystulos oli ratkaiseva liigasssa säälimiselle. (Last week’s surprise result was decisive in consolidating a place in the league.)

Hyphenated compound: Viime viikon musiikki-ilta oli niin suosittu, että kuukauden päästä järjestetään samanlai- nen. (Last week’s music evening was so popular that next month a same kind of event will be organized.)

The sentences were presented in Courier one at a time and took up a maximum of one line of text; the critical word never appeared as the initial or final word. With a viewing distance of about 80 cm, one character space subtended approximately 0.35 degrees of visual angle. The 44 target sentences were mixed with 96 filler sentences. The sentences were presented in two blocks, so that the paired sentences never appeared in the same block. The order of the blocks was counterbalanced across participants, and within a block the order of sentences was randomized. The experimental blocks were preceded by eight practice sentences.

Procedure

Prior to the experiment, the eyetracker was calibrated using a 3-point calibration grid that extended over the horizontal middle axis of the computer screen. Prior to each sentence, the calibration was checked by presenting a fixation point in the 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 silently the sentences for comprehension and were asked to paraphrase approximately every seventh sentence.

Results and Discussion

In order to get insight into the time course of processing, we considered the following dependent measures for the target words: first fixation duration, gaze duration on the first constituent (subgazeC1), and gaze duration on the whole compound word. Let us assume that the word yllätystulos elicits four fixations (fixations 1–4 in Figure 1) during first-pass reading, before the word is exited to the right or left. Comparing the duration of the first fixation (the circle with “1” inside) on yllätystulos with that on musiikki-ilta allows us to assess whether the hyphen exerts an effect at a very early stage, since first fixation duration is the earliest possible durational measure on a word. SubgazeC1 includes all fixations on the first constituent, before the eye saccades away from it. For yllätystulos in Figure 1 subgazeC1 is the summed duration of fixations 1 and 2. This measure is

It is assessed by the self-designed software program WordMill of Laine and Virtanen (1999). Our database comprises 22.7 million word forms and 1.48 million word types. Almost 800,000 of the word types (53.1%) are compounds. The database contains all words from March 1994 to June 1996 of the second largest newspaper in the country (Turun Sanomat).
indicative of the segmentation process. That is, if the word is easily broken down into its constituents by quickly identifying the constituent boundary, the reader seldom needs to fixate on the first constituent for a second time. The less often a refixation is needed, the shorter subgazeC1. If the segmentation process proceeds more smoothly for hyphenated than for concatenated compounds, subgazeC1 should be shorter for musiikki-ilta than for yllätystulos. In addition to these earlier measures, we considered gaze duration, the time spent fixating on the word during first-pass reading, that is before exiting it to the left or right. In other words, gaze duration also incorporates fixations that reflect later stages of compound word processing (Figure 1, gaze duration is the summed duration of fixations 1–4). If integration of constituents is equally difficult for hyphenated as for concatenated compounds, we should observe that the size of the effect obtained for subgazeC1 is similar in gaze duration. We also assessed spillover effects, but both in Experiments 1 and 2 they turned out to be nonsignificant (all p’s > .10). The results on the target word are presented in Table 2. About 3.4% of the data was excluded before analyses due to blinks, skips, or fixations being shorter than 50 ms.

First Fixation Duration

There was no significant difference in this measure, t1,2 < 1.

SubgazeC1

There was a significant difference of 74 ms in favor of hyphenated compounds, t1(23) = 5.67, p < .001, ηp² = .58; t2(42) = 4.06, p = .001, ηp² = .28; min F(1, 65) = 11.32, p = .001. The difference can be led back to participants refixating the first constituent of concatenated compounds more often (1st constituent refixation probability, 0.45 vs. 0.29, t1(23) = 4.13, p < .001, ηp² = .43; t2(42) = 4.36, p < .001, ηp² = .31; min F(1, 59) = 8.57, p < .01.

Gaze Duration

The difference in gaze duration was highly significant and practically the same as in subgazeC1. Hyphenated compounds elicited on average 64 ms shorter gaze durations than concatenated compounds, t1(23) = 3.55, p < .01, ηp² = .35; t2(42) = 2.52, p < .02, ηp² = .13; min F(1, 65) = 4.22, p < .05.

The results indicate that the hyphen is indeed a good segmentation cue that facilitates the identification of the constituent boundary and the first constituent, and with that the identification of the whole compound word. Thus, Experiment 1 provides evidence for the view that hyphenation yields processing benefits for long compounds that need to be recognized sequentially due to visual acuity reasons. In addition, the finding that the processing advantage for hyphenated compounds was similar in size in subgazeC1 and gaze duration indicates that later integration of constituents is not hindered by hyphenation, unlike what was observed for inserting a space between constituents (Juhasz et al., 2005). The finding also suggests that a similar amount of visual information is extracted from the second constituent for both concatenated and hyphenated compounds.

Experiment 2

Experiment 2 tested our hypothesis asserting that an insertion of a hyphen at the constituent boundary is detrimental to the recognition of short, 7–8-letter compound words, as the hyphen will encourage sequential processing in cases where simultaneous constituent processing and with that rapid access to whole-word representation is a viable option.

Method

Participants

Twenty-four Turku university students took part in the experiment as part of a course requirement. All participants were native speakers of Finnish who did not participate in Experiment 1.

Table 2. First fixation duration (ms), subgazeC1 (ms), and gaze duration (ms) for long concatenated and hyphenated compounds (with standard deviations in parentheses) in Experiment 1

<table>
<thead>
<tr>
<th>Eye movement measure</th>
<th>Long concatenated compounds (e.g., potilashuone)</th>
<th>Long hyphenated compounds (e.g., vaihto-ohjelma)</th>
</tr>
</thead>
<tbody>
<tr>
<td>First fixation duration</td>
<td>M (SD)</td>
<td>M (SD)</td>
</tr>
<tr>
<td>SubgazeC1</td>
<td>382 (88)</td>
<td>308 (62)</td>
</tr>
<tr>
<td>Gaze duration</td>
<td>568 (124)</td>
<td>504 (105)</td>
</tr>
</tbody>
</table>
Apparatus and Procedure

The apparatus and procedure were the same as in Experiment 1.

Materials

Twenty short, 7–8-letter hyphenated and twenty short concatenated Finnish compounds were selected as target words. In order to allow for a direct comparison with Experiment 1, we (a) selected the target words in such a way that their lexical-statistical properties were matched with those of the target words in Experiment 1 (see Table 1); (b) constructed and normed sentences in the same way as in Experiment 1; (c) included the same 8 practice sentences and 96 filler sentences as in Experiment 1.

Results and Discussion

Means and standard deviations are presented in Table 3. About 2% of the data was excluded before analyses due to blinks, track losses, skips, or fixations being shorter than 50 ms.

First Fixation Duration

First fixation duration was shorter for hyphenated than concatenated compounds, $t(23) = 5.41, p < .001, \eta^2_p = .56$; $t(38) = 5.41, p < .001, \eta^2_p = .43$; min $F(1, 57) = 13.21, p < .001$.

SubgazeC1

There was a difference of 26 ms in favor of hyphenated compounds, which was marginally significant in the participant and item analyses, $t(23) = 1.86, p = .08, \eta^2_p = .13$; $t(38) = 1.77, p = .09, \eta^2_p = .08$; min $F(1, 65) = 1.65, p = .21$.

Gaze Duration

The difference in gaze duration was significant in the participant and item analyses, $t(23) = 3.68, p < .001, \eta^2_p = .37$; $t(38) = 2.31, p = .03, \eta^2_p = .12$; min $F(1, 58) = 3.53, p = .065$. However, unlike in Experiment 1 concatenated compounds elicited significantly shorter gaze durations than hyphenated compounds.

Taken together, the results of Experiment 2 suggest that the identification of short compound words is disrupted by the presence of a hyphen at the constituent boundary, presumably due to encouraging sequential processing in case where simultaneous constituent processing and with that rapid access to whole-word representation is a viable option.

Table 3. First fixation duration (ms), subgazeC1 (ms), and gaze duration (ms) for short concatenated and hyphenated compounds (with standard deviations in parentheses) in Experiment 2

<table>
<thead>
<tr>
<th>Eye movement measure</th>
<th>Short concatenated compounds (e.g., kesäsaari)</th>
<th>Short hyphenated compounds (e.g., peli-ilma)</th>
</tr>
</thead>
<tbody>
<tr>
<td>First fixation duration</td>
<td>276 (45)</td>
<td>239 (32)</td>
</tr>
<tr>
<td>SubgazeC1</td>
<td>306 (71)</td>
<td>290 (62)</td>
</tr>
<tr>
<td>Gaze duration</td>
<td>376 (103)</td>
<td>419 (93)</td>
</tr>
</tbody>
</table>

General Discussion

The present study examined the role a hyphen may have during printed word recognition. In written English a hyphen may appear at the boundary of two-constituent compounds (e.g., line-up) signaling that the two morphological components form a single meaning unit. At the same time, it visually demarcates the two meaning components from each other. English compound words also appear in spaced (e.g., rush hour) or unspaced (e.g., backyard) format. Spaced compounds differ from hyphenated ones in that the tight link between the two meaning units is not visually marked, which may disrupt their reading (Juhasz et al., 2005; Staub et al., 2007). Concatenated compounds share with the hyphenated ones the feature that the morphological constituents are visually unified. On the other hand, the constituent boundary may be obscured, for instance, when bigrams around the constituent boundary frequently occur within one and the same lexeme (e.g., lampshade), which may lead to disruption in processing (see Bertram et al., 2004; Lemhöfer, Koester, & Schreuder, 2011); in these kinds of occasions a segmentation cue like the hyphen may be useful. All in all, the hyphen appears as a good writing device that may benefit word identification during reading.

The present study conducted in Finnish demonstrated that the hyphen indeed helps in the identification of two-constituent compounds, but only when they are long. Hyphenated short compounds elicited actually longer gaze durations than concatenated ones. The discrepancy in the gaze duration results of Experiment 1 and 2 is confirmed by a significant interaction between hyphenation and experiment in a combined analysis of the two experiments, $F_1(1, 46) = 24.90, p < .001, \eta^2_p = .35$; $F_2(1, 80) = 10.78, p < .01, \eta^2_p = .12$.

This pattern of results is readily explained by the visual acuity principle put forth by Bertram and Hyöna (2003). According to this principle, readers make use of the first constituent simply because they initially do not have enough letter information available on the latter part of the word. Thus, the identification is initiated with access of the first constituent. In case of long hyphenated compounds, access to the initial constituent is helped by the hyphen, as it visually demarcates the first from the second constituent. However, the identification of short hyphenated compounds...
is slowed down, as the hyphen encourages sequential processing in case where simultaneous constituent processing is viable. This is in line with recent full decomposition accounts (Fiorentino & Poeppel, 2007; Taft & Nguyen-Hoan, 2010), which posit that access to the first and second constituent is required before access to the whole word can be achieved. Thus according to this account the slower identification of short hyphenated compounds would be caused by delayed access to the second constituent in comparison to their concatenated counterparts. Hyphenated short compounds would also be processed more slowly than concatenated ones, if they were accessed directly by their whole-word representations. This is a possibility offered by dual-route accounts in case the compound is short and sufficiently frequent (Bertram, Schrueder, & Baayen, 2000; Grainger & Ziegler, 2011; Pollatsek et al., 2011). More specifically, initially ignoring second constituent information – as can be assumed for hyphenated compounds – would delay direct access to the whole-word representation and thereby slow down compound processing. Note that the results are not in line with older decomposition models which hold that access to the whole word is not mediated via the second constituent but by access to the first constituent only (see Taft & Forster, 1976). If this were the case, hyphenated short compounds should have been processed faster than concatenated ones, as first constituent identification should be easier when the constituent boundary is clearly signaled.

Possible Benefits of Hyphenation in Compound Spelling

It may be the case that hyphenation in complex words is even more beneficial for less skilled than skilled readers, a claim supported by the study of Harley and O'Mara (2006). They found that their phonological dyslectic patient JD read aloud morphologically complex words like needless and paranormal very well once hyphens demarcating morpheme boundary were included (need-less, para-normal), but not when they were written in concatenated format. JD was not able to read any of the 20 concatenated words aloud, whereas their hyphenated counterparts were read correctly in 85% of the cases. Morphologically structured nonwords including hyphenation (para-move, need-ly) were all read correctly, whereas JD was unable to read any of them in concatenated format (paramove, needly).

Häikio, Bertram, and Hyönä (2011) found that short 7–8-letter hyphenated compounds were read slower than short concatenated ones by proficient Finnish elementary school readers (2nd, 4th, and 6th graders), but less proficient 2nd graders did benefit from the hyphen at the constituent boundary. Häikio et al. argued that the perceptual span of young and less proficient readers is smaller than that of mature readers (Häikio, Bertram, Hyönä, & Niemi, 2009; Rayner, 1986), due to which they will not be able to extract all letter information of 8-letter words within a single fixation. Consequently, compound identification is initiated with access of the first constituent and this is facilitated by the hyphen, similar to long compound identification for more skillful readers. Similarly, Lernhofer et al. (2011) showed that both native and nonnative speakers benefitted from a segmentation cue (an infrequent bigram around the constituent boundary) in processing long compounds, but only the less proficient nonnative speakers benefitted from such cue in short compound processing. Bertram, Kuperman, Baayen, and Hyönä (2011) showed that even illegally inserted hyphens (i.e., hyphens inserted against spelling regulations) may facilitate compound processing. They found that conventionally concatenated triconstituent Finnish compounds (jalkapallo-liitto “football association”) were processed faster when a hyphen was inserted at the major constituent boundary (jalkapallo-liitto).

Staub et al. (2007) found that in processing long (11–17 letters) spaced compounds, the first constituent is typically misanalyzed as the head of a noun phrase. This indicates that the space introduces ambiguity with respect to the role of the first constituent. Our study shows that the hyphen does not introduce this kind of ambiguity. Specifically, if the first constituent would have been initially misanalyzed as the head of the noun phrase in long compounds, one should have seen a processing disadvantage in later measures for hyphenated compounds in comparison to concatenated compounds. Since this was not the case, one may conclude that – unlike the space – the hyphen in biconstituental compounds indicates that the first constituent is a modifier of the second constituent and that the two constituents are to be unified. The notion that the hyphen allows for smoother integration of morphological constituents than the space offers interesting practical implications. It, for instance, predicts that readers of English would benefit from replacing spaces with hyphens (rush-hour instead of rush hour). In that light it may seem curious that some 16,000 hyphenated words were eliminated from the newest edition of the Shorter Oxford English dictionary. From a processing point of view it at least seems that a hyphen at the constituent boundary is more beneficial to compound reading than a space at the constituent boundary.

The benefits of hyphenation are clearest in case of long compounds. The current study showed that long hyphenated compounds are processed faster than equivalent concatenated ones. For shorter compounds an opposite pattern was observed. On the basis of these findings, we could argue that longer compounds should be hyphenated, whereas shorter ones should be concatenated. Thus from this perspective, e-mail should be written as email, but gingerbread as ginger-bread.

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