Preview benefit in English spaced compounds

Citation for published version:
Cutter, MG, Drieghe, D & Liversedge, SP 2014, 'Preview benefit in English spaced compounds', *Journal of Experimental Psychology: Learning, Memory, and Cognition*, vol. 40, no. 6, pp. 1778-1786. https://doi.org/10.1037/xlm0000013

Digital Object Identifier (DOI):
10.1037/xlm0000013

Published In:
Journal of Experimental Psychology: Learning, Memory, and Cognition

Preview Benefit in English Spaced Compounds

Michael G. Cutter, Denis Drieghe, and Simon P. Liversedge

University of Southampton

Author Note

Michael G. Cutter, Denis Drieghe, and Simon P. Liversedge, School of Psychology, University of Southampton, Southampton, England.

The Authors thank Barbara Juhasz, Sarah White, and an anonymous reviewer for their helpful comments on an earlier version of this article.

Correspondence regarding this article should be addressed to Michael G. Cutter, School of Psychology, Shackleton Building, University of Southampton, Highfield Campus, Southampton SO17 1BJ. E-mail: M.G.Cutter@soton.ac.uk.

Word count: 5,866

Abstract

In an eye tracking experiment during reading we examined whether preview benefit could be observed from two words to the right of the currently fixated word if that word was the second constituent of a spaced compound. The boundary paradigm (Rayner, 1975) was used to orthogonally manipulate whether participants saw an identity or non-word preview of the first (e.g. *teddy*) and second constituent (e.g. *bear*) of a spaced compound located immediately beyond the boundary, respectively words *n*+1 and *n*+2. Linear mixed-effects models revealed that participants gained an *n*+2 preview benefit, such that they spent less time fixated on word *n*+1 when given an identity preview of word *n*+2. However, this effect was only observed if there was also an identity preview of word *n*+1. Our findings suggest that the two constituent words of spaced compounds are processed as part of a larger lexical unit during natural reading.

Keywords: parafoveal processing, multi-word units, spaced compounds, eye movements, preview benefit

A well-established finding in research on eye movements during reading is that lexical processing is a primary influence on when to move the eyes (Liversedge & Findlay, 2000; Rayner, 1998; Rayner, Liversedge, White, & Vergilino-Perez, 2003). This is an important assumption of major current models of eye movement control such as E-Z Reader (Reichle, Rayner, & Pollatsek, 2003) and SWIFT (Schad & Engbert, 2012). An assumption of these models that is considerably more controversial is whether words are lexically processed in a serial or parallel fashion during sentence reading. According to E-Z Reader words are lexically processed one at a time in serial order, with processing not beginning on subsequent words until the prior words have been fully identified. In contrast to this, SWIFT proposes that multiple words around the point of fixation are lexically processed simultaneously. On the surface it might seem obvious that the basic lexical unit in English is a word as defined by spaces on either side. However, as we will argue in this paper, this is not necessarily the case, and given the controversy it is essential to establish what can form a lexical unit as this will have direct implications on whether lexical processing during reading occurs in a serial versus parallel fashion.

The question of whether more than one word is lexically processed simultaneously is closely related with how models assume parafoveal information is being processed. Parafoveal processing has mainly been investigated using the boundary paradigm (Rayner, 1975). In this paradigm the preview of a target word is manipulated to be correct or incorrect until the point of fixation crosses an invisible boundary preceding the preview. At this point the preview is replaced with the target word. Reduced fixation times on a word observed after a correct compared to an incorrect preview is known as *preview benefit.* Preview benefit is reliably obtained from one word to the right of fixation (word *n*+1; see Schotter, Angele, & Rayner, 2012), which is predicted by both models. Within SWIFT word *n*+1 is processed at the same time as word *n*. Within E-Z Reader processing of word *n* is completed and the processing of word *n*+1 begins before a saccade is made to word *n*+1. As such, preview benefit effects on word *n*+1 are not controversial.

A considerably more contentious issue is whether preview benefit is obtained from word *n*+2. Reliably gaining a preview benefit this far into the parafovea would be indicative of word *n*+2 being processed simultaneously with preceding words, since ordinarily processing should not begin on word *n*+2 before a saccade is made to word *n*+1. The exception would be when word *n*+1 is very easy to process, allowing it to be completely identified in the parafovea, which would cause the saccade aimed at word *n*+1 to be reprogrammed to word *n*+2, and would result in a short amount of time when attention is on word *n*+2, even though the eyes are still on word *n*. Thus, the false preview of word *n*+2 should not generally be processed often enough for it to have substantial (and reliable) effects upon reading. In contrast SWIFT predicts that word *n*+2 is processed during fixations on word *n* as long as it falls in the perceptual span. The perceptual span in SWIFT is determined by the processing difficulty of the foveal word, and as such, when foveal processing progresses unhindered, SWIFT predicts that *n*+2 preview effects will occur quite often. However, effects of word *n*+2 have only been shown when word *n*+1 was three letters long and highly frequent (Angele & Rayner, 2011; Kliegl, Risse, & Laubrock, 2007; Radach, Inhoff, Glover & Vorstius, 2013), not when it was longer (Angele, Slattery, Yang, Kliegl, & Rayner, 2008; Rayner, Juhasz, & Brown, 2007). Furthermore, the effect has typically been observed during fixations on word *n*+1 rather than *n*+2. Proponents of parallel processing claim that the reason for the effect being restricted to such cases is that a longer word *n*+1 pushes word *n*+2 too far out of the perceptual span. In contrast, advocates of a serial account claim that it is due to word *n*+1 being easily identified because it is so frequent whilst the eyes remain fixated on word *n*. One goal of the current study is to investigate whether an *n*+2 preview benefit can be found in instances where word *n+1* is not as short and highly frequent compared to previous observations of *n+2* preview effects. More specifically, we will examine *n*+2 preview effects when word *n*+2 forms part of a larger linguistic, and possibly lexical, unit with word *n*+1. Were this to be found it would indicate that the constraint on *n*+2 preview benefit is linguistic rather than perceptual.

As mentioned, the idea that the basic lexical unit in English is a word as defined by spaces on either side seems almost trivial, but this is not necessarily the case. Several theories of language posit that the lexicon may contain multi-word units (MWUs). For example, Bybee's usage-based theory of grammar (2006) proposes that cognitive representations of language are based on experiences with it, and as such commonly occurring MWUs will be lexicalised alongside individual words. Even theories with a distinction between lexical units and the grammar used to build these into sentences allow for the existence of MWUs, such as the Words-and-Rules theory (Pinker, 1999). In this theory the lexicon is comprised of listemes, which are any linguistic units that have to be memorised since they cannot be generated by rules, including MWUs. Thus, while these theories take differing views regarding the representation of language, they both allow for certain MWUs to be lexicalised. Research has shown that MWUs are processed more quickly than non-formulaic language (see Conklin & Schmitt, 2012), suggesting that MWUs may indeed be stored in the lexicon. However, thus far little research has investigated whether MWUs are treated similarly to single words during natural reading.

In the current study a spaced compound is considered to be two frequently co-occurring words which refer to a single concept (e.g *teddy bear*). Given their close relation such MWUs may have a unified lexical entry. That is to say, as well as the lexicon containing separate entries for the words *teddy* and *bear* it may also contain one for *teddy bear*. This possibility is consistent with theories explaining how unspaced compounds (e.g. blackbird) are processed. In dual-route (Pollatsek, Hyönä, & Bertram, 2000) and multiple-route

(Kuperman, Schreuder, Bertram & Baayen, 2010) models of compound processing, it is posited that compounds are processed via both a compositional route, in which each constituent is identified separately and then combined to form the compound, and a direct lookup route which accesses a unified lexical entry for the whole compound. Given that the only difference between spaced and unspaced compounds is whether the constituents are spatially separated it is possible that they are processed similarly. Thus, spaced compounds may also have unified lexical entries, which are accessed via a direct-lookup route. If unspaced and spaced compounds are identified as single lexical units, then their constituent lexemes should be processed in parallel.

Several studies have investigated whether the constituents of unspaced compounds are processed in serial or parallel, by using the boundary paradigm. Drieghe, Pollatsek, Juhasz, and Rayner (2010) presented invalid previews of the second half of monomorphemic words (e.g. *fountaom* as a preview of *fountain*) and unspaced compounds (e.g. *bathroan* as a preview of *bathroom*) until a boundary in the centre of the word was crossed. Although they observed substantial preview benefits for both types of words, the manipulation only led to significant disruption prior to the eyes crossing the boundary (a parafoveal-on-foveal effect; see Drieghe, 2011) in the case of monomorphemic words. The invalid information at the end of an unspaced compound's second constituent failed to disrupt processing of the first constituent, suggesting that each constituent was processed serially, rather than in parallel.

In contrast, Häikiö, Bertram, and Hyönä (2010) found evidence that the constituent lexemes of unspaced compounds are sometimes processed in parallel. These researchers conducted a boundary study in which an invalid preview of an unspaced Finnish compound's second constituent was presented prior to the eyes moving onto it. In their analysis Häikiö et al. divided their stimuli on the basis of whether the compound was high or low-frequency. Increased fixation durations were observed upon the first constituent when participants were given an invalid preview of the second constituent, but only for the high-frequency compounds. Häikiö et al. argued that this demonstrated that the constituent lexemes of high-frequency compounds were processed in parallel because high-frequency compounds were more likely to be identified via the direct lookup of a unified lexical entry. In contrast, Häikiö et al. suggest that direct lookup processing is less efficient for low than high frequency words, and for this reason, a low frequency compound word is more likely to be identified through the serial processing of its constituent lexemes via a compositional process. Thus, based on Drieghe et al. and Häikiö et al., it appears that the constituents of an unspaced compound can be processed serially or in parallel, depending upon whether a compositional or direct lookup route to identification is more efficient.

Juhasz, Pollatsek, Hyönä, Drieghe, and Rayner (2009) conducted a study using the same boundary manipulation as Drieghe et al. (2010), within spaced compounds. It was found that the preview benefit for the second constituent of a spaced compound was larger than had been observed in prior studies presenting non-compound words with the same types of preview. One possible explanation for this is that the spaced compounds were processed as single lexical units, and as such both constituents were being processed simultaneously. However, not all of Juhasz et al.'s findings were consistent with this explanation. For example, they also observed a level of preview benefit within novel adjective-noun pairs similar to the spaced compound words. Since novel adjective-noun pairs rarely co-occur, then there should not be a unified lexical entry within the mental lexicon corresponding to them. Given this, Juhasz et al. proposed that the second constituents in both adjective-noun pairs and spaced compounds are highly syntactically predictable, thus allowing them to be processed more efficiently in the parafovea. Whilst this alternative explanation may, or may not be correct, for present purposes, our primary focus concerns the possibility that the spaced compounds were processed as single lexical units.

In the current study we positioned the boundary before the first (*n*+1) constituent of a spaced compound, comprised of words *n*+1 and *n*+2. The preview of each constituent was manipulated orthogonally to be either an identity preview, or a non-word (see Figure 1). When a saccade crossed the boundary the entirety of the spaced compound was displayed correctly. Importantly, word *n*+1 in the current study was, on average, 5.65 characters long and of low frequency (see Table 1), as distinct from the shorter and high frequency words that have been used in other studies. Thus, any effect of the *n*+2 preview might suggest that the two constituent words of spaced compounds are processed as part of a single lexical unit. Furthermore, it would demonstrate that the limiting factor on *n*+2 preview benefit is linguistic rather than perceptual.

We hypothesised that if spaced compounds are processed as single lexical units there should be an *n*+1 preview benefit, and an interaction between the previews of each word, such that there should be an *n*+2 preview benefit only when there is a correct preview of word *n*+1. We reasoned that the first constituent must be present to indicate the compound nature of words *n*+1 and *n*+2. In this way, word *n*+1 licences the processing of the whole of the spaced compound through a direct-lookup route.

Method

Participants

44 native English speakers with normal or corrected to normal vision participated. An additional 17 participants were tested but removed from the analysis due to them noticing over three display changes.[1] Participants were rewarded with course credits or £4.50.

Apparatus

Participants' eye movements were tracked using an SR Research Eyelink 1000 system with a sample rate of 1000 hertz. Only movements of the right eye were recorded, although viewing was binocular. Sentences were displayed in black on a grey background, on a single line of a ViewSonic P227f 20 inch CRT monitor, running at a refresh rate of 75 hertz.[2] Viewing distance was 70cm and at this distance 1° of visual angle was occupied by 3.2 characters of monospaced Courier font.

Materials and Design

Forty spaced compounds with a mean transitional probability of 0.42 in the British National Corpus were selected (see Table 1). This means that the first constituent appeared as part of the spaced compound 42% of the time within the corpus. These spaced compounds were positioned at least two words from the end of the sentence and were embedded in sentence frames that provided fairly predictive contexts (see Appendix). This was done to make the compounds as easy as possible to process, thus maximising the chances of the spaced compounds being processed while still in the parafovea. A sample item, under the different preview conditions, is shown in Figure 1. A cloze task showed that the whole compound was 33% predictable given the sentence up to and including the pre-target word (e.g. *fluffy* in Figure 1), and that the second constituent was 97% predictable given the sentence up to and including the first constituent (e.g. *teddy* in Figure 1). Thus, it can be seen that the second constituent of the spaced compounds was highly predictable, with the majority of the predictability deriving from the first constituent.

Using the boundary paradigm (Rayner, 1975) the previews of the first (*n*+1) and second (*n*+2) constituent were orthogonally manipulated to be either an identity preview or a non-word. Hence, the current study used a 2 (*n*+1 preview: Identity vs. Non-word) X 2(*n*+2 preview: Identity vs. Non-word) design. The non-word previews were generated using the same algorithm as Kliegl et al. (2007), which replaced the words with randomly chosen letters, but preserved word shape.

Procedure

Upon arrival participants were presented with an information sheet and consent form. They were seated in front of the eye tracker and a head rest was used for stabilisation. Participants were calibrated using a three point horizontal calibration grid, with an acceptance criterion of an average error below 0.33 degrees.

Each trial consisted of a drift check in the middle of the screen followed by a gaze-contingent fixation cross the size of a single character in the position of the first character. If the cross did not trigger or the drift check indicated more than 0.33 degrees of error then the participant was recalibrated. Furthermore, the participant was re-calibrated at regular intervals. When the cross triggered, the sentence appeared. Participants were instructed to read for comprehension, and press a button to move on. There were eight practice sentences. The forty experimental items were mixed in with 69 filler items, 45 of which were part of another gaze-contingent study. On one third of the trials participants were shown a yes/no comprehension question. Responses were made using a game controller. Across all participants 96% of the questions were answered correctly. The experiment took approximately 30 minutes.

Results

To analyse the data linear mixed-effects models were constructed using the lme4 package (Bates, Maechler, & Bolker, 2012) in R (2013). This type of analysis retains statistical power to a greater extent than ANOVAs in unbalanced designs (see Baayen, 2008), and so is ideal for analysing boundary studies in which trials are often excluded due to early triggers and late display changes. Each preview was treated as a fixed factor with the non-word previews as the baseline, and an interaction term was included. Subjects and items were treated as crossed random factors. Furthermore, two contrasts were programmed to test for *n*+2 preview effects at each level of the *n*+1 preview. The first contrast compared the conditions in which *n*+1 was correct (e.g. *teddy hocu* vs. *teddy bear*), and the second contrast compared the conditions in which the *n*+1 preview was a non-word (e.g. *fohbg hocu* vs. *fohbg bear*).

Trials in which the boundary change happened early or participants blinked in a critical region were excluded. Furthermore, trials in which the boundary change completed more than 10ms after fixation onset were excluded, in accordance with Slattery, Angele, and Rayner (2011). These criteria were employed due to a large proportion of late changes (26% of trials). Furthermore, analyses were only conducted on trials where the pre-target word was fixated, in order to ensure that the previews had been seen as words *n*+1 and *n*+2. Altogether these exclusions account for 44% of the data.

Analyses were carried out on words *n* (the pre-boundary word), *n*+1 (the first constituent), *n*+2 (the second constituent), and the whole compound, whereby *n*+1 and *n*+2 constituted a single region. For each interest area five first-pass measures were computed and reading times on a target word were included in the analyses only when participants fixated this word prior to fixating a subsequent word. The first pass measures were first fixation duration (FFD; the duration of the first fixation in a region), gaze duration (GD; the total time between first fixating a region and making a saccade to another region), go-past time (GP; the total time between first fixating a region and making a progressive saccade beyond it), single fixation duration (SFD; the duration of a fixation when it is the only one made on a word), and skipping rate (the proportion of times when a word is not fixated during first pass reading). The means and standard deviations are shown in Table 2. The beta values from the models are displayed in Table 3. In the case of a significant interaction the beta values from the contrasts are also displayed. The fixation time analyses were carried out on log-transformed data to increase normality. The skipping data were analysed using logistic models due to the binary nature of the variable.

Word *n*

There were no significant differences between conditions on word *n*.

Word *n*+1

There was a significant effect of *n*+1 preview type in all measures, such that fixation times were shorter on word *n*+1 when participants had received an identity preview rather than a non-word preview, thus replicating Rayner (1975). More interestingly, there was an interaction between the two previews across all fixation time measures. The planned contrasts showed that in the case of all measures this was due to a significant *n*+2 preview benefit when *n*+1 was available but not when *n*+1 was unavailable. The one exception to this was in FFD, where there was a significant main effect of the *n*+2 preview type in both contrasts. The effects in both contrasts went in opposite directions depending upon the *n*+1 preview, such that FFDs on word *n+1* were shorter for an identity *n*+2 preview when *n*+1 was an identity preview but longer when word *n*+1 was a non-word preview. This effect disappeared in later measures. We suspect this pattern to be due to an increased number of second fixations when the whole compound was disrupted (n=55) than when only word n+1 was disrupted (n=38), given that first fixations tend to be shorter when there is a second fixation (Rayner, Sereno, & Raney, 1996).

Finally, there was a marginal interaction on skipping probabilities, with a significant *n*+2 effect such that an invalid *n*+2 preview led to increased skipping of *n*+1 when *n*+1 was available, but not when *n*+1 was unavailable. This effect suggests that the disrupted *n*+2 attracted attention, but only when word *n*+1 was undisrupted.

In summary, we found both an *n*+1 preview benefit and strong evidence for an *n*+2 preview benefit when the preview of the first constituent was correct.[3]

Word *n*+2

There were no significant effects in this region.

Whole compound

FFD was not examined in this region since it would mainly consist of the same data as for word *n*+1. While there was a significant effect of the *n*+1 preview across all fixation time measures, the effects of the *n*+2 preview and the interaction failed to reach significance in any measure.

Discussion

The current study tested whether *n*+2 preview effects could be observed when *n*+1 and *n*+2 were constituents of a spaced compound. The existence of *n*+2 preview benefit has been controversial with findings limited to experiments using a short and highly frequent word *n*+1. The current experiment demonstrates reliable and sizeable *n*+2 preview effects when *n*+1 and *n*+2 constitute a spaced compound. Because *n*+1 was longer and lower frequency than in previous experiments showing *n*+2 preview effects, this experiment convincingly demonstrates that previous failures to find *n*+2 effects were not necessarily due to *n*+2 being too far into the parafovea. It appears that when lexical processing of word *n*+1 licenses parafoveal processing of word *n*+2, a parafoveal preview benefit of word *n*+2 can be observed.

It was hypothesised that if spaced compounds are processed as lexical units then an interaction would be observed, such that there would be an *n*+2 preview benefit, but only when the first constituent of the spaced compound was available. This pattern of effects is exactly what was found in fixation times on word *n*+1. This preview benefit was 16ms in first fixation duration, 21ms in single fixation durations, and 27ms in gaze duration and go-past time. This suggests that processing of the second constituent of the spaced compound occurred while it was two words to the right of fixation, but only if this was licensed by the first constituent indicating the compound nature of the stimuli. It is our contention that this is due to the two words having a unified lexical entry, which is identified as a single unit through a direct lookup route after an initial period of compositional processing.

A full specification of how processing may be extended further into the parafovea due to multiple words forming a single lexical unit is beyond the scope of the current article. However, one way in which we envision this occurring is through feed-down activation in the context of an interactive-activation framework (McClelland & Rumelheart, 1981). In this approach processing would begin on the first constituent of a spaced compound in the parafovea, causing excitation of the lexical entries for both the individual constituent, and the spaced compound it is a part of. Both these lexical entries would become activated and then feed activation back down to the letter level of the lexical processing system. The activation that was fed down from the lexical entry of the spaced compound would activate letters associated with both the first and the second lexeme of the compound. This, along with orthographic information about the second lexeme extracted from the parafovea, would boost the activation of these letters leading to facilitated identification of the entry associated with the spaced compound at the word level. Future work involving both formal modelling and further empirical investigation of lexical identification of spaced compounds is required to fully develop and evaluate this explanation.

The fact that the *n*+2 preview effect appeared during fixations on word *n*+1 is consistent with prior *n*+2 boundary studies. Debate exists as to whether this is typically due to fixations targeted towards word *n*+2 undershooting and landing on word *n*+1, or a delayed cost associated with processing the false preview of *n*+2 from word *n*, which itself does not appear in the eye movement record until fixations on word *n*+1 (see Risse & Kliegl, 2012). It is our contention that an alternative explanation is more plausible for the current study. If words *n*+1 and *n*+2 are processed as parts of a larger MWU then processing of word *n*+1 occurs simply as part of processing associated with the larger MWU (and therefore simultaneously with word *n*+2). Given that on ninety per cent of trials word *n*+1 was fixated prior to word *n*+2, it is hardly surprising that this is the region where we observed effects of the display change.

The lexicon containing units larger than single words is in line with several theoretical accounts (e.g. Bybee, 2006; Pinker, 1998). Within these theories spaced compounds are only one subset of MWUs that may be lexically represented, with other candidates including idioms, clichés, collocations, binomial word pairs (e.g. *bride and groom*, see Siyanova-Chanturia, Conklin, & van Heuven, 2011) and other common phrases. It is important to note that these theories vary with regard to which MWUs are lexicalised and which are not. According to the Words-and-Rules theory only MWUs that cannot be generated out of smaller lexical units via rules should have lexical entries (Pinker, 1998). In contrast, usage-based theories propose that all commonly occurring MWUs should be lexicalised (Bybee, 2006). Given that the current study strongly suggests that one type of MWU is indeed lexicalised, it is important for future research to establish what other kinds of MWU are and are not lexicalised, and what the criteria for lexicalisation are. By establishing such criteria it will be possible to resolve some of the points of dispute between current theories.

While we have framed our results in terms of lexicalised MWUs some researchers may consider that our findings arose solely as a consequence of how predictable word *n*+2 was. Indeed, current models of eye movement control state that lexical identification is linked to predictability. Furthermore, much like in Juhasz et al.'s (2009) study, there would have been a high degree of syntactic predictability for the second constituent of the spaced compounds given the first constituent. However, while it has been found that predictability influences the degree of preview benefit from word *n*+2 (Radach et al., 2013), we believe there are good reasons why predictability is a less feasible account of our findings than our targets forming lexicalised MWUs. In the current study the predictability of word *n*+2 arose predominantly due to word *n*+1 rather than the preceding context. Recall, word *n*+2 was only 33% predictable from the sentence up to the pre-target word, and became 97% predictable given word *n*+1. As such, for the high predictability of word *n*+2 to have driven our effect it would have been necessary for word *n*+1 to be identified and integrated into the sentential context during fixations on word *n*. This is true from the perspective of both serial and parallel models. It is unlikely that this occurred reliably enough to have driven our effect, given that word *n*+1 was both long and low frequency. The fact that prior studies have failed to find *n*+2 preview effects when *n*+1 is long supports this idea. In Radach et al.'s study, in which *n*+2 effects were obtained, word *n*+1 was always "the", making it highly likely to be identified and integrated during fixations on word *n*. As such, it is unlikely that Radach et al.'s and our findings arose for the same reasons. Rather, the more plausible explanation for our finding is that word *n*+1 was parafoveally processed to an extent that the compound nature of the two upcoming words became clear during fixations on word *n*, and thus, processing of the second constituent was licensed as part of a lexicalised MWU. It is important to note that our explanation does not reject the role of predictability, and that these two explanations are not mutually exclusive. It is possible that the high predictability provided by the first constituent of the spaced compounds contributes to the licensing process. Where our position diverges from a standard predictability account is that we propose that predictability merely contributes to early processing of *n*+2 as part of a lexicalised MWU, as opposed to it simply being processed more efficiently once *n*+1 has been fully identified.

Arguably, our findings may pose issues for models of eye movement control such as E-Z Reader (Reichle, Rayner, & Pollatsek, 2003) and SWIFT (Schad & Engbert, 2012). Currently these models do not take into account that some lexical entries could be composed of multiple words and may be processed as single units. Given that some analyses suggest that about 50% of written discourse may consist of MWUs (Erman & Warren, 2000) this might be something that should be incorporated into the models. Within E-Z Reader word identification proceeds serially and sequentially, with lexical processing only beginning on a word after all preceding words have been fully identified. This was clearly not the case in the current study, with processing of the second constituent of a spaced compound occurring whilst the word before the compound was still fixated. While this finding may seem problematic for the idea of serial processing, we believe that it is not, due to our position that spaced compounds may be processed as single lexicalised MWUs. Under this viewpoint lexical processing would have still only encompassed one lexical unit at a time, with this lexical unit consisting of two letter strings separated by a space.

It is clearly not an issue for parallel models that two parafoveal words are processed in parallel,[4] with the models predicting such effects. However, our findings do become problematic when considered in the wider context of prior studies investigating *n*+2 preview benefits. Proponents of parallel models argue that the reason such effects are not found when word *n*+1 is longer is because under such circumstances *n*+2 is no longer in the perceptual span (e.g. Kliegl, Risse, & Laubrock, 2007). The current study brings this suggestion into question, since the second constituent of our spaced compounds was quite far to the right of fixation yet still produced preview effects. Thus, it seems more likely that the extent to which information is processed parafoveally is influenced by linguistic factors, and in the case of the current study whether the parafoveal words form a single lexical unit.

In closing, the current study has extended and supported prior work on the lexical representation of spaced compounds by showing that they may be processed as single units in the parafovea. We believe this to be one of the strongest pieces of evidence thus far in favour of MWUs having unified lexical entries. Given how prevalent such units may be it is important to gain a clearer understanding of how they are processed during natural reading and what it is that causes certain MWUs to become lexicalised. Thus, it seems likely that the degree to which words are processed in the parafovea is not only constrained by perceptual limitations, but also the linguistic characteristics of those words. Specifically, in the case of the current study, whether the words form a single lexical unit.

References

Angele, B., & Rayner, K. (2011). Parafoveal processing of word n + 2 during reading: Do the preceding words matter? *Journal of Experimental Psychology: Human Perception and Performance, 37,* 1210-1220. doi:10.1037/a0023096

Angele, B., Slattery, T. J., Yang, J., Kliegl, R. & Rayner, K. (2008). Parafoveal processing in reading: Manipulating n+1 and n+2 previews simultaneously. *Visual Cognition, 16:6,* 697-707. doi:10.1080/13506280802009704

Baayen, R.H. (2008). *Analyzing linguistic data: A practical introduction to statistics using R.* New York: Cambridge University Press.

Bates, D., Maechler, M., & Bolker, B. (2012). lme4: Linear mixed-effects models using S4 classes. (R Package Version 0.999999–0). Retrieved from http://CRAN.R-project.org/package=lme4

Bybee, J. (2006). From usage to grammar: The mind's response to repetition. *Language,82,* 711-733. Retrieved from: http://www.jstor.org/stable/4490266

Conklin, K., & Schmitt, N. (2012). The processing of formulaic language. *Annual Review of Applied Linguistics, 32,* 45-61. doi: 10.1017/S0267190512000074

Drieghe, D. (2011). Parafoveal-on-foveal effects on eye movements during reading. In S. Liversedge, I. Gilchrist, & S. Everling (eds.) *Oxford Handbook on Eye Movements* (pp. 839-855). Oxford, GB: Oxford University Press.

Drieghe, D., Pollatsek, A., Juhasz, B. J., & Rayner, K. (2010). Parafoveal processing during reading is reduced across a morphological boundary. *Cognition, 116,* 136-142. doi:10.1016/j.cognition.2010.03.016

Erman, B., & Warren, B. (2000). The idiom principle and the open choice principle. *Text and Talk, 20,* 29-62. doi: 10.1515/text.1.2000.20.1.29

Häikiö, T., Bertram, R., & Hyönä, J. (2010). Development of parafoveal processing within and across words in reading: Evidence from the boundary paradigm. *The Quarterly Journal of Experimental Psychology, 63,* 1982-1998. doi:10.1080/17470211003592613

Juhasz, B. J., Pollatsek, A., Hyönä, J., Drieghe, D., & Rayner, K. (2009). Parafoveal processing within and between words. *The Quarterly Journal of Experimental Psychology, 62,* 1356-1376. doi:10.1080/17470210802400010

Kliegl, R., Risse, S., & Laubrock, J. (2007). Preview benefit and parafoveal-on-foveal effects from word n+2. *Journal of Experimental Psychology: Human Perception and Performance, 33*, 1250-1255. doi:10.1037/0096-1523.33.5.1250

Kuperman, V., Schreuder, R., Bertram, R., & Baayen, R. H. (2009). Reading polymorphemic Dutch compounds: Toward a multiple route model of lexical processing. *Journal of Experimental Psychology: Human Perception and Performance, 35,* 876-895. doi:10.1037/a0013484

Liversedge, S. P., & Findlay, J.M. (2000). Saccadic eye movements and cognition. *Trends in Cognitive Science, 4,* 6-14. doi: 10.1016/S1364-6613(99)01418-7

Pinker, S. (1999). *Words and rules: The ingredients of language*. New York, NY: Harper-Collins.

Pollatsek, A., Hyönä, J., & Bertram, R. (2000). The role of morphological constituents in reading Finnish compound words. *Journal of Experimental Psychology: Human Perception and Performance, 26,* 820-833. doi: t0.1037//0096-1523.26.2.820

R Development Core Team. (2013). *R: A language and environment for statistical computing.* R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, Retrieved from http://www.Rproject.org/

Radach, R., Inhoff, A. W., Glover L., & Vorstius, C. (2013). Contextual constraint and n+2 preview effects in reading. *The Quarterly Journal of Experimental Psychology*, doi:10.1080/17470218.2012.761256

Rayner, K. (1975). The perceptual span and peripheral cues during reading. *Cognitive Psychology, 7,* 65-81.

Rayner, K. (1998). Eye movements in reading and information processing: 20 years of research. *Psychological Bulletin, 124,* 372-422. doi:10.1037/0033-2909.124.3.372

Rayner, K., Juhasz, B. J., & Brown, S. J. (2007). Do readers obtain preview benefit from word N+2? A test of serial attention shift versus distributed lexical processing models of eye movement control in reading. *Journal of Experimental Psychology: Human Perception and Performance*, *33*, 230-245. doi:10.1037/0096-1523.33.1.230

Rayner, K., Liversedge, S. P., White, S. J., & Vergilino-Perez, D. (2003). Reading disappearing text: Cognitive control of eye movements. *Psychological Science*, *14,* 385-388. doi:10.1111/1467-9280.24483

Rayner, K., Sereno, S. C., & Raney, G. E. (1996). Eye movement control in reading: A comparison of two types of models. *Journal of Experimental Psychology: Human Perception and Performance, 22,* 1188-1200. doi: 10.1037/0096-1523.22.5.1188

Reichle, E. D., Rayner, K., & Pollatsek, A. (2003). The E-Z Reader model of eye movement control in reading: Comparisons to other models. *Behavioral and Brain Sciences*, *26,* 445-476. doi:10.1017/S0140525X03000104

Risse, S., & Kliegl, R. (2012). Evidence for delayed parafoveal-on-foveal effects from word *n*+2 in reading. *Journal of Experimental Psychology: Human Perception and Performance, 38,* 1026-1042. doi: 10.1037/a0027735

McClelland, J. L., & Rumelheart, D. E. (1981). An interactive activation model of context effects in letter perception: I. An account of basic findings. *Psychological Review, 88,* 375-407. doi: 10.1037/0033-295X.88.5.375

Schad, D. J., & Engbert, R. (2012). The zoom lens of attention: Simulating shuffled versus normal text reading using the SWIFT model. *Visual Cognition, 20,* 391-421. doi: 10.1080/13506285.2012.670143

Schotter, E. R., Angele, B., & Rayner, K. (2012). Parafoveal processing in reading. *Attention, Perception, and Psychophysics, 74,* 5-35. doi: 58/s13414-011-0219-2

Slattery, T. J., Angele, B., & Rayner, K. (2011). Eye movements and display change detection during reading. *Journal of Experimental Psychology: Human Perception and Performance, 37,* 1924-1938. doi: 10.1037/a0024322

Siyanova-Chanturia, A., Conklin, K., & van Heuven, W. J. B. (2011). Seeing a phrase "time and again" matters: The role of phrasal frequency in the processing of multiword sequences. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 37,* 776-784. doi:10.1037/a0022531

Footnotes

[1] This exclusion rate is not unusual for studies making display changes over multiple words (Angele & Rayner, 2011).

[2] Typically boundary change studies are run at a refresh rate of either 120 or 150 hertz. Unfortunately, due to a technical oversight, the current study was run at 75 hertz. As such, more of the display changes occurred late than is usual for this kind of study. However, we are confident that our data exclusion criteria ensured that the late changes did not contribute to the effects we report.

[3] To ensure that the restrictions on our data set did not contribute to any statistical effects, we also conducted further analyses on our data set, using both more stringent, and more liberal, exclusion criteria. In one analysis we applied the existing exclusion criteria, and also excluded trials in which the boundary change was even 1 ms late (leaving 44% of the data). In this data set the slower refresh rate could not have influenced our results. The overall pattern was very similar, and critically, the pattern of effects was identical in the *n*+1 target region. Specifically, the effect in the *n*+1 target region for this analysis showed that there was an *n*+2 preview benefit given a valid *n*+1 preview of 16, 22, 24, and 15 ms for FFD, GD, GP, and SFD, respectively. Furthermore, we conducted an analysis which included trials in which the pre-target word was skipped or the boundary was triggered during a saccade that landed on word *n* (leaving 76% of the data). We originally excluded these trials due to the target words not being previewed, and therefore, the addition of these trials could have weakened our effect. However, the pattern in the data remained significant and the same, with the preview benefit amounting to 15, 19, 16, and 17 ms in the various measures. Given the similarity of these different analyses it seems reasonable to assume that our effect is robust, and does not arise as an artefact of the refresh rate or our exclusion criteria.

[4] While our main finding is not problematic for a parallel model, it is interesting to note the null effect of our preview manipulation on reading word *n*. This constitutes a failure to replicate controversial orthographic parafoveal-on-foveal effects. This was true even in the case of when both words *n*+1 and *n*+2 were non-words compared to when both were correct. The extent of the illegal information here is greater than in many prior studies, and yet there was no effect. As such our data strongly contradicts the idea of orthographic parafoveal-on-foveal effects, which are important for parallel accounts of processing.

```
The small child gently cuddled his fluffy| teddy bear while trying to get to sleep.
The small child gently cuddled his fluffy| teddy hocu while trying to get to sleep.
The small child gently cuddled his fluffy| fohbg bear while trying to get to sleep.
The small child gently cuddled his fluffy| fohbg hocu while trying to get to sleep.
```

Figure 1. An example of the stimuli under different preview conditions. The vertical black line represents the position of the invisible boundary. As the eye crossed this boundary the preview was replaced with the correct version of the spaced compound (e.g. “teddy bear”).

Table 1

Length and Frequency Characteristics of the Spaced Compounds, their Constituent Words, and the Pre-Boundary Word. Standard Deviation are Displayed in Parentheses.

Target word	Minimum-maximum length (letters)	Mean length	Mean word frequency per million
Pre-boundary	5-6	5.25 (0.44)	67 (111)
First constituent	4-9	5.65 (0.92)	5 (19)
Second constituent	3-8	4.68 (1.25)	45 (84)
Whole compound	9-14	11.33 (1.54)	3 (15)

Note. Word frequencies were obtained using the British National Corpus.

Table 2

Fixation Time Measures (in Milliseconds) and Fixation Probability for all Target Regions. Standard Deviations are Presented in Parentheses.

Preview	Word *n*	Word *n*+1	Word *n*+2	Whole compound
		First fixation duration		
Both identity	232(69)	230(69)	197(73)	-
n+2 non-word	230(78)	246(74)	206(74)	-
n+1 non-word	234(72)	286(91)	198(74)	-
Both non-word	235(72)	267(89)	196(60)	-
		Gaze duration		
Both identity	247(100)	241(76)	211(90)	354(143)
n+2 non-word	239(96)	268(83)	220(86)	393(161)
n+1 non-word	248(85)	325(97)	207(83)	437(157)
Both non-word	249(92)	323(103)	206(79)	464(157)
		Go-past time		
Both identity	253(110)	249(82)	211(90)	375(151)
n+2 non-word	247(97)	276(92)	226(93)	408(172)
n+1 non-word	253(94)	335(101)	215(93)	468(163)
Both non-word	255(97)	334(110)	210(82)	484(157)
		Single fixation duration		
Both identity	231(69)	235(70)	193(67)	226(72)
n+2 non-word	232(80)	256(75)	207(74)	257(78)
n+1 non-word	238(74)	305(87)	196(76)	296(90)
Both non-word	237(73)	295(87)	195(60)	313(74)
		Skipping probability		
Both identity	-	.09(.29)	.33(.47)	.01(.11)
n+2 non-word	-	.18(.39)	.26(.44)	.01(.11)
n+1 non-word	-	.07(.26)	.33(.47)	.00(.06)
Both non-word	-	.07(.26)	.25(.43)	.00(.07)

Note. Skipping data for word *n* is not available due to its exclusion in the data cleaning procedure. First fixation duration data for the whole compound is not presented for reasons discussed in the text.

Table 3

Fixed Effect Estimates from the LME Models for all Measures across All Regions.

Factor	First fixation duration	Gaze duration	Go-past time	Single fixation duration	Skipping probability
			Word *n*		
n+1 preview	-0.02	-0.04	-0.02	-0.02	-
n+2 preview	0.00	0.00	0.00	0.01	-
Interaction	0.01	0.02	0.01	-0.02	-
			Word *n*+1		
n+1 preview	-0.07*	-0.19***	-0.19***	-0.14***	1.19***
n+2 preview	0.08**	0.01	0.01	0.03	0.00
Interaction	-0.14***	-0.12**	-0.11**	-0.13**	-0.89+
First contrast[a]	-0.08**	-0.13***	-0.13***	-0.13***	-1.04**
Second contrast[b]	0.08**	0.02	0.02	0.05	-0.00
			Word *n*+2		
n+1 preview	0.04	0.06	0.07	0.05	0.03
n+2 preview	-0.01	0.00	0.00	-0.01	0.37
Interaction	-0.04	-0.04	-0.08	-0.05	0.01
			Whole compound		
n+1 preview	-	-0.17***	-0.19***	-0.22**	1.23
n+2 preview	-	-0.05	-0.03	-0.08	-0.20
Interaction	-	-0.07	-0.07	-0.05	0.04

[a]Refers to the comparison between the two conditions in which an identity preview of word *n*+1 was given. [b]Refers to the comparison between the two conditions in which there was a non-word preview of word *n*+1.

*$p<.05$

**$p<.01$

***$p<.001$

+$p<.10$

Appendix

A list of the sentences used in the current study. The constituent words of the spaced compounds are italicized. The non-word preview for each constituent is displayed in brackets.

1. He knew the shaman's fortune telling was just silly *mumbo (umnkc) jumbo (gmvke)* that should be ignored.
2. As the witch threw the rat into the cauldron she yelled *hocus (kaovz) pocus (gaawz)* and began stirring.
3. One gym class involved using the waist and hips to spin a large *hula (bmto) hoop (bcaq)* round the body.
4. The deer triggered a tripwire, and was caught in a nasty *booby (haedp) trap (fvcq)* out in the forest.
5. The lighting manager for the local club set up his flashy *strobe (zlmoko) lights (tfdpsz)* for the rave.
6. She gently stroked from the head to the tail of the white *pussy (qrzzj) cat (ool)* sat on her lap.
7. One of her favourite Christmas puddings is tasty *mince (vfmec) pies (gtoz)* with loads of cream.
8. She saw the man with a cold wipe the snot from his gross *runny (vmvrg) nose (meza)* with a tissue.
9. The Muslim man's meal would be incomplete without some tender *halal (kefcf) meat (wael)* in a sauce.
10. The man living near an airport got annoyed by the noisy *jumbo (ymrdc) jets (yofz)* landing so nearby.

11. The small child gently cuddled his fluffy *teddy (fohbg) bear (hocu)* while trying to get to sleep.
12. The Japanese gardener looked sadly at the dying *bonsai (hcvzcf) tree (lnao)* that she had not watered.
13. He loved to go to the Indian and get a spicy *tikka (ftddo) masala (vozetc)* to eat during the football.
14. As it purred she caringly cuddled the happy *tabby (lchdp) cat (oel)* that was lying in her arms.
15. Since the ground was wet and muddy outside she wore her green *welly (uoftj) boots (declz)* to the park.
16. The old dog lover patted the hairy *cocker (oaabou) spaniel (zqomlot)* that came up to him on the head.
17. She tried to complete a thousand piece *jigsaw (qtpzou) puzzle (qwssta)* during her holiday in Wales.
18. At the zoo the child watched the cute, grey, furry *koala (hcetc) bear (kaov)* slowly climb a tree.
19. He was kept up by his housemate's wet clothes being in the noisy *tumble (lvvdto) dryer (hmjow)* all night.
20. The view of the fairground from the top of the giant, round *ferris (tcwwtz) wheel (ubaot)* was astounding.
21. During hide and seek she hid quietly behind the wooden *Wendy (Nomkj) house (kamzc)* in the play area.
22. At the fair she had fun sliding down and around the bright *helter (kaftan) skelter (zhoffon)* several times.

23. The war was confirmed at a press conference by the Dutch *Prime (Rwtno) Minister (ulmlzfom)* last Tuesday.

24. As he climbed the security fence the thief cut his leg on the sharp *barbed (doudcb) wire (ntmo)* on top.

25. The woman greedily ate the entire pot of honey roast *cashew (aezdcv) nuts (rvlz)* all by herself.

26. Baked beans, sausages, and creamy *mashed (uezkch) potato (gelclc)* made up his daughter's favourite dinner.

27. She cooked her eggs on the electric hob in a metal *frying (lwgtvy) pan (gcv)* full of melted butter.

28. The secretary put the document back into the steel *filing (lfftmq) cabinet (oekfmaf)* in the corner.

29. Since it was cold he put on his hat, scarf, gloves and thick *duffle (bnlltc) coat (aacl)* before leaving.

30. At the Indian restaurant she had a side dish of plain *pilau (yttow) rice (ufec)* with her chicken korma.

31. She spread both the jelly and crunchy, thick *peanut (qaevrl) butter (kmffcv)* onto the toast for her son.

32. On Christmas Eve she loved to heat up and drink spiced *mulled (vwffab) wine (vlro)* before going to bed.

33. Using newspaper and glue in art class she made a giant *papier (gcgfav) mâché (vcako)* model of a hippo.

34. The cocaine smuggler looked nervously at the brown *sniffer (zmfllam) dog (haq)* by the airport gate.

35. I stuck the broken box back together using glue, extra sticky *masking (uczhfvp) tape (leqo)*, and staples.

36. If they were going to swim in it, his toddlers' dirty *paddling (jekktfwj) pool (jaef)* needed a good wash.

37. He breaks the shell, beats the yolk and white, and then makes *scrambled (zoueudtok) eggs (cppz)* on toast.

38. The small coastal town had been flooded and ruined by the giant *tidal (ftbef) wave (nowo)* last August.

39. She had seen many underwater fish over summer while *scuba (zamke) diving (hlmlrq)* in the Maldives.

40. He covered the vegetables he wanted to roast in cheap *olive (attuc) oil (ctf)* and put them in an oven.