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The Effects of Word Frequency, Text Case, and Contextual Predictability on Binocular Fixation During Reading

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THE EFFECTS OF WORD FREQUENCY, TEXT CASE, AND CONTEXTUAL PREDICTABILITY ON BINOCULAR FIXATION DURING READING

by

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Abstract

Properties of text which affect binocular coordination during reading have received little attention compared to other areas of eye movement research. The evidence, to date, has been equivocal, with some suggesting that the visual system tolerates less binocular fixation disparity (BFD) under conditions which make reading difficult and others reporting no such effect. Two eye movement experiments were conducted to investigate this issue further. In *Experiment 1*, participants read sentences containing high and low frequency words. Half of sentences were presented in normal case and half in alternating case (e.g., aLtErNaTiNg cAsE), replicating Juhasz, Liversedge, White & Rayner (2006). Results showed that neither frequency nor case affected the magnitude of disparity. In *Experiment 2*, BFD was investigated in a more linguistically rich reading context by manipulating predictability (high vs. low) in addition to frequency and case. Results showed that BFD was significantly smaller for low frequency target words in contexts which made reading difficult. It is concluded that the linguistic and orthographic properties of the text do, in fact, influence binocular coordination. Implications of these results are discussed in relation to models of reading.

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Definitions

Below is a list definitions for all abbreviations used in the present thesis:

AC: Alternating case

BFD: Binocular fixation disparity

FFD: First fixation duration

GD: Gaze duration

HF: High frequency

HP: High predictability

LED: Light emitting diode

LF: Low frequency

LP: Low predictability

ms: Milliseconds

NC: Normal case

SD: Standard deviation

SE: Standard error

Chapter 1

Introduction

Many studies have been conducted over the past 40 years investigating eye movements to understand the cognitive processes that occur during visual processing and written language comprehension (Liversedge & Findlay, 2000). There presently exists a large body of research which has investigated eye movement behaviours during reading (for reviews, see Rayner, 1998, 2009). However, one aspect which has received little attention is that of *binocular disparity*. Binocular disparity refers to the difference between the fixation positions of each eye when attending to visual stimuli. Considering the depth of research which has been conducted into eye movement behaviour, the lack of research into the role of binocularity is surprising. One of the principal reasons as to why this area has received little attention is that it has been assumed that both eyes are fixated on the same point during reading (Liversedge, White, Findlay & Rayner, 2006), resulting in researchers only taking monocular recordings for their studies as half of the data set was assumed to be redundant. However, this is not always the case (Heller & Radach, 1999).

A number of reasons have contributed to why binocular coordination has not been recognised as a stand-alone research topic, but two reasons are particularly evident. The first is that there has been a tendency for different disciplines to focus on different theoretical issues and the second is that there have been different methodological approaches taken to study different, but related, issues. For instance, some researchers have been particularly interested in the low-level characteristics of binocular coordination and have exposed participants, typically, to stimuli made up of light emitting diodes (LEDs; Collewijn, Erkelens, and Steinman, 1988). Other researchers have been investigating binocular disparity in children, particularly those suffering from dyslexia to see if binocular coordination is the source of their reading difficulty (Cornelissen, Bradley, Fowler & Stein, 1992; Stein, Richardson & Fowler, 2000). Finally, psycholinguists have been interested in binocular coordination during reading in particular (Heller & Radach, 1999; Juhasz, Liversedge, White & Rayner, 2006; Liversedge et al., 2006). Participants are presented with individual words, sentences, or passages of text and binocularity is investigated through that. The area of investigation by this final group of researchers shall be the focus of the present thesis. However, prior to investigating binocularity, it is important to understand some of the basic characteristics of eye movements elucidated from monocular studies.

Eye movement characteristics during reading

Two of the principle eye movement behaviours during reading are *fixations* and *saccades*. Fixations are periods in which the eyes remain relatively stationary, allowing information to be processed. Fixations typically last between 150-500 milliseconds (ms), with the average fixation duration during silent reading lasting around 200-300 ms (Rayner, 1998). Saccades, in contrast, are rapid movements that take place between fixations that can have velocities as high as 500° per second. The average saccade amplitude is 7-9 characters. Saccades are measured in characters, as opposed to absolute distance, due to the fact that saccades are the same, in terms of character length, regardless of the distance of the text (O'Regan, Levy-Schoen, & Jacobs, 1983) or the angle at which it is presented (Morrison & Rayner, 1981). New information is not obtained during saccades, as the speed at which the eyes pass over the stimuli would result in merely a blur being perceived (Uttal & Smith, 1968). This reduced visual sensitivity during saccades in known as *saccadic suppression* (Matin, 1974).

The purpose of a saccade is to bring new information into the fovea so it can be fixated on (Rayner, 1998). There are three regions in the retina of varying visual acuity:

the *fovea*, the *parafovea*, and the *periphery* (Rayner, 1974). However, these regions should not be thought of as categorically distinct, but rather as continuous regions in which visual acuity varies. The region with the greatest visual acuity is the fovea, which makes the central 2° of visual angle. Next is the parafovea, which extends 5° outward from the fovea and visual acuity is moderate in this region. Finally, there is the periphery, which is the area of the retina which extends beyond the parafovea and has the poorest visual acuity. In order to perceive visual stimuli with clarity, the eyes must be oriented so that light from the stimulus falls on the fovea.

Due to this reduced visual acuity in the parafovea and the periphery, it is almost impossible to read when text is visible in only these regions (Rayner, Inhoff, Morrison, Slowiaczek, & Bertera, 1981). In order to read a word, the eyes must be fixated on that word. However, not all words are fixated on. Words can be categorised into two types: *content words* and *function words*. Content words are words that have meanings which can be defined, such as nouns, verbs, and adjectives (eg. *camel, drink, gigantic*), and are fixated on around 85% of the time. Function words, on the other hand, are words that show the grammatical relationship of other words to a sentence, such as articles, conjunctions, and prepositions (eg. *the, and, from*), and are fixated on only around 35% of the time (Rayner & Duffy, 1986). In addition to word type, length also influences whether a word is fixated on or not. Words made up of 2-3 letters are fixated on around 25% of the time, whereas words made up of 8 or more letters are almost always fixated on, with some long words requiring multiple fixations (Rayner & McConkie, 1976).

Although the vast majority of saccades made when reading English are made from left to right, in approximately 10-15% of cases, saccades are made from right to left (Rayner, 1998). Saccades going from right to left are of two types: *regressions* and *return sweeps*. Regressions take place when the reader needs to refixate on material which they have already read and takes place not only between words, but also within words. Regressions between words occur when the text being read is conceptually difficult or ambiguous and requires the reader to read again (Jacobson & Dodwell, 1979). Regressions within words occur when the reader has not fixated optimally on a word and require readjustment. One factor which has been found to increase the frequency of regressions is text difficulty (Rayner, 2009). Text difficulty also affects the length of fixations and the size of saccades. Return sweeps, on the other hand, are made when the reader has completed reading a line of text and moves onto the next line.

As saccades are motor movements, planning time is required to determine when to execute the saccade and where the saccade should land. Consensus has yet to be reached on whether these 'when' and 'where' processes of saccades are unified or whether they are determined independently (Rayner &McConkie, 1976; Rayner & Pollatsek, 1987, 1989). Saccades and fixations have been widely studied during reading under a number of different manipulations, orthographic and linguistic, in order to determine the factors which influence reading. How words of different length (Rayner, Sereno & Raney, 1996), frequency (Hand, Miellet, O'Donnell & Sereno, 2010; White, 2008), contextual predictability (Hand et al., 2010; Rayner & Well, 1996; Rayner, Li, Juhasz & Yan, 2005), letter transposition (Grainger & Whitney, 2004; Velan & Frost, 2007), and word constraint (Hand, O'Donnell & Sereno, 2012; Lima & Inhoff, 1985) affect reading have all been researched and a range of interesting results have been obtained from them.

However, all of the previously mentioned studies have collected data by recording monocular eye movements. The role of binocularity, as mentioned earlier, has been given little attention. The following sections will detail the research which has been conducted into binocular eye movements, starting with binocular disparity in non-reading tasks and then moving onto research investigating binocular coordination in reading specifically.

Binocular coordination during non-reading tasks

Although the human visual system is binocular, the world is perceived as a unified, cyclopean whole. Binocular coordination is required in order to maintain this integrity. Without this precise and systematic coordination, the visual input from each eye would be perceived independently. It is, therefore, crucial to understand the subtle eye movements involved in binocular coordination.

When investigating oculomotor control of binocular vision, two factors are particularly important to take into consideration: the direction and distance of the visual object. Both these pieces of information are required so the eyes can accurately fixate on the target object. There are three main ways in which the eyes achieve this: *pure vergence movements*, *conjugate saccades*, and *disjunctive saccades* (Kirkby, Webster, Blythe & Liversedge, 2008). Pure vergence movements are eye movements which account for changes in depth alone, conjugate saccades (which are also sometimes referred to as *pure version movements*) are movements in same direction, and, finally, disjunctive saccades are eye movements which account for changes in both depth and direction.

Although it is understood that the eyes move in different directions during pure vergence movements, it has been generally assumed, as mentioned earlier, that when executing conjugate saccades, and fixations are made, both eyes are fixated on exactly the same place (i.e., in reading, the same letter). The assumption has been that the saccades are perfectly conjugate. However, research has shown that there is a disparity in binocular coordination even during conjugate movements when measurements of saccades taken for each eye.

A study conducted by Collewijn, Erkelens, and Steinman (1988) investigated how the depth and direction of a target influences the duration, amplitude, and velocity of saccades. They used a revolving magnetic field–sensor coil technique (see Collewijn, Martins, & Steinman, 1981) to measure where the participants' eye positions in space. Participants took part in two conditions: the first entailed following light emitting diodes (LEDs) which were positioned horizontally, without any changes in depth; the second required participants to, once again, follow LEDs, but this time the position of the LEDs changed in both horizontal direction and depth.

Collewijn et al. (1988) found that there was a difference in the size of saccades made between the two eyes when horizontal saccades were made. They found that the saccades of the *abducting eye* (the eye moving temporally) were significantly larger in size, shorter in duration, and had higher maximum velocities than the *adducting eye* (the eye moving nasally). They also found that the saccades of the abducting eye were more skewed (the time between the saccade onset and peak velocity as a fraction of saccade duration) than that of the adducting eye. This difference between the two eyes resulted in there being a slight divergence during the saccade.

In another study, Bains, Crawford, Cadera, and Vilis (1992) investigated when, during a saccade, the eyes become non-conjugate. Participants were seated 2 metres away from a circular target board, which had a central fixation point and 12 targets, which were placed on the edges of the target board, 30° apart, in the fashion of the numbers on a clock. Participants were asked to make consecutive saccades from the central fixation point to each of the targets while binocular eye movements were recorded. The results showed that successive saccades made in the same direction varied in curvature, velocity, and duration. Although the peak velocities of the two eyes were similar, slight differences were observed. During horizontal saccades, the abducting eye was executed earlier and had a higher peak velocity than the adducting eye. These findings are consistent with those of Collewijn et al.'s (1988), demonstrating that there was a slight divergence during the saccade. Bains et al. (1992) tried to explain this by suggesting that these differences between the two eyes could be due to synaptic delays or the mechanical dynamics of the muscles controlling the two eyes.

Disjunctive saccades have also been studied, with results being notably different from that of conjugate saccades. Disjunctive saccades have been found to have lower velocities and longer durations than conjugate saccades (Kirkby et al., 2008). This difference in speed and duration suggests that these two types of saccades are possibly executed in different ways. In a study conducted by Zee, Fitzgibbon & Optican (1992), participants were asked to make saccades between different targets, which involved both vergence and version movements being made, while binocular eye movements were recorded. Vergence movements were manipulated by placing a Plexiglas strip in front of the participants, along the midsagittal plane, with LEDs positioned so vergence changes of 2.5°, 5°, or 10° were made, relative to a 0° LED that was projected onto a translucent tangent screen that was placed 1 metre away. Version movements were manipulated by positioning LEDs on the tangent screen, horizontally and vertically, which called for version changes of 2.5°, 5°, or 10° relative to the 0° LED. The results of the study were consistent with that of Collewijn et al. (1988) and Bains et al. (1992). There was a slight difference in horizontal alignment when participants made both vertical and horizontal version movements, but only during the initial moments of the saccades. After these initial moments, the eyes became convergent. They also found that the velocity of vergence movements was greatest when disjunctive saccades were made than when conjugate saccades were made.

In another study, Collewijn, Erkelens, and Steinman (1995) investigated the interaction between vergence and version movements. They looked at the dynamics of binocular gaze shifts, made horizontally, between pairs of three-dimensional targets. They differed the angle of the target in three ways: direction only (conjugate saccades), depth only (pure vergence), or in both direction and depth (disjunctive saccades). The gaze shifts between targets that participants had to make in the experiment were referred to as being in *manual working space*; this is the area in which most visuo-motor activity takes place. When gaze shifts occur in this space, it requires both changes in version and vergence movements. The results of their study showed that the majority of gaze shifts within manual working space, as expected, were disjunctive. Collewijn et al. (1995) also designed stimuli intended to elicit pure vergence movements, but found that they still induced disjunctive saccades as participants were making small version movements, even though they were not required. When targets were at further distances, a little vergence was necessarily noted in gaze behaviour, but gaze shifts were typically conjugate in nature. These findings are in agreement with the results reported by Collewijn et al. (1988) and Bains et al. (1992). They all demonstrate that there is some level of disconjugacy in binocular coordination during non-reading tasks.

Based on the studies mentioned previously, it is evident that the assumptions that saccades are spatially and temporally conjugate are not entirely justified. Results of the studies have clearly shown that there is a subtle divergence between the eyes during a saccade. When saccades are made between targets in different directions, eye movements are non-conjugate. There is a slight delay in the onset of saccades between the two eyes, with the abducting eye executing saccades a little earlier than the adducting eye, suggesting that the timing of binocular saccades may modulate the coordination of the eyes. There is also a difference in the duration, peak velocity, and skew of the abducting and adducting eyes during saccades, with saccade amplitudes being larger for the abducting eye. However, it should be noted that the divergence reported may not necessarily manifest due to poor yoking between the eyes, but may result from differences in muscular control or synaptic transmission between the eyes. One point to note is that although these slight differences are present, there is no perceptual experience of them. This lack of detection could be due to two reasons: (1) saccadic suppression, as defined earlier, occurs during saccades; (2) the speed at which a saccade takes place does not allow time for a difference to be perceived.

Of the few studies which have investigated binocular coordination, most have focused on the differences in binocular alignment during saccades (e.g. Bains et al., 1992; Collewijn et al., 1988; Zee et al., 1992), with few having investigated what happens during fixations (e.g. Heller & Radach, 1999; Hendriks, 1996). This could be due to the assumption that the eyes remain relatively stationary during fixations, unlike during saccades, so any disparity between the eyes would be absent or negligible at best. However, this is not necessarily the case. A number of different methods have been used to investigate binocular disparity in fixations, but the stimuli have always been linguistic in nature (words, sentences, and texts). The following section of this thesis looks at the research conducted into binocular coordination during fixations, specifically during reading. As will become apparent, the findings are consistent with those already discussed; however, there are methodological and theoretical differences which merit further exploration.

Binocular fixation coordination during reading

Of the few studies conducted into binocular coordination during reading, most early studies have suggested that coordination was either very good or perfectly synchronous (Tinker, 1958; Yarbus, 1967). One of the first studies which showed conflicting evidence was conducted by Smith, Schremser & Putz (1971), who investigated coordination during directional motion using a real-time computer method. They presented participants with text of varying difficulty, which was oriented horizontally, rotated clockwise, or rotated anticlockwise and measured the difference in timings to initiate saccades between the eyes. Their results showed that there was a difference in saccade onset times between the eyes, which, interestingly, appeared to cluster around three values. The left eye typically led the right eye by 1 ms, 7-9 ms, or 14 ms when the text was oriented horizontally. The same effect was present when the text was rotated 15° from the horizontal position. Text difficulty, however, did not influence the results. This demonstrates that saccades are not conjugate during reading, as Tinker (1958) and Yarbus (1967) suggested, but, instead, shows that there is a slight delay in saccadic initiation, possibly in order to maintain coordination of the eyes. Smith et al. (1971) suggest that this difference could be due to neurons in the midbrain and cortex being time and direction specific when guiding and coordinating the eyes.

However, as Smith et al.'s (1971) study was one of the first to show a difference in saccade onset, Williams & Fender (1977) questioned the findings. They suggested that the difference in saccade onset times reported could have been due to the way in which Smith et al. (1971) inferred saccade onset times. Williams & Fender (1977) investigated the difference, seeking to identify whether the discrepancy would be reflected in the acceleration of each eye shortly after saccade onset. One point to note is that although their experiment did not involve a reading task, the findings are still relevant to binocular coordination during reading due to relatively small saccades involved.

In their study, Williams & Fender (1977) required participants to look at bright spots which were presented on a dark background. The spots would randomly appear on the left, centre, or right side of the background. The difference in visual angle between left-to-centre and centre-to-right spots was 1° and the difference between left-to-right spots was 2°. There were three viewing conditions: monocular (right eye), monocular (left eye), and binocular. Their results showed that there was a degree of synchronisation between the two eyes, independent of saccade direction (left vs. right) and viewing condition (monocular vs. binocular). Their results also showed that there was a difference in peak velocity for the abducting and adducting eyes. But most importantly, they found that there was no difference in saccade onset times for any of the conditions, counter to what Smith et al. (1971) had reported.

Some studies conducted more recently have sought to elucidate the nature of binocular coordination and the extent to which disparity exists during fixations while reading. In a study by Hendriks (1996), vergence velocities were investigated during fixations, post-saccadically. Binocular eye movements were recorded as participants read either a passage of text or a list of unrelated words. They were asked either to read normally while paying attention to the meaning of what they were reading or to read while sounding words out subvocally. The results showed that vergence velocities during fixations were higher when reading a passage of text than when reading unrelated words. Additionally, vergence velocities were higher when text was read for meaning than when pronounced subvocally. Hendriks (1996) suggested that one of the reasons for the relatively lower vergence velocities when subvocally sounding out words was because the meaningful information that context provides was absent and the reader was forced to rely on visual information alone. Hendriks (1996) further argued that under such conditions, fixations tend to be more stable and the saccades produced are smaller in amplitude than when reading passages of text for meaning. Additional findings showed that vergence velocities were faster during fixations after long saccades than after shorter ones. As readers make larger saccades when reading for meaning than when pronouncing words subvocally, this resulted in faster vergence velocities during fixation.

Heller & Radach (1999) investigated different aspects of binocular coordination during reading by conducting three experiments. They were interested in understanding how fixation positions on a page of text influences binocular disparity. More specifically, they were looking to see whether the residual disparity which remains at the end of fixation accumulates as the reader progresses through multiple lines of text. They also investigated the differences in binocular fixation disparity between monocular and binocular reading conditions and whether difficulty had any influence on binocular parameters. Their findings were consistent with those reported by Collewijn et al. (1988) – the differences in saccade amplitudes observed between the abducting and adducting eyes observed in the non-reading task were also observed during reading. However, contrary to Collewijn et al. (1988), vergence movements were noticeably slower and a residual disparity at the end of each reading fixation was observed.

In order to investigate whether residual disparity accumulates over several lines of text, Heller & Radach (1999) presented participants with twenty passages of text containing six lines each. Participants were told to read through each of the passages fluently, without stopping at the beginning of each new line. Their findings showed that there was a difference in the magnitude of binocular disparity over the first line of each of the passages compared to the remaining five lines. An accumulation of fixation errors was observed over the first line, which averaged 2 characters. However, this pattern was reduced over subsequent lines and then reversed, resulting in a mean fixation disparity of 1.5 characters. Heller & Radach (1999) argued that the visual system is only able to tolerate a certain level of accumulated binocular disparity and does not tolerate disparity beyond that point. However, one point to note is that Heller & Radach's (1999) results should be treated with caution as they only reported descriptive statistics.

In their second experiment, Heller & Radach (1999) investigated the difference between monocular and binocular reading. Participants were asked to read a total of 600 lines of text in three viewing conditions: 200 lines were read binocularly, 200 lines were read monocularly with one eye occluded, and the final 200 lines were read with the other eye occluded. Their findings showed that under monocular reading conditions, fixation durations, the number of fixation, and the number of regressive saccades increased, suggesting that reading monocularly is more difficult than reading binocularly. One unexpected finding was that there was notable increase in the amplitude of progressive saccades when reading under monocular conditions. Heller & Radach (1999) suggested that this peculiar finding could be due to some difficulty experienced by the visual system, under monocular conditions, which makes it so the saccadic system is not able to adapt easily to the changes in the viewing field. More importantly, their results showed that there was no difference in saccade amplitudes between the left or right eye under monocular viewing conditions, a finding consistent with Collewijn et al. (1988). With regards to the slower vergence movements that occurred during fixations, as mentioned earlier, no differences were observed between monocular and binocular viewing conditions. This appears to suggest that slow vergence movements during fixations pre-programmed and act in a reflex-like fashion, instead of being calculated in response to the stimuli being observed.

In their final experiment, Heller & Radach (1999) investigated whether the demands of a task influence binocular saccades while reading. They looked at whether the saccade amplitudes between the two eyes would be reduced under difficult reading conditions, based on the assumption that the visual system is able to tolerate less disparity when reading is made more difficult. In order to test this hypothesis, participants were presented with passages of text written in either normal case or in alternating case (e.g., AlTeRnAtInG cAsE). Previous research has shown that text in alternating case increases reading difficulty, making it harder to identify words (Coltheart & Freeman, 1974; Rayner, 1998). Their results showed that text difficulty did have an effect, with participants making shorter saccades and more fixations for longer durations when the text was written in alternate case. Most importantly, they found that binocular saccade amplitudes were reduced when reading in alternate case. As a result, vergence velocities were slower for text in alternate case than in normal case. The findings from this third experiment suggest that the visual system is able to tolerate larger binocular fixation disparities under normal conditions than under difficult to read conditions. Heller & Radach (1999) also found that vergence velocities remained similar under both monocular and binocular reading conditions. They suggested that this could be due to vergence movements during fixation being reflexive and not requiring binocular input to manifest. Demands of the task appear to mainly influence how saccades are coordinated, with vergence movements subsequently being a result of those binocular saccade metrics.

A more recent study showing systematic binocular fixation disparity was conducted by Kliegl, Nuthmann & Engbert (2006). In their study, participants were presented with 144 sentences as binocular eye movements were recorded. Although binocular coordination was not the focus of their study, Kliegl et al. (2006) investigated the effects of binocular disparity on saccade amplitudes, duration of first pass, and single fixations. Their results showed that the eyes were fixated on different characters on 41% of fixations. However, they did not find any influence of binocular disparity on fixation duration or the amplitude of incoming or outgoing saccades.

Kliegl et al.'s (2006) findings that there was no difference in saccade amplitudes between the abducting and adducting eyes is a little peculiar, given the majority of the previously mentioned studies have reported a difference. One of the reasons for this absence could be because of how saccade amplitudes and disparities were computed. Disparity was reported as the mean disparity during fixations, rather than calculating saccade amplitudes on the basis of disparity at the beginning and end of a saccade. One of the possibly more important findings was that there was also an absence of any effect of disparity on fixation duration. Their findings suggest that binocular disparity does not affect linguistic processing.

Another interesting finding in Kliegl et al.'s (2006) is the frequency of crossed fixations (where the right point of fixation is to the left and vice versa by more than one character). They reported more crossed than uncrossed fixations – a pattern which has previously been found to be the opposite. Presently, it is unclear why such a pattern was observed; therefore, more research is required to investigate the issue.

Finally, Kliegl et al. (2006) investigated an aspect which has not been looked into previously – the frequency of binocular fixations on the same word. They found that participants made first-pass single fixations on the same word 77% of the time, meaning that on 23% of fixations, each eye was fixated on a different word. As there is currently little data in this area, Kirkby et al. (2008) re-examined the data from participants in a study conducted by Blythe et al. (2006). In their study, Blythe et al. (2006) asked participants to read sentences containing target words of different lengths: short (4 characters), medium (6 characters), and long (10 characters) words. The data from their study provided the opportunity to investigate the effects of word length on the frequency with which both eyes are fixated on the same word.

Re-examining the Blythe et al.'s (2006) data, Kirkby et al. (2008) found that pattern of fixation was similar to that reported by Kliegl et al. (2006). Participants fixated binocularly on the same word 85% of the time, meaning fixations were on different words on 15% of fixations. Consistent with the results of Kliegl et al. (2006), word length affected the results in an expected fashion. Both eyes were fixated on the same word for short words 79% of the time, medium words 81% of the time, and long words 95% of the time. The consistency between the two studies suggests that there is a higher probability that each eye will be fixated on a different word for shorter words than for longer words, possibly due to the *preffered viewing location* being deeper in the word for longer words (O'regan, Lévy-Schoen, Pynte & Brugaillère, 1984). The preferred viewing location is the point in a word on which readers fixate initially and tends to be half way between the beginning and the middle of a word.

The final study that will be reviewed in this section is that conducted by Liversedge et al. (2006) on binocular coordination. In their study, they attempted to replicate and extend Heller & Radach's (1999) study, by investigating the nature of binocular fixation disparity and its magnitude, the frequency with which it occurs, and its direction. They also compared the exact positions of fixations at their onset and offset in order to examine vergence movements made during fixations. Participants were presented with 72 single line sentences (e.g. *The janitor cleaned the filthy blackboard in the classroom*.) of a variety of syntactic constructions, after a third of which comprehension questions were asked to ensure participants were interpreting the sentences fully. Their results showed that fixations were binocularly disparate by one character more on 47% of fixations across the entire sentence. Their findings support those reported by Heller & Radach (1999), providing further evidence contrary to the widely held assumption that both eyes always fixate on the same character during reading. Liversedge et al. (2006) also reported the frequency of aligned (53%), uncrossed (39%), and crossed (8%) fixations, which were constant, approximately, across all participants. They also recorded eye dominance, but found that it had no effect on binocular fixation disparity or the frequency of aligned, uncrossed, or crossed fixations.

With regards to changes in alignment during fixations, Liversedge et al. (2006) found that the percentage of aligned fixations at the end of fixations (53%) was higher than at the beginning (48%), with the magnitude of fixation disparity being greater at the beginning of fixation than at the end. Their analyses showed that the eyes converged on 52% of fixations and diverged on 25%. One explanation for these vergence movements is that although the eyes are relatively still during fixations, there are still some movements taking place to allow for optimal viewing. However, one point to note is that the likelihood of vergence movement is dependent on fixation alignment. Vergence movements during fixations are corrective in nature, so they are more likely to occur when fixations are unaligned at the beginning of fixation.

Present thesis

Although disparity is common, it is not homogenous. The magnitude of binocular fixation disparity changes from fixation to fixation. Consequently, it is unclear to what extent the linguistic and visual properties of a text affect disparity. The present thesis seeks to investigate this further, to deepen the understanding of binocular fixation disparity during reading.

Experiment 1 (**Chapter 2**) investigates the effects of linguistic and orthographic manipulations, word frequency and case alternation respectively, to determine how these factors affect binocular fixation disparity. Although these aspects have been investigated once previously, as the findings conflicted with other research into binocular fixation disparity, the present thesis will re-examine the relationship between these variables in an attempt to provide greater clarity on the relationship.

Experiment 2 (**Chapter 3**) extends the first experiment by investigating the nature of binocular fixation in a more linguistically rich reading context. This is achieved by manipulating contextual predictability in addition to word frequency and case alternation to observe the effects all three aspects in conjunction have on binocular fixation disparity.

Chapter 2

Revisiting the effects of frequency and case on binocular coordination during reading

Introduction

A great deal of information has been acquired in recent decades on eye movement behaviours during reading (see **Chapter 1**). Numerous studies have investigated reading under different orthographic and linguistic manipulations to understand the behaviours of eye movements, particularly saccades and fixations, and their sensitivities to such manipulations. One linguistic manipulation which has been rigorously studied is word frequency.

Word frequency is measured by the number of times the word appears in written texts. The frequency of a word is calculated by counting the number of times word appears in an extremely large body of texts (e.g., BNC, CELEX, BYU corpus). Once the frequency of words has been calculated, these can then be categorised as high or low frequency, based on the threshold selected by the experimenter. Typically, high frequency words occur more than 40 times per million words, whereas low frequency words occur less than 10 times per million words (Hand et al., 2010; Miellet, Sparrow & Sereno, 2007). Numerous studies have been conducted, recording eye movements, which demonstrate that word frequency has an effect on processing time. Results reliably show that high frequency words (e.g., *account, business*, *children*) require less processing time than low frequency words (e.g., *satchel, vocation, broccoli*) (Inhoff & Rayner, 1986; Kliegl, Grabner, Rolfs & Engbert, 2004; Rayner & Duffy, 1986; Rayner & Raney, 1996; Slattery, Pollatsek & Rayner, 2007; White, 2008). The robust nature of the effect makes it a standard for models of eye movement control while reading (e.g., The E-Z Reader model; Reichle, Rayner & Pollatsek, 2003).

Studies investigating eye movements have typically recoded monocularly and most investigating binocular coordination have utilised non-reading tasks (see **Chapter 1**). As a result, little is known about how the eyes coordinate during reading. It has been generally assumed that both eyes are fixating on precisely the same location during reading (Rayner, 1998; Radach & Kennedy, 2004). However, a number of studies conducted more recently have reported results contradicting this finding. Heller & Radach (1999) reported that binocular fixations were often disparate by 1-2 characters. Additionally, Liversedge et al. (2006) found that binocular fixations were aligned (where the eyes are within one character space of each other) in only around half (53%) of fixations. They also found that fixation times influenced the size of disparity, with disparities being smaller at the end of longer fixations.

Although both these studies help demonstrate that binocular fixation disparity is present during reading, they do not clearly establish the factors which affect it. Heller & Radach (1999) did attempt to identify how disparity is influenced by task demands in their experiment which presented participants with 200 lines of text in normal case and alternating case, while the differences in saccade amplitudes between the two eyes were recorded. Their results showed that there was greater disparity when text was written in normal case than when it was written in alternating case, from which they concluded that the visual system is able to tolerate a greater level of disparity under easy to read conditions.

Although methodologically different from Heller & Radach (1999), Hendriks (1996) also suggested that the type of reading material had an effect on binocular coordination. Hendriks' (1996) study, which recorded vergence velocities while participants read a list of unrelated words or a short passage of text, found that vergence velocities were slower when reading a list of unrelated words. Hendriks (1999) suggested that the absence of meaningful context when reading a list of unrelated words made the task more difficult.

However, the research into binocular fixation coordination during reading is not unequivocal. A recent study conducted by Bucci and Kapoula (2006) failed to reproduce these results. Participants in the study completed two tasks while their eye movements were tracked: the first was a non-reading task and the second was a single-word reading task. In the first task, participants were presented with LEDs placed horizontally. The target LED jumped 0° to 10° or 20° to the right or to the left. The second task involved fixating on a cross on the left side of a display screen, then pronouncing a word subvocally which was presented at the centre of the screen, and then fixating on a cross on the right side of the screen. Although Bucci and Kapoula (2006) found a difference in binocular coordination between children and adults, they did not find a difference between the tasks for either group. Based on these findings, they questioned the findings of Heller & Radach (1999) that task demands affected binocular coordination.

The lack of consistency in findings between the previously mentioned studies makes it difficult to draw any firm conclusions on the nature of binocular coordination during reading and the factors which influence it. Further research is required in order to understand what is happening. The findings from Bucci and Kapoula (2006) need to also be treated with some caution as single-word reading tasks do not allow for generalisability to normal reading conditions. The failure to find any differences between the tasks in Bucci and Kapoula's (2006) study, when compared to Hendriks (1996), could be because of the nature of the tasks used.

In order to gain clarity on the nature of binocular fixation disparity during reading properties of text which affect it, Juhasz et al. (2006) conducted their study, expanding on the research conducted by Heller & Radach (1999) and Bucci and Kapoula (2006). Juhasz et al. (2006) tracked participants' eye movements binocularly as they read sentences containing high and low frequency words. Additionally, half of their trials were written in normal case and the other half in alternate case. By including high and low frequency words, Juhasz et al. (2006) were able to establish whether difficulty in language processing influenced binocular disparity. Finally, by presenting trials in normal and alternate case, they were able to identify whether difficulties in visual processing influenced disparity.

The frequency of aligned fixations reported by Juhasz et al. (2006) was similar to that reported by Liversedge et al. (2006). Fixations were aligned 55% of the time and fixation durations were not affected by the pattern of binocular fixation disparity. With regards to the word frequency and text case manipulations that they made, neither variable had an effect on disparity. A standard effect was present, however, of word frequency on fixation times, with low frequency words being fixated on for longer than high frequency words.

Juhasz et al.'s (2006) findings are inconsistent with those of Heller & Radach (1999). While Heller & Radach (1999) reported reduced fixation disparity when text case was alternating, Juhasz et al. (2006) found no such effect. Their findings are also inconsistent with Hendriks (1996) who reported that task difficulty affected fixation disparity. However, the findings are consistent with Bucci and Kapoula (2006), who reported no differences in fixation disparity, regardless of the type of task.

All these different findings make it difficult to understand the properties of fixation disparity during reading. One of the key issues is that the four studies mentioned all investigated binocular coordination using different methods and taking different measures to infer disparity. Heller & Radach (1999) presented participants with passages of text, Hendriks (1996) and Juhasz et al.'s (2006) presented single sentences, and Bucci and Kapoula (2006) presented only single-word targets. Although the three former studies used somewhat similar methods, their results are inconsistent with one another. Additionally, the studies used different measures to infer disparity. Hendriks (1996) measured vergence velocities, Heller & Radach (1999) measured differences in saccade amplitudes, Juhasz et al. (2006) measured disparity in terms of the visual angle between the two eyes, and Bucci and Kapoula (2006) measured saccade latencies. The differing methods and measures taken make it almost impossible to draw direct comparisons between the studies and obscure the understanding of binocular coordination during reading. It also makes it very difficult to establish normative data on binocular fixation coordination.

Experiment 1

The aim of *Experiment 1* is to re-investigate the nature of binocular fixation disparity during reading by revisiting the experiment conducted by Juhasz et al. (2006). The experiment seeks to identify whether linguistic factors, which have been previously reported to induce processing difficulty, will be reflected in the nature of binocular fixation disparity. Additionally, it seeks to identify whether visual processing difficulty influences disparity, as has been previously reported. Thus, it is hypothesised that binocular fixation disparity will be reduced under conditions which make text difficult to read (i.e., low frequency words in alternating case) as the visual system is less tolerant of disparity under difficult conditions (Heller & Radach, 1999).

Method

Participants

Thirty-four University of Bedfordshire students (21 females; mean age = 24 years old, SD = 7 years) were recruited to take part in the study. All participants had normal or corrected to normal vision and were all native English speakers. None of the participants were diagnosed with any reading disorders.

Apparatus

Eye movements were recorded using an SR Research Desktop-Mount EyeLink 1000+ eye tracker, with a chin and forehead rest. The resolution of the eye tracker was less than 10 min of arc and its signal was sampled every millisecond. The tracker was interfaced with a personal computer. Sentences were presented on a 17-inch display unit, with participants positioned 560mm from the display: each character subtended 0.25 degrees of visual angle. Sentences were presented in black on a white background in a 14-point non-proportional font (Lucida Console) in the top-left corner of the display. Viewing was binocular with the movements of both eyes recorded. The brightness of the display was adjusted to a comfortable level and the room was lit dimly. Stimuli presentation and data collection was conducted using SR Research Experiment Builder and data pre-processing and analysis was conducted using EyeLink Data Viewer.

Design

A 2 (word frequency: high [HF] vs. low [LF]) × 2 (text case: normal [NC] vs. alternating [AC]) repeated measures experimental design was used. Target words appeared in one-line passages in which the sentence, including the target word, was presented in NC or AC. Passages were designed to accommodate both HF and LF target words. The HF target words were in NC for half of the sentences, while the LF target words were in AC; for the other half of sentences, HF target words were presented in AC, while LF target words were presented in NC. Participants were presented target words for a total of 80 experimental sentences, with each participant viewing 20 items in each of the 4 experimental conditions (HF-NC, HF-AC, LF-NC, and LF-AC). Target words were positioned near the middle of the line and sentences were presented in a different random order to participants. Binocular fixation disparity was measured in terms of the difference between the horizontal fixation positions of the two eyes. The difference was then converted to differences in character positions between the eyes for ease of discussion.

Materials

As this experiment was a replication, the target words and sentences presented were those used in the study by Juhasz et al. (2006; see Appendix I for stimuli). A total of 80 nouns were selected by Juhasz et al. – 40 HF nouns (*M* = 143 words per million using Celex written frequency; Baayen, Piepenbrock, & Guilkers, 1995) and 40 LF nouns (*M* = 1.35 words per million). To eliminate word length as a confounding variable, word length of HF and LF targets were matched pairwise (*M* = 7.85; range 7-10 characters). Two neutral sentence frames were created for each word pair so that it was plausible for either word to fit in the sentence. Predictability of the target word in the frame was assessed by showing the beginnings of sentences to another set of participants and asking them to write the next word they believed would fit in the sentence. Very low average predictability was reported with only 0.50% for high-frequency target words and 1.63% for low-frequency target words. The values did not differ significantly ($p > .20$). Sentence length ranged from 49-60 characters Examples of the experimental items can be viewed in Table 2.1.

Table 2.1. Example materials for *Experiment 1*

Freq.	*Case*	*Example Materials*
HF	NC	We saw the entire **process** being performed by the doctor.
	AC	PaUl aSkEd wHeThEr tHe **pRoCeSs** wOuLd tAkE A LoNg tImE.
LF	NC	We saw the entire **autopsy** being performed by the doctor.
	AC	PaUl aSkEd wHeThEr tHe **aUtOpSy** wOuLd tAkE A LoNg tImE.

Note: HF = high frequency; LF = low frequency; NC = normal case; AC = alternating case. Target words presented in bold for illustration purposes only.

Procedure

Participants were invited to take part in a study investigating eye movements during reading. On arrival to the laboratory, participants were informed of the aims of the study, given both verbal and written instructions detailing the procedure to be undertaken, and informed of right to withdraw at any time. They were also made aware that all data acquired would be retained for re-analysis and as complementary data for future research

Prior to presenting the sentences, the eye tracking device was calibrated using a 9-point calibration display which was made up of a series of calibration points extending over the horizontal and vertical extremities of the display. After the participants fixated on each point in a random order, the validity of the calibration was checked; only if the calibration was accurate (within 1 degree of each calibration point) was the experiment continued. This process was done for each eye independently and the calibration processes was repeated during the experiment if the need arose.

Once the device had been calibrated, the experiment commenced. Each trial began with a drift-check target [⦿] being presented in the top-left corner of the display, which corresponded to the position of the beginning of the sentence to be displayed. Once the researcher could see that participant had fixated on the target, the sentence was revealed. After the participant completed reading the sentence, they were requested to left click the mouse button to clear the screen and move on to the next trial.

The experimental session began with 8 practice trials (four in normal case and four in alternating case) to provide an opportunity for participants to familiarise themselves with the task. Participants were also required to answer comprehension questions (simple *yes* or *no* questions related to the previous item) after 25% of trials; mean comprehension was 94%.

Results

Descriptive statistics for sentence reading

General descriptive statistics are reported for binocular coordination for sentence reading, following the examples of both Liversedge et al. (2006) and Juhasz et al. (2006). These statistics are useful in characterising the nature of binocular coordination during reading. A number of descriptive statistics were computed for each participant: the average absolute binocular disparity at the end of fixation, the percentage of aligned, uncrossed, and crossed fixations, and the average fixation duration. Staying consistent with both Liversedge et al. (2006) and Juhasz et al. (2006), prior to analysis, fixations were removed based on the following criteria: (a) tracking was lost for either eye, (b) the fixation duration was below 80 ms or above 1,200 ms, and (c) the binocular fixation disparity was outside of 2.5 standard deviations of the participant's mean fixation disparity.

Using the criteria above, 6.3% of fixations were removed, leaving 23,894 fixations for analysis. Results showed the average absolute fixation disparity was 0.85 characters (SD = 0.85). However, based on this information alone, it was not possible to distinguish the pattern of binocular fixation disparity. Fixations were, therefore, categorised into three types in the manner set out by Liversedge et al. (2006). Cases in which the fixations of each eye were within one character of each other were considered *aligned*; where the eyes were more than one character apart, but did not cross were considered *uncrossed*; and where the eyes were more than one character apart, but the left eye was further ahead than the right eye and vice versa were considered crossed. Aligned fixations made up 69% of fixations. For the remaining fixations, 20% were uncrossed and 11% were crossed. Both the percentages of uncrossed (27%) and crossed (18%) fixations are less than those reported by Juhasz et al. (2006). Further inspection reported that of those whose fixations were disparate, the majority of participants (19 out of 33) showed more uncrossed than crossed fixations.

The mean fixation disparity for uncrossed fixations was 1.85 characters (SD = 0.76) and for crossed fixations it was 1.83 characters (SD = 0.96). An independent-samples t test reported a non-significant difference in size of disparity, $t(4611) = -1.11$, $p = .27$. Levene's Test indicated unequal variances, $F = 33.57$, $p < .001$, so degrees of freedom were adjusted from 7406 to 4611.

The mean fixation duration across all fixations was 233 ms. Results of a one-way repeated measures analysis of variance (ANOVA) reported that fixation duration was significantly related to the nature of the fixation disparity (aligned = 226 ms, uncrossed = 239 ms, crossed = 244 ms; see Figure 2.1), $F(1.98, 5339.85) = 28.21$, $p < .001$, $\eta^2 = .01$ (Mauchly's test indicated that the assumption of sphericity had been violated, $X^2(2) = 31.55$, $p < .001$, therefore Huynh-Feldt corrected tests were reported). Bonferroni post-hoc tests revealed that the fixation durations for uncrossed ($p < .001$) and crossed ($p < .001$) fixations were significantly longer than aligned fixations. There were no significant differences found between uncrossed and crossed fixations ($p = .24$).

Target word analyses

A 2 (word frequency: high vs. low) × 2 (text case: normal vs. alternate) ANOVA was computed for first fixation duration (FFD), gaze duration (GD), and binocular fixation disparity (BFD; on the first fixation) on the target words for both participants (F_1) and items (F_2). Both word frequency and text case were regarded as within-participant variables and within-item variables (frequency was treated as a within-item variable as the target word was presented across both sentence frames). Trials were removed from analyses if tracking was lost for either eye, the target word was skipped, fixation duration was shorter than 80 ms or longer than 1,200 ms, and fixation disparity was 2.5 standard deviations outside of the participant's mean BFD. Using these criteria, 27% of fixations were removed, leaving 2,023 fixations for analysis.

Figure 2.1. Mean fixation durations for aligned, uncrossed, and crossed fixations across all fixations for *Experiment 1* with error bars (±1 *SE*)

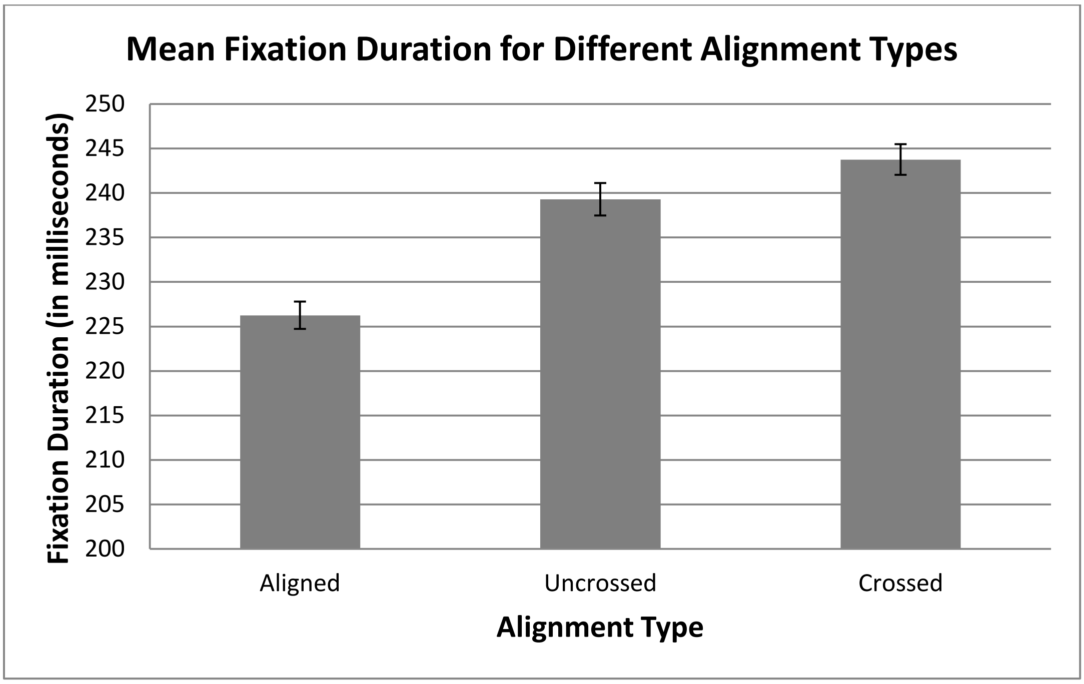


Table 2.2. Mean (and SD) FFD, GD, and BFD of target words as a function of word frequency and text case

Frequency	*Case*	*FFD*	*GD*	*BFD*
High	Normal	221 (53)	243 (73)	.72 (.33)
	Alternating	232 (55)	260 (72)	.78 (.34)
	Total	227 (54)	251 (73)	.75 (.33)
Low	Normal	242 (59)	287 (91)	.79 (.38)
	Alternating	252 (54)	339 (125)	.77 (.34)
	Total	247 (56)	313 (108)	.78 (.36)
Total	Normal	232 (56)	265 (82)	.75 (.35)
	Alternating	242 (54)	299 (98)	.78 (.34)
	Total	237 (55)	282 (90)	.77 (.35)

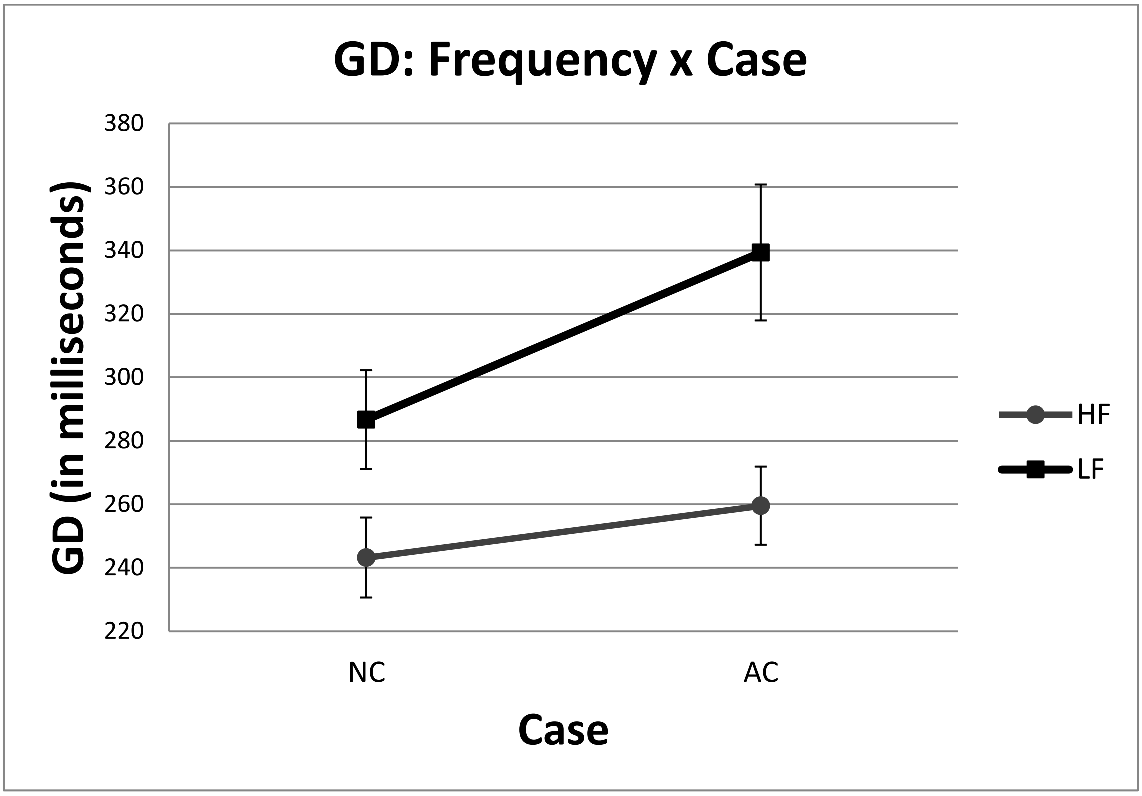
Note: FFD = first fixation duration, measured in milliseconds; GD = gaze duration, measured in milliseconds; and BFD = binocular fixation disparity, measured in characters. Figures reported are the mean values, with the standard deviations in parentheses.

Means and standard deviations for FFD, GD, and BFD on target words are presented in Table 2.2. FFD was significantly longer for LF words than for HF words by 20 ms $F_1(1, 33) = 43.83$, $MSE = 325.55$, $p < .001$, $\eta^2 = .57$; $F_2(1, 39) = 22.04$, $MSE = 560.30$, $p = .001$, $\eta^2 = .36$. Target words presented in AC were also fixated significantly longer, by 10 ms, than target words in NC, $F_1(1, 33) = 7.74$, $MSE = 490.44$, $p = .009$, $\eta^2 = .19$; $F_2(1, 39) = 10.56$, $MSE = 541.97$, $p = .002$, $\eta^2 = .21$. There were no significant interactions of frequency and case on FFD (both *ps* > .72).

A similar pattern was observed for GD, with LF words being gazed at 62 ms longer than HF words, $F_1(1, 33) = 41.36$, $MSE = 3121.47$, $p < .001$, $\eta^2 = .56$; $F_2(1, 39) = 30.81$, $MSE = 4177.51$, $p < .001$, $\eta^2 = .44$. GD for target words in AC was also significant longer, by 34 ms, $F_1(1, 33) = 22.67$, $MSE = 1784.59$, $p < .001$, $\eta^2 = .41$; $F_2(1, 39) = 15.94$, $MSE = 2863.54$, $p < .001$, $\eta^2 = .29$. A significant interaction was also found (see Figure 2.2), with GD being longest for LF words presented in AC (339 ms), $F_1(1, 33) = 8.59$, $MSE = 1304.10$, $p = .006$, $\eta^2 = .21$; $F_2(1, 39) = 6.44$, $MSE = 2254.50$, $p = .014$, $\eta^2 = .15$. Subsequent analyses of simple effects using paired samples t tests revealed a significant difference in GD between HF and LF target words written in AC, $t(33) = -5.70$, $p < .001$, $d = .78$.

Although large effects were observed for both FFD and GD, neither frequency nor case significantly affected mean BFD. Measurements for BFD were taken at the end of fixation (after vergence movements had been completed). The results showed non-significant main effects for frequency, $F_1(1, 33) = 2.28$, $MSE = .02$, $p = .14$; $F_2 < 1$, and case (both *F*s < 1). Interactions were also non-significant, $F_1(1, 33) = 1.95$, $MSE = .03$, $p = .17$; $F_2 < 1$.

Figure 2.2. Two-way interaction between frequency and case on gaze duration (GD) with error bars (±1 *SE*)



Note: HF = high frequency; LF = low frequency; NC = normal case; AC = alternating case

Discussion

The aim of *Experiment 1* was to revisit the frequency × case relationship on binocular fixation disparity that had been investigated by Juhasz et al. (2006). It was hypothesised that conditions in which linguistic and visual processing difficulties were induced would result in reduced fixation disparities as had been previously reported by Heller & Radach (1999). However, the results of the present experiment did not find such differences. Neither linguistic nor orthographic manipulations saw any change disparity; therefore, the experimental hypothesis is rejected.

The results of the present study are not particularly surprising and are almost identical to those found by Juhasz et al. (2006), with a few notable exceptions. The first is in the frequency of aligned fixations. Whereas both Juhasz et al. (2006) and Liversedge et al. (2006) reported that around half of fixations were aligned, 69% of fixations were aligned in the present experiment. This is particularly interesting because the size of disparity for non-aligned fixations found in this experiment was almost identical to that of Juhasz et al. (2006), so the frequency of non-aligned fixations does not appear to be related to the size of disparity. A more interesting finding is that unlike Juhasz et al. (2006) and Liversedge et al. (2006), fixation duration was related to the nature of fixation disparity in the present study. Non-aligned fixations were significantly longer than aligned fixations, suggesting that a processing difficulty occurs when binocular coordination is poor.

With regards to the absence of any effect of case manipulation on disparity, this is not surprising either, as Juhasz et al. (2006) reported the same results, counter to what Heller & Radach (1999) found. The pattern of disparity observed was also similar to that of Juhasz et al. (2006). Participants showed an increase in fixation disparity when text was manipulated to induce processing difficulty, both linguistic and orthographic. Although, it should be noted that the differences were non-significant in both the present experiment and in Juhasz et al.'s (2006).

However, there are numerous differences between the present study and Heller & Radach's (1999) which could have contributed to the varying findings. Heller & Radach (1999) presented participants with passages of text containing 200 lines, whereas in the present experiment single, unrelated sentences were shown to participants during each trial. It is possible that presenting passages of text in alternating case produces different results to single sentences, due to multiline passages possibly creating a visual environment which makes it more difficult to read. Additionally, the use of longer passages may provide additional context which makes use of higher level cognitive factors. An effect of meaningful context was also reported by Hendriks (1996). Thus, the effects of context need to be explored further.

The effects of contextual predictability have been studied widely and the presence of a processing cost for target words when context is manipulated has been well established. However, the effects of contextual predictability on binocular coordination have yet to be studied. **Chapter 3** will investigate this relationship.

<u>**Chapter 3**</u>

Predictability, frequency, and case – implications for binocular co-ordination during reading

Introduction

The effects of contextual predictability, often referred to as *contextual constraint*, on eye movement behaviours have been studied widely over recent decades (Balota, Pollatsek & Rayner, 1985; Hand et al., 2010; Kliegl, Grabner, Rolfs & Engbert, 2004; Morris, 1994; Rayner & Well, 1996; Rayner, Warren, Juhasz & Liversedge, 2004). Contextual predictability refers to the likelihood a specific word will occur, considering the way the discourse has developed up until that point. For example, the word *pizza* is highly predictable in the context, *He grabbed another slice of* _____, but has low predictability in the context *He gazed lovingly upon the* ______. Unlike word frequency, there are no corpuses to determine the predictability of a word given a certain context. Instead, *Cloze* and *word rating* tasks are used to determine the probability of a word appearing in a certain fragment of text.

Predictability has been found to have an influence on a number of eye movement behaviours. Although there have been some differences in experiments investigating how and when predictability effects appear, the evidence from these experiments has convincingly shown that target words in a highly predictable context are read faster than those in a low predictability context (Binder, Pollatsek & Rayner, 1999; Altarriba, Kroll, Sholl & Rayner, 1996; Rayner, Ashby, Pollatsek & Reichle, 2004). This effect is present on both first fixation duration (Lavigne, Vitu, & d'Ydewalle, 2000) and gaze duration (Balota et al. 1985; Rayner & Well, 1996; Lavigne et al. 2000).

However, while predictability has been investigated in relation to reading times, it has yet to be investigated in relation to binocular coordination. Hendriks (1996) suggested context had affected binocular disparity, but the study did not manipulate predictability, so conclusions were drawn from the differences in results produced by single-word and sentence reading tasks. While Juhasz et al. (2006) found no differences in fixation disparity when manipulating word frequency and case, their single-line sentence reading task did not manipulate contextual predictability either. The same is the case for Heller & Radach (1999); however, given the large passages of text that they presented in their experiments, it would be logical to assume that some degree of meaningful context was available which may have accounted for why they observed fixation disparity while Juhasz et al. (2006) did not.

Experiment 2

The aim of *Experiment 2* is to understand the role of contextual predictability in binocular coordination. However, predictability will not be investigated in isolation. This experiment will expand on *Experiment 1*, manipulating word frequency and text case in addition to contextual predictability in order to understand the effects of all three factors. Given the trials in the current experiment are attempting to simulate Heller & Radach (1999) to some degree, it would be logical to assume that a similar pattern of disparity will be found. Thus, it is hypothesised that binocular fixation disparity will be reduced under conditions which make text difficult to read as the visual system is less tolerant of disparity under difficult conditions.

Methods

Participants

Twenty-six University of Bedfordshire students (17 females; mean age 24 years old, SD = 5 years) were recruited to take part in the study. All participants had normal or corrected to normal vision and were all native English speakers. None of the participants were diagnosed with any reading disorders.

Apparatus

See Chapter 2, *Experiment 1*.

Design

A 2 (word frequency: high [HF] vs. low [LF]) × 2 (text case: normal [NC] vs. alternating [AC]) × 2 (predictability: high [HP] vs. low [LP]) repeated measures experimental design was used. Target words appeared in two-line passages, with each target word being considered either contextually predictable (HP) or not (LP). The passages were designed to accommodate a HF and LF target word. HF target words were in HP for half of the sentences, while the LF target words were in LP; for the other half of sentences, HF target words were presented in LP, while LF target words were presented in HP. Of these 4 conditions, half were presented in NC and the other half in AC, resulting in a total of 8 experimental conditions (HF-NC-HP, HF-NC-LP, HF-AC-HP, HF-AC-LP, LF-NC-HP, LF-NC-LP, LF-AC-HP, and LF-AC-LP). For a total of 88 items, there were 11 items for each condition. Target words were positioned near the middle of the line and sentences were presented in a different random order to participants. Binocular fixation disparity was measured in terms of the difference between the horizontal fixation positions of the two eyes. The difference was then converted to differences in character positions between the eyes for ease of discussion.

Materials

As Heller & Radach (1999) did not control for frequency or predictability in their experiment, the rich linguistic condition of their experiment is being simulated, while controlling for frequency and predictability, by using the items utilised by Hand et al. (2010; see Appendix II for stimuli). A total of 88 nouns were selected by Hand et al. (2010), using the British National Corpus (BNC) to acquire word frequencies – 44 HF nouns (*M* = 144 words per million) and 44 LF nouns (*M* = 5 words per million). To eliminate word length as a confounding variable, word length of HF and LF targets were matched pairwise (*M* = 5.89; range 5-8 characters).

In order to determine predictability, Hand et al. (2010) presented twenty participants with the passage of text and presented the target word in bold. Participants then rated how predictable they considered the target word to be in that passage on a scale ranging from 1 (highly unpredictable) to 7 (highly predictable). Predictability ratings for the target words for their various conditions were 6.2 (HF-HP), 4.1 (HF-LP), 6.1 (LF-HP), and 3.7 (LF-LP). See Hand et al. (2010) for a complete explanation of materials. Examples of the experimental items can be viewed in Table 3.1.

Table 3.1. Example materials for *Experiment 2*

Freq.	*Case*	*Pred.*	*Example*
HF	NC	HP	On holiday for a week, Jill and Harry decided to redecorate some rooms in their **house** that they felt needed making over.
		LP	Exhausted from driving, and lost on the dusty highway, Tony decided to stop at the first **house** to get directions.
	AC	HP	oN HoLiDaY FoR A WeEk, JiLl aNd hArRy dEcIdEd tO ReDeCoRaTe SoMe rOoMs iN ThEiR **HoUsE** ThAt tHeY FeLt nEeDeD MaKiNg oVeR.
		LP	eXhAuStEd fRoM DrIvInG, aNd lOsT On tHe dUsTy hIgHwAy, tOnY DeCiDeD To sToP At tHe fIrSt **hOuSe** tO GeT DiReCtIoNs.
LF	NC	HP	Exhausted from driving, and lost on the dusty highway, Tony decided to stop at the first **motel** to get directions.
		LP	On holiday for a week, Jill and Harry decided to redecorate some rooms in their **motel** that they felt needed making over.
	AC	HP	eXhAuStEd fRoM DrIvInG, aNd lOsT On tHe dUsTy hIgHwAy, tOnY DeCiDeD To sToP At tHe fIrSt **mOtEl** tO GeT DiReCtIoNs.
		LP	On hOlIdAy fOr a wEeK, jIlL AnD HaRrY DeCiDeD To rEdEcOrAtE sOmE RoOmS In tHeIr **mOtEl** tHaT ThEy fElT NeEdEd mAkInG OvEr

Note: HF = high frequency; LF = low frequency; NC = normal case; AC = alternating case; HP = high predictability; LP = low predictability. Target words highlighted in bold for illustrative purposes only.

Procedure

See Chapter 2, *Experiment 1*. The only notable difference in procedure is that comprehension questions were not asked in this experiment.

Results

Descriptive statistics for sentence reading

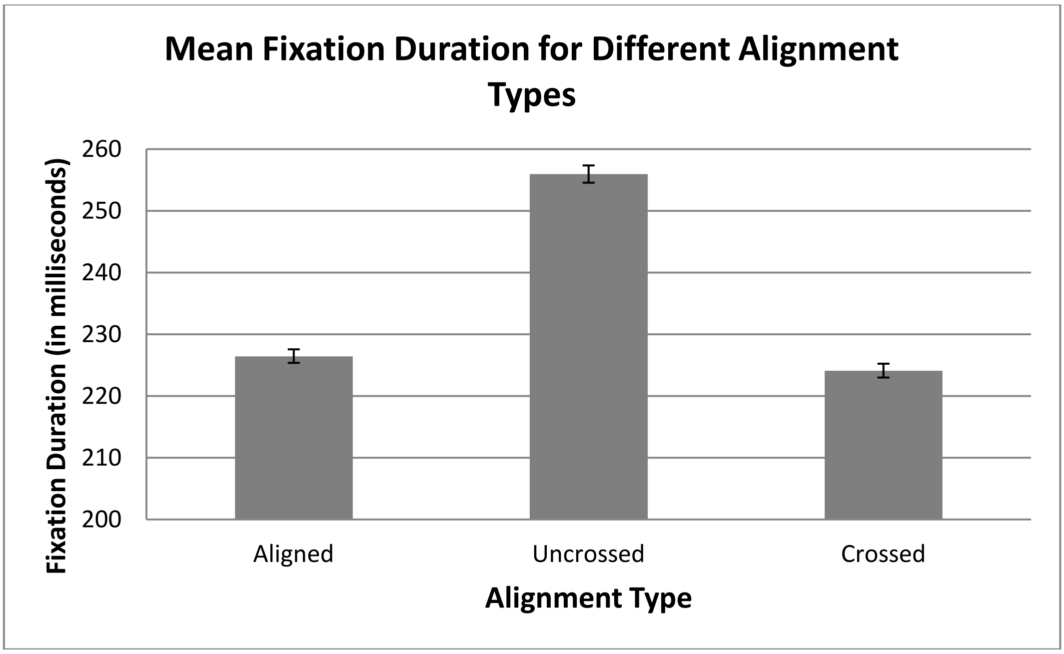
As in the previous experiment, general descriptive statistics are reported for binocular coordination for sentence reading in order to characterise the nature of binocular coordination during reading. The average absolute binocular disparity at the end of fixation, the percentage of aligned, uncrossed, and crossed fixations, and the average fixation duration were computed for each participant. Staying consistent with both Liversedge et al. (2006) and Juhasz et al. (2006), prior to analysis, fixations were removed based on the following criteria: (a) tracking was lost for either eye, (b) the fixation duration was below 80 ms or above 1,200 ms, and (c) the binocular fixation disparity was outside of 2.5 standard deviations of the participant's mean fixation disparity.

A total of 6.9% of fixations were removed using the criteria above, leaving 37,379 fixations for analysis. Results showed that the absolute binocular fixation disparity was 0.88 characters (SD = 0.80), similar to *Experiment 1*. Fixations were again categorised as *aligned*, *uncrossed*, or *crossed*, using the criteria detailed in the previous experiment. Aligned fixations made up 67% of the total fixations. Of the remaining 33%, 17% were uncrossed and 16% were crossed. The percentage of uncrossed fixations was lower than in *Experiment 1* (17% vs. 27%) and the number of crossed fixations was higher (16% vs. 11%). Similarly to *Experiment 1*, further inspection reported that the majority of participants (19 out of 26) showed more uncrossed fixations than crossed fixations.

For disparate fixations, the mean fixation disparity for uncrossed fixations was 1.60 characters (SD = 0.49) and for crossed fixations was 2.05 characters (SD = 0.80). An independent-samples t test reported a significant difference in size of disparity, $t(9540) = 36.71$, $p < .001$, $d = .68$. Levene's Test indicated unequal variances, $F = 1548.87$, $p < .001$, so degrees of freedom were adjusted from 12378 to 9540.

The mean fixation duration across all fixations was 234 ms. Results of a one-way repeated measures analysis of variance (ANOVA) reported that fixation duration was significantly related to the nature of the fixation disparity (aligned = 229 ms, uncrossed = 258 ms, crossed = 224 ms; see Figure 3.1), $F(1.93, 11292.32) = 212.36$, $p < .001$, $\eta^2 = .04$ (Mauchly's test indicated that the assumption of sphericity had been violated, $X^2(2) = 225.56$, $p < .001$, therefore Huynh-Feldt corrected tests were reported). Bonferroni post-hoc tests revealed a pattern different to *Experiment 1*, with fixation durations for aligned ($p < .001$) and crossed ($p < .001$) fixations being significantly shorter than uncrossed fixations. There were no significant differences found between aligned and crossed fixations ($p = .39$).

Figure 3.1. Mean fixation durations for aligned, uncrossed, and crossed fixations across all fixations for *Experiment 2* with error bars (±1 *SE*)

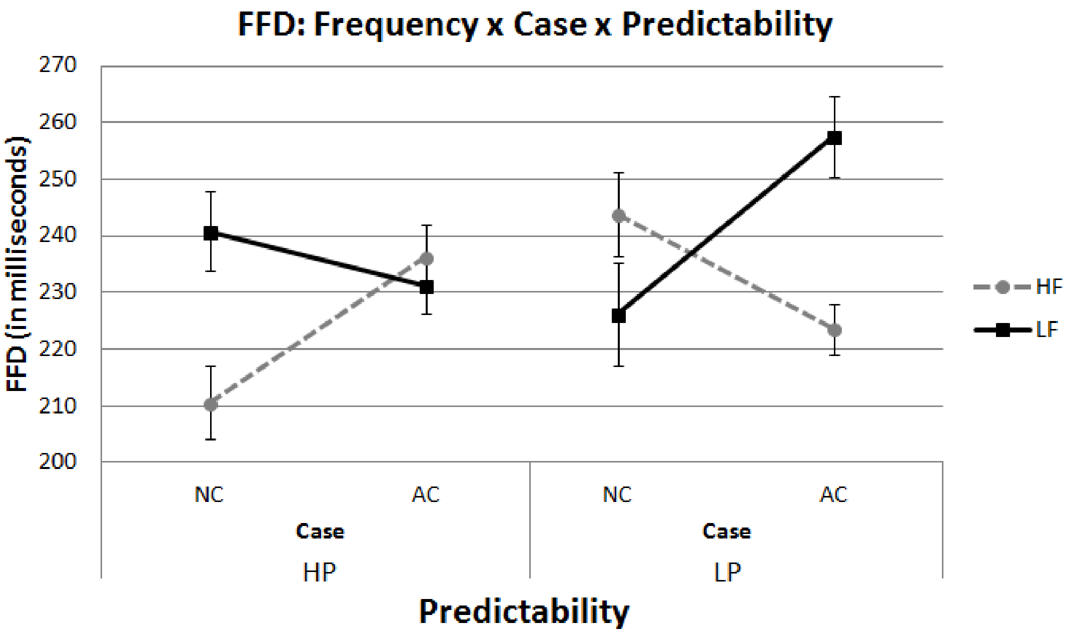


Target word analyses

A 2 (word frequency: high vs. low) × 2 (text case: normal vs. alternate) × 2 (predictability: high vs. low) ANOVA was computed for first fixation duration (FFD), gaze duration (GD), and binocular fixation disparity (BFD; on the first fixation) on the target words for both participants (F_1) and items (F_2). Word frequency, text case, and predictability were all regarded as between-participant variables (due to participants not having taken part in all eight combinations of conditions, frequency and predictability had to be analysed as between participant variables) and between-item variables for the analyses. Prior to analysis, trials were removed using the criteria mentioned earlier. As a result, 38% of fixations were removed, leaving 1,434 fixations for analysis.

Means and standard deviations for fixation disparity, FFD, and GD on target words are presented in Table 3.2. FFD was significantly longer for LF words than for HF words by 10 ms, but this was only significant by item analyses, $F_1(1, 96) = 1.15$, $p = .29$; $F_2(1, 338) = 4.89$, $p = .03$, $\eta^2 = .01$. Main effects for case, $F_1 < 1$; $F_2(1, 338) = 2.08$, $p = .15$, and predictability, $F_1 < 1$; $F_2(1, 338) = 2.91$, $p = .09$, were both non-significant. Two-way interactions between frequency and case, frequency and predictability, and predictability and case were also all non-significant (all *ps* > .39). However, significant three-way interactions between frequency, case, and predictability on FFD were reported, $F_1(1, 96) = 4.97$, $p = .03$, $\eta^2 = .05$; $F_2(1, 338) = 21.24$, $p < .001$; $\eta^2 = .06$ (see Figure 3.2). Subsequent simple interactions revealed significant two-way interactions for frequency and case on FFD for target words in sentences of both HP, $F_1(1,48) = 1.80$, $p = .19$; $F_2(1,167) = 8.28$, $p = .005$; $\eta^2 = .05$, and LP, $F_1(1,48) = 3.26$, $p = .08$; $F_2(1,171) = 13.08$, $p < .001$, $\eta^2 = .07$. FFD was significantly shorter for HF target words written in NC in sentences with HP (211 ms) and significantly longer for LF target words written in AC in sentences with LP (258 ms).

Figure 3.2. Three-way interaction between frequency, case, and predictability on first fixation duration (FFD) with error bars (±1 *SE*)

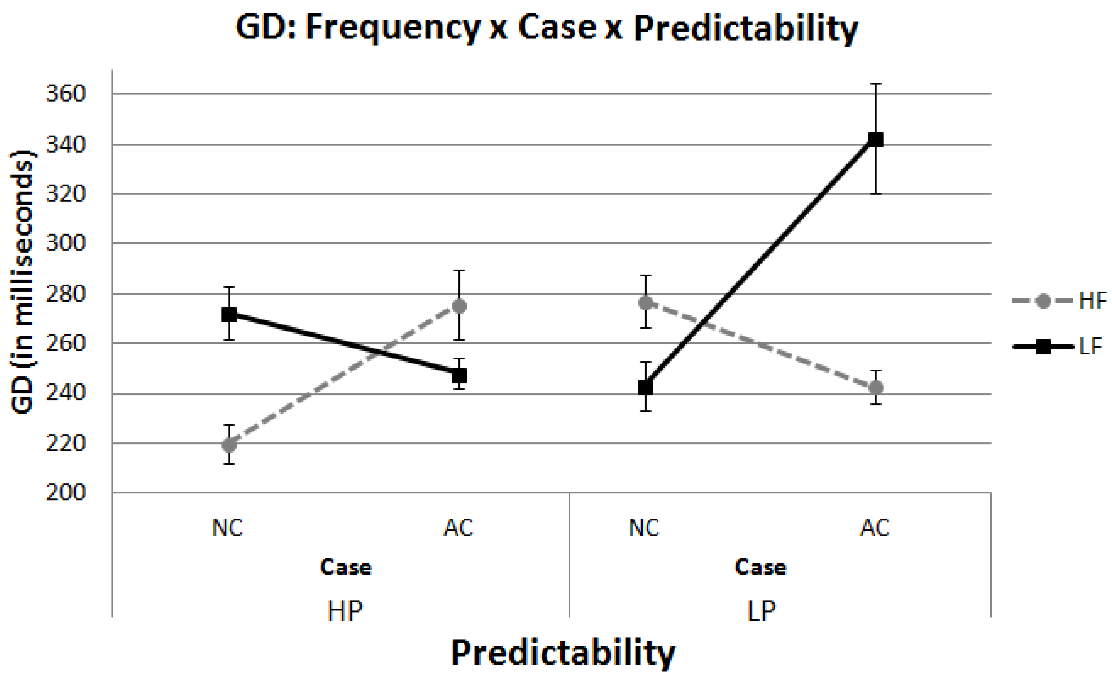


Note: HF = high frequency; LF = low frequency; NC = normal case; AC = alternating case; HP = high predictability; LP = low predictability.

A slightly different pattern was observed for GD. Main effects for word frequency reported that LF words were gazed at 23 ms longer than HF words, significant by item analyses, $F_1(1, 96) = 1.67$, $p = .20$; $F_2(1, 338) = 7.07$, $p = .008$, $\eta^2 = .02$. Similarly, target words in AC were fixated on for 23 ms longer than words written in NC, significant by item analyses, $F_1(1, 96) = 1.69$, $p = .20$; $F_2(1, 338) = 7.96$, $p = .005$, $\eta^2 = .02$. Finally, main effects for predictability reported that target words in a LP context were fixated on for 22 ms longer than target words in a HP context, again, significant by item analyses only, $F_1 < 1$; $F_2(1, 338) = 6.73$, $p = .01$, $\eta^2 = .02$. Two-way interactions between frequency and case, $F_1 < 1$; $F_2(1, 338) = 2.42$, $p = .12$, frequency and predictability, $F_1 < 1$; $F_2(1, 338) = 1.45$, $p = .23$, and predictability and case, $F_1 < 1$; $F_2 < 1$, on GD were also all non-significant. Similarly to FFD, significant three-way interactions between frequency, case, and predictability on GD were found, $F_1(1, 96) =$

9.47, p = .003, η^2 = .09; F_2(1, 338) = 39.09 p < .001, η^2 = .10 (see Figure 3.3). Simple interactions revealed significant two-way interactions for frequency and case on GD, for target words in sentences of both HP, F_1(1,48) = 3.07, p = .09; F_2(1,167) = 15.91, p < .001, η^2 = .09, and LP, F_1(1,48) = 6.67, p = .01, η^2 = .12; F_2(1,171) = 23.59, p < .001, η^2 = .12. GD was significantly shorter for HF target words written in NC in sentences with HP (220 ms) and significantly longer for LF target words written in AC in sentences with LP (342 ms).

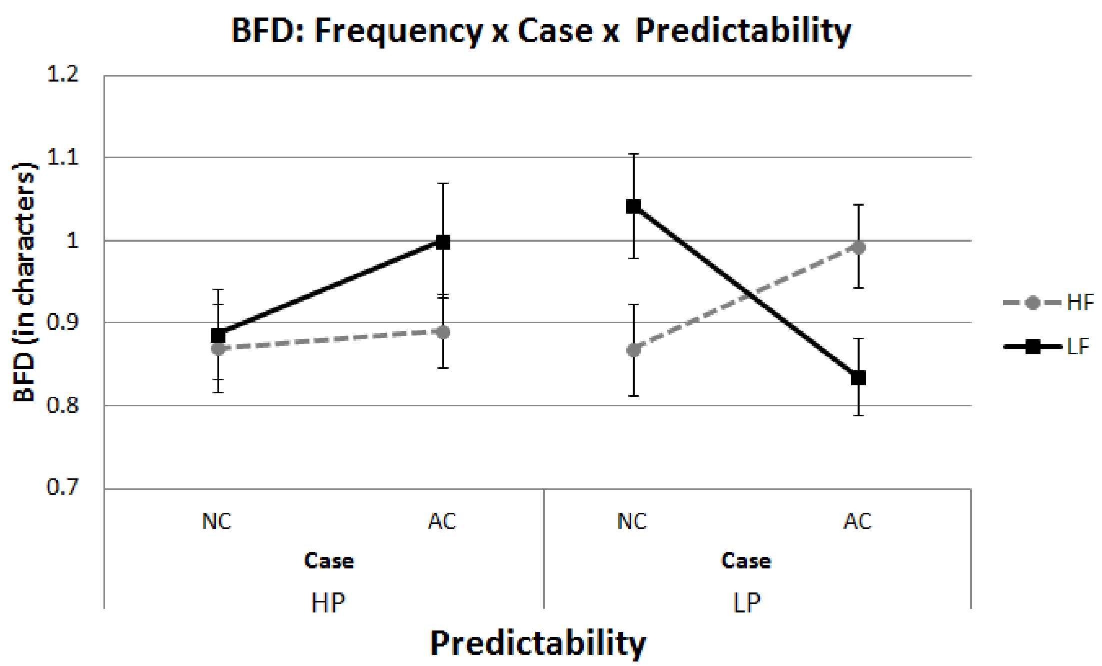
Figure 3.3. Three-way interaction between frequency, case, and predictability on gaze duration (GD) with error bars (±1 *SE*)



Note: HF = high frequency; LF = low frequency; NC = normal case; AC = alternating case; HP = high predictability; LP = low predictability.

Although some significant main effects were observed for both FFD and GD, neither frequency nor case nor predictability alone significantly affected mean BFD (all *ps* > .36). Similarly, two-way interactions between frequency and case, F_1 < 1; F_2(1, 338) = 2.34, p = .13, frequency and predictability (both *F*s < 1), and predictability and case, $F_1 < 1$; $F_2(1, 338) = 1.92$, $p = .17$, on BFD were also all non-significant. However, significant three-way interactions were once again found for item analyses, $F_1 < 1$; $F_2(1, 338) = 7.37$, $p = .007$, $\eta^2 = .02$. Simple interactions revealed a significant two-way interaction for frequency and case on BFD, when the target word was in a LP sentence, $F_1 < 1$; $F_2(1, 171) = 9.38$, $p = .003$, $\eta^2 = .05$ (see Figure 3.4). Subsequent independent t tests investigating simple effects revealed a significant difference in BFD between HF (.87 character) and LF (1.04 characters) target words written in normal case, $t(85) = -2.07$, $p = .04$, $d = .44$; between HF (.99 characters) and LF (.83 characters) target words written in alternate case, $t(86) = 2.30$, $p = .02$, $d = .49$; and LF words written in NC (1.04 characters) or AC (0.83 characters), $t(77.68) = 2.63$, $p = .01$, $d = .56$.

Figure 3.4. Three-way interaction between frequency, case, and predictability on binocular fixation disparity (BFD) with error bars (±1 *SE*)



Note: HF = high frequency; LF = low frequency; NC = normal case; AC = alternating case; HP = high predictability; LP = low predictability.

Table 3.2. Mean (and SD) FFD, GD, and BFD of target words as a function of word frequency, text case, and predictability.

Frequency	*Case*	*Predictability*	*FFD*	*GD*	*BFD*
High	Normal	High	211 (41)	220 (51)	.87 (.34)
		Low	244 (49)	277 (71)	.87 (.37)
		Total	228 (48)	250 (68)	.87 (.35)
	Alternating	High	236 (38)	276 (91)	.89 (.29)
		Low	224 (29)	243 (45)	.99 (.34)
		Total	230 (34)	259 (73)	.94 (.32)
	Total	High	224 (41)	248 (78)	.88 (.31)
		Low	234 (41)	260 (61)	.93 (.35)
		Total	229 (42)	254 (70)	.91 (.34)
Low	Normal	High	241 (47)	273 (70)	.89 (.36)
		Low	226 (59)	243 (60)	1.04 (.42)
		Total	234 (54)	258 (69)	.96 (.39)
	Alternating	High	231 (33)	248 (40)	1.00 (.46)
		Low	258 (47)	342 (148)	.83 (.31)
		Total	244 (42)	295 (118)	.92 (.40)
	Total	High	236 (41)	260 (58)	.94 (.41)
		Low	242 (55)	293 (124)	.94 (.38)
		Total	239 (48	277 (98)	.94 (.40)
Total	Normal	High	226 (47)	247 (67)	.88 (.35)
		Low	235 (55)	260 (69)	.95 (.40)
		Total	231 (51)	254 (68)	.92 (.38)
	Alternating	High	234 (35)	262 (71)	.95 (.39)
		Low	241 (42)	293 (120)	.91 (.33)
		Total	237 (39)	277 (99)	.93 (.36)
	Total	High	230 (41)	255 (69)	.91 (.37)
		Low	238 (49)	277 (99)	.93 (.37)
		Total	234 (45)	266 (86)	.92 (.37)

Note: FFD = first fixation duration, measured in milliseconds; GD = gaze duration, measured in milliseconds; and BFD = binocular fixation disparity, measured in characters. Figures reported are the mean values, with the standard deviations in parentheses.

Discussion

The aim of *Experiment 2* was to determine the influence of linguistic and orthographic manipulations on binocular fixation disparity, extending *Experiment 1* by investigating the influence of contextual predictability in addition to word frequency and text case. It was hypothesised that fixation disparity would be reduced under conditions which made reading difficult. Based on the findings of *Experiment 2*, significant reductions in disparity were observed, to some degree, under difficult reading conditions; therefore, the hypothesis is partially accepted.

Before discussing the key findings in the present study, some peculiar findings with relation to the sizes of disparate fixations and the nature of their relationship to fixation times are worth noting. *Experiment 2* reported that crossed fixations were significantly larger than uncrossed fixations, a difference which was not reported in *Experiment 1*, by Juhasz et al. (2006) in their original experiment, or by Liversedge et al. (2006). Additionally, fixation duration was related to the nature of disparity, as in *Experiment 1*; however, the way they related differed. *Experiment 1* found that non-aligned fixations were significantly longer than aligned fixations, suggesting poor fixation alignment has a processing cost. However, *Experiment 2* found that uncrossed fixations were fixated on for significantly longer than aligned or crossed fixations. With this being the case, it is too hasty to simply conclude that non-aligned fixations have a processing cost. The relationship appears to be more complicated than that.

One of the reasons for these differences in these results between the experiments could be due to the nature of the stimuli used. *Experiment 1* used single-line sentences, whereas *Experiment 2* presented participants with a passage of text across two lines. The absence of any cost of crossed fixations on fixation durations could suggest that the visual system is able to able to tolerate crossed disparity more than it is uncrossed disparity. However, all these suggestions are merely speculative at the moment and the inconsistencies in fixation disparity sizes and fixation durations depending on the nature of disparity will require further investigation to understand why fixations differed as they did.

Moving onto the key objectives of *Experiment 2,* some interesting findings were reported, particularly in relation to the pattern of disparity displayed. Heller & Radach (1999) found that disparity was reduced under conditions which made reading difficult; whereas Juhasz et al. (2006) found that the level of reading difficulty had no effect on fixation disparity. On the contrary, they reported a slight increase in fixation disparity under conditions which made it difficult to read; although it should be noted that these differences were non-significant. The current experiment affirmed both of these findings. When only investigating the influence of word frequency and text case, the results were almost identical to those of Juhasz et al. (2006) – neither variable significantly affected binocular fixation disparity, but a pattern of disparity was observed which showed an increase in disparity under conditions which made reading difficult. However, when the effects of contextual predictability were also taken into consideration and predictability was low, binocular fixation disparity reduced significantly – a pattern similar to that of Heller & Radach (1999).

These findings suggest that the relationship between reading difficulty and fixation disparity is not a simple linear one, but rather one which may be curvilinear. Disparity is relatively small under conditions which make it easy to read, with disparity increasing when some difficulty in induced. Finally, under exceedingly difficult conditions, disparity reduces again, shrinking to a size which is smaller than under conditions which make it easy to read. However, caution should be taken when attempting to interpret these results as curvilinear as (1) these results were found only during item analyses and (2) only linear statistical models were used. The process of dichotomisation, where continuous variables such as frequency and predictability are assigned to categories in order to perform ANOVAs, results in a loss of rich continuous information. Future studies may wish to utilise linear mixed-models, which would not only allow keeping the variables continuous, but also allow for the inclusion of variables such as word length. Nonetheless, *Experiment 2* does present some interesting new insights into the nature of fixation disparity during reading, highlighting the need for further research.

Chapter 4

General Discussion

The present experiments aimed to further the understanding of binocular fixation coordination during reading under different linguistic and orthographic manipulations in order to understand how the properties of a text influence binocular fixation coordination. Previous research has been equivocal on the matter, so normative data has been difficult to establish. The results of the present experiments have helped provide some clarity on the nature of binocular disparity in reading, but some interesting new insights have also been gleaned. Due to the nature of some of these uniquely new findings, more questions have arisen regarding the nature and pattern of disparity in reading. However, one finding which has remained consistent across all studies, also confirmed within the present thesis, is that the eyes are disparate to some degree during reading, usually between 1 to 2 characters.

This disparity proves problematic for the split-fovea theory (McDonald & Shillcock, 2005; Monaghan, Shillcock, & McDonald, 2004; Shillcock, Ellison, & Monaghan, 2000), which claims that the fovea is split precisely through the middle, which has implications when it comes to word recognition. The key aspect of the split fovea theory is that different parts of a fixated word project to different hemispheres. Fixation location is a critical part of the theory, with even a small shift in fixation having a considerable effect on the hemispheric processing of the fixated word. For example, if the word *radish* is fixated on between *d* and *i*, the input received to the right hemisphere would be *rad* and to left hemisphere would be *ish*. The theory suggests that lexical processing is then initiated, with each hemisphere independently processing, for some period, the part of the word that is available to it. The two parts of the word are then processed separately so the number of possible lexical candidates can be narrowed down. The obvious problem which arises from the example above is that the frequency of non-aligned fixations complicates the split-fovea theory. The theory has yet to demonstrate whether it can overcome this complication, accounting for all three binocular fixation patterns during reading (aligned, crossed, and uncrossed). However, something which may make it easier for the theory to account for these different patterns of disparity are the results of the present thesis, which indicate that fixation durations are, in fact, related to pattern of fixation disparity. Word recognition was easier when fixations were aligned. It should be noted, however, that this was only the case for *Experiment 1*. Although *Experiment 2* did report a relationship between fixation times and the nature of disparity, the processing cost was only for uncrossed fixations. Nevertheless, these findings do provide some hope for the split-fovea theory in reconciling the complications that fixation disparity presents it with.

To date, there have been very few investigations into the factors which affect binocular fixation disparity in reading. The findings of the present thesis, as well as that of Juhasz et al. (2006), should only be regarded as preliminary evidence for the role of linguistic and orthographic factors. Reading fluency is obviously related to binocular fixation coordination during reading. The findings in the present thesis that fixation disparity varies as a function of certain types of linguistic and orthographic manipulations implies that binocular coordination is an important area for future research. Consider the study by Bucci & Kapoula (2006), which found a difference in reading behaviours between adults and children. Adults made fewer fixations and regressions, made longer saccades, and had shorter fixation durations, making them the more effective readers. However, what remains unclear from current research is whether this has anything to do with improvements in binocular coordination due to the visual system maturing, resulting in more effective reading, or whether it has to do with reading experience improving binocular coordination.

Another question which arises is how does the visual system account for the differences in binocular coordination and produce a cyclopean representation? Is the retinal input from one eye suppressed or is a process of fusion taking place? The evidence presented from previous studies and the present thesis clearly shows that a large portion of fixations are disparate by more than one character. Not only are the fixations disparate, but the magnitude of disparity has been shown to vary from fixation to fixation and under different manipulations. The visual array is perceived as being unified during reading – the text visible clearly and *diplopia* (double vision) is not experienced. Additionally, considering the fact that the magnitude of disparity differs from fixation to fixation, it would suggest that the system which reconciles this difference must have a degree of flexibility. Liversedge, Rayner, White, Findlay & McSorley (2006) investigated this using a dichoptic presentation methodology and concluded that unification of the visual perpects from each eye is achieved through a process of fusion, not suppression. However, these are preliminary findings and it would be hasty to conclude that suppression does not take place at all. The influences of linguistic and orthographic manipulations have yet to be investigated. With *Experiment 2* demonstrating an effect of these manipulations on fixation disparity, exploring whether the context in which words appear modulates any fusion effects will help elucidate the higher order cognitive processes involved in reading.

The findings of the present thesis also have methodological implications more generally for those investigating the effects of linguistic and orthographic processing during reading. Research into eye movements during reading has typically recorded monocularly. As a result, single points of fixation have typically been regarded as accurately determining the precise point of overt visual attention, with the *perceptual span* being oriented around it. The perceptual span is the area in which useful information can be extracted by the reader and expands 4 characters to left of fixation and 8 characters to the right of fixation in English (Rayner, 1998). Thus, single points of fixation from one eye have been used by researchers to determine the precise portion of the text from which information can be extracted. However, it is clear from the present experiments and those conducted previously that the precise point at which attention is given is located at either point of fixation or possibly somewhere in between. This is slightly problematic for researchers who have strictly assumed that both eyes are fixated on a single point, like proponents of the split-fovea model. The absence of any effects of linguistic and orthographic manipulations on fixation disparity previously has led researchers to conclude that reflects fundamental, low level aspects of eye movement behaviours. However, the presence of an effect in the current experiments, suggests that this view needs to be reconsidered. The nature of disparity affects fixations times as do linguistic and orthographic manipulations.

One final area worth considering that the results of the present thesis have implication for relates to models of eye movement control in reading and the *parafoveal-on-foveal* effect (see Kennedy, 1998). The parafoveal-on-foveal effect occurs when the lexical characteristics of a word in the parafovea (word $n + 1$), which is not being directly fixated on, influences the processing of the word that is being fixated on (word n). Although these effects are often small, the information acquired parafoveally has been reliably shown to be beneficial to readers and necessary in order to read at a normal rate (Rayner, 1998). One reason why this effect has particularly been under considerable scrutiny is because it is central to an important distinction between two models of eye movement control in reading: serial models (e.g., EZ Reader of Reichle et al., 2003) and parallel models (e.g., SWIFT of Engbert, Nuthmann, Richter & Kliegl, 2005). An assumption central to serial models is that words are processed sequentially, with a serial movement of attention towards the word in parafovea preceding the eye movement to that word (Reichle et al., 2003). Parallel models, on the other hand, state that several words within the perceptual span are processed in parallel (Engbert et al., 2005). Advocates of parallel models state that the existence of parafoveal-on-foveal effects, where the lexical characteristics of word *n* + 1 influence the processing of word *n*, count as strong evidence against serial models and favour parallel ones (Kennedy, 2008). Proponents of serial models have suggested that the parafoveal-on-foveal can arise as a result of misdirected fixations – that is, saccades targeted at word *n* + 1, but landing just short of it. As a result, the processing that takes place during these fixations is determined by the word to which the saccade was targeted, rather than to the word on which the fixation was mistakenly made. However, another possible explanation for the presence of these effects is binocular disparity. With fixations being non-aligned on between a third to a half (Liversedge et al., 2006) of all fixations and up to two characters in some cases, studies recording monocularly are unable to account for the effects of such disparities. Fixations on which parafoveal-on-foveal effects are present could be due to the eye which is not being recorded actually fixating on word *n* + 1. In order to fully understand the implications of binocular disparity in this area, further investigation is required.

In conclusion, the current thesis has presented some interesting new findings, casting light onto a number of interesting questions which are of theoretical importance. Relationships between the nature of disparity and fixation duration have been established and fixation disparity has been found to be related to the linguistic and orthographic manipulations. These findings have implications on models of reading and possibly for investigators who have relied solely on single points of fixation to draw their conclusions. However, the study of binocular fixation disparity is still in its early stages. Patterns of fixation disparity appear to be more complicated than previously assumed. Future research in this area may wish to investigate other types of linguistic, orthographic or other visual manipulations in order to see how other factors modulate fixation disparity.

Declaration

I declare that this thesis is my own unaided work. It is being submitted for the degree of Master of Science at the University of Bedfordshire. It has not been submitted before for any degree or examination in any other University.

Mohammed Abdul Khaled

January, 2016.

Appendix I

Experimental Materials for *Experiment 1* – Chapters 2

Note. These materials are taken from Juhasz et al. (2006). Participants read each sentence containing either a high-frequency (first in parentheses) or a low-frequency (second in parentheses) target word. The questions asked in the study are also included. Each question could be answered yes or no by clicking the relevant response as it appeared on the screen.

Take your money out of the (**account | satchel**) and pay the debt.
Christine put the money in her (**account | satchel**) for safe keeping.
Did Christine spend all of her money?

I told Betty about the long (**argument | splinter**) that I had last week.
Tom said that the painful (**argument | splinter**) caused him much distress.
Was Tom distressed?

We tried to get the celebrity's (**attention | autograph**) but we could not.
Sandy got the star's (**attention | autograph**) after the movie was over.

Mary loved her little (**brother | terrier**) so much that she spoiled him.
Kim took care of her friend Bob's (**brother | terrier**) when he went away.

Lynn succeeded in her new (**business | vocation**) and made a good salary.
Was Lynn paid a nice salary?
My father loved his (**business | vocation**) and always enjoyed working.
Did my father like working?

Deb did not read the (**chapter | tabloid**) when I told her what was in it.
Rick opened up the (**chapter | tabloid**) and read it out loud to his wife.
Did Rick's wife read to him?

I read a book about a useless (**character | scoundrel**) who no one liked.
My uncle is a strange (**character | scoundrel**) and is not very trustworthy.

Fiona stopped to pick up the (**children | broccoli**) after work.
Betty says that she hates (**children | broccoli**) but it is not true.
Is Betty believable?

The man was brought to the (**council | dungeon**) after committing a crime.
Tim was scared to see the (**council | dungeon**) so he decided not to go.

Mark went to the (**department | pharmacist**) for help with his problem.
Mary asked the (**department | pharmacist**) to recommend a possible solution.
Did Mary think of a solution on her own?

Mark received his (**education | doctorate**) from a prestigious university.
Chris wanted to finish his (**education | doctorate**) soon and get a job.

Ron discussed the painful (**experience | amputation**) that he recently had.
Bob had a horrible (**experience | amputation**) that left him very weak.

My mum said that a degree in (**history | zoology**) would be very helpful.
Beth wanted to study (**history | zoology**) at a college in Canada.
Did Beth want to go to Spain?

Pete climbed to the top of the large (**machine | trellis**) and cleaned it.
John was able to repair the broken (**machine | trellis**) very quickly.
Was the repair very quick?

We were unable to repair the (**marriage | ligament**) even though we tried.
I was sad that my brother's (**marriage | ligament**) could not be fixed.

Val needed some (**material | scissors**) before she could start the project.
Please bring me the (**material | scissors**) and a needle right away.

Being a good (**minister | educator**) is a noble profession for anyone.
Tony was a great (**minister | educator**) and took pride in helping people.
Was Tony proud to help people?

Tara realized she had left her (**picture | mascara**) in her other handbag.
Pam picked up the discarded (**picture | mascara**) off the dirty floor.
Was the floor clean?

Dan said that the extensive (**practice | tutorial**) helped him on the exam.
Melanie attended the lengthy (**practice | tutorial**) yesterday afternoon.

Tina witnessed the clumsy (**president | ballerina**) fall off of the stage.
Kathy disliked the snobby (**president | ballerina**) and refused to say hello.
Did Kathy refuse to say hello?

The boy could not solve the (**problem | anagram**) so he asked for help.
The teacher gave a difficult (**problem | anagram**) as the final question.

We saw the entire (**process | autopsy**) being performed by the doctor.
Paul asked whether the (**process | autopsy**) would take a long time.

I learned a lot from the wise (**professor | astronaut**) who spoke in class.
I would like to be a famous (**professor | astronaut**) when I get older.

The scientist's (**research | abstract**) was submitted to a conference.
Jane found the (**research | abstract**) interesting and wanted to read more.

Clive hates studying (**science | algebra**) because he finds it very hard.
Mr. Jones taught (**science | algebra**) because he loved the subject.
Did Mr. Jones like the subject he taught?

The burglar shot an innocent (**secretary | bystander**) during the robbery.
The journalist interviewed a young (**secretary | bystander**) for the story.

Sue said that the (**service | cuisine**) is bad at that restaurant.
I enjoyed the great (**service | cuisine**) at the local Indian restaurant.
Did the restaurant serve Indian food?

Chris was sad about his (**situation | deformity**) and refused to see guests.
Michael's odd (**situation | deformity**) was the topic of many conversations.
Do people talk about Michael?

Jane yelled as the (**student | sparrow**) fell out of a tree in the park.
Duncan thought that the young (**student | sparrow**) was small for his age.

The neighbour's loud (**telephone | accordion**) really bothered Barbara.
The sudden sound of her friend's (**telephone | accordion**) woke Valerie up.
Was Valerie awoken suddenly?

My gran's (**trouble | amnesia**) started right after her sixtieth birthday.
The doctor said that Dad's (**trouble | amnesia**) was only temporary.
Was Dad's problem permanent?

Ralph rested in the (**village | hammock**) before he started on his trip.
Sam sat down in the small (**village | hammock**) since he was really tired.
Did Sam have a lot of energy?

I heard that the (**company | brewery**) made a large profit this past year.
We toured a local (**company | brewery**) and wrote a report for our course.

Sara rushed her (**husband | toddler**) to the doctor after he hurt himself.
Liz showed us a picture of her (**husband | toddler**) during the lunch.

Ruth admired the ring's (**quality | emerald**) and asked how much it cost.
We knew from the (**quality | emerald**) that the necklace was expensive.
Was the necklace cheap?

I had too much (**success | tequila**) very quickly and could not handle it.
It was nice of Robert to share his (**success | tequila**) with his brother.
Was Robert mean to his brother?

Mark asked for some (**support | aspirin**) when he was not feeling well.
I need some (**support | aspirin**) before I can finish this long project.

I took a tour of a famous (**building | catacomb**) while I was on holiday.
The police closed off the dangerous (**building | catacomb**) yesterday.

Rebecca soaked the (**surface | platter**) with soap to get the grease off.
Please clean the dirty (**surface | platter**) before you put food on it.

The scientists created a new (**technology | camouflage**) for the military.
Soldiers are now safer due to better (**technology | camouflage**) and weapons.

Appendix II

Experimental Materials for *Experiment 2* – Chapters 2

Note. These materials are taken from Hand et al. (2010). Target words are presented in **bold**. HF / LF = high / low frequency targets; HP / LP = high / low predictability targets. [lb] indicates where experimental items were split over two lines of on-screen display.

HF-HP | LF-LP	On holiday for a week, Jill and Harry decided to redecorate [lb] some rooms in their **house | motel** that they felt needed making over.
LF-HP | HF-LP	Exhausted from driving, and lost on the dusty highway, [lb] Tony decided to stop at the first **motel | house** to get directions.
HF-HP | LF-LP	The gifted students were selected to receive extra lessons [lb] at the local **school** | **circus** during weekends and holidays.
LF-HP | HF-LP	All the children were thoroughly amused by the clowns that [lb] came once a year to the **circus** | **school** in their village.
HF-HP | LF-LP	Denice was inconsolable after her friend's death. At the [lb] funeral, she wore a sombre **black** | **satin** dress and cried throughout.
LF-HP | HF-LP	In preparation for her luxury spa weekend trip, Lucy treated [lb] herself to some fancy, new **satin** | **black** pyjamas from the boutique.
HF-HP | LF-LP	Helena enjoyed literature and writing essays. She was going [lb] to university to study **English** | **Zoology** and hoped to teach one day.
LF-HP | HF-LP	Paul was sure he'd be made curator of exotic animals at the [lb] nature park. He had a degree in **Zoology** | **English** and vast experience.
HF-HP | LF-LP	Construction work was now complete, and everyone was excited [lb] about the opening of the new **building** | **monument** in the city centre.
LF-HP | HF-LP	Many locals had died in the battle. In their memory, the [lb] community erected a **monument** | **building** in the town square.
HF-HP | LF-LP	When Ann served against a superior tennis opponent, she [lb] always expected that the ball would **return** | **bounce** even faster.
LF-HP | HF-LP	Robbie enjoyed playing football. He spent hours kicking the [lb] ball against a wall and having it **bounce** | **return** back to him.
HF-HP | LF-LP	A problem with the cattle was that they would occasionally [lb] wander into the nearby **field** | **swamp** that belonged to Farmer Smith.
LF-HP | HF-LP	When crossing the marshlands, it was possible to become [lb] trapped in a muddy **swamp** | **field** if there had been heavy rainfall.
HF-HP | LF-LP	Rinsing hadn't stopped the bleach from burning his eyes. [lb] He needed emergency attention from the **hospital** | **optician** immediately.
LF-HP | HF-LP	As he had grown older, his eyesight had deteriorated. He [lb] thought he should visit the **optician** | **hospital** and get new glasses.
HF-HP | LF-LP	Guests were arriving and Jen's flat was a sty. She picked up [lb] her clothes from the **floor** | **couch** and quickly cleaned the bathroom.
LF-HP | HF-LP	Clare had been on her feet all day. Armed with a pizza and [lb] a video, she laid down on the **couch** | **floor** for a relaxing evening.

HF-HP | LF-LP	None of the baker's plans for the wedding cake had satisfied [lb] the bride. He had completely run out of **ideas** | **yeast** and was irate.
LF-HP | HF-LP	Amy's bread dough for the dinner wouldn't rise and the shops [lb] were now closed. She had run out of **yeast** | **ideas** and was panicking.
HF-HP | LF-LP	Before her big date tonight, Natalie brushed her teeth until [lb] she was sure they were thoroughly **clean** | **shiny** before meeting Luke.
LF-HP | HF-LP	Wanting to make a good impression at the interview, Albert [lb] polished his nicest shoes to make them as **shiny** | **clean** as possible.
HF-HP | LF-LP	They could have spent a week at the castle, but their train [lb] was leaving. They rushed to the **station** | **dungeon** before time ran out.
LF-HP | HF-LP	Hearing about torture in the castle made Debbie squeamish. [lb] She left the tour group in the **dungeon** | **station** and went for a smoke.
HF-HP | LF-LP	The dentist carelessly let the extracted tooth slip from his [lb] tweezers into the patient's **mouth** | **beard** to their mutual surprise.
LF-HP | HF-LP	As the scruffy professor struggled for inspiration, he would [lb] pace his office and stroke his **beard** | **mouth** hoping to find answers.
HF-HP | LF-LP	Frank was going to call the police. He was fed up with kids [lb] throwing stones at his **windows** | **chimney** as damage could be done.
LF-HP | HF-LP	The real coal fire was wonderful, but every month we had to [lb] have the sooty **chimney** | **windows** cleaned, to our great inconvenience.
HF-HP | LF-LP	Arriving late, Penelope thought the birthday cake would be [lb] finished, but there was still a small **piece** | **crumb** left in the box.
LF-HP | HF-LP	Roger loved eating biscuits in bed. However, he was very [lb] careful not to drop a single **crumb** | **piece** as his wife would be mad.
HF-HP | LF-LP	Because of heavy congestion on the roads, most of the [lb] freight was transported by **train** | **barge** whenever possible.
LF-HP | HF-LP	The gypsies travelled along the canal by hiding in the [lb] cargo of a slow moving **barge** | **train** in the middle of the night.
HF-HP | LF-LP	While Linda was away on holiday, she arranged for her friend [lb] to come by and water all the **plants** | **tulips** in her window boxes.
LF-HP | HF-LP	Our photos from Holland were mostly of museums, windmills, [lb] and well-kept parks full of **tulips** | **plants** of all different colours.
HF-HP | LF-LP	The Boy Scouts' weekend trip was a good way to teach them how to set up camp in the **forest** | **jungle** should they ever have to.
LF-HP | HF-LP	Their plane went down miles from any village. Injured and lost, they had to survive the **jungle** | **forest** to make it back alive.
HF-HP | LF-LP	At her favourite band's concert, Melissa pushed to the front [lb] and was so close that she could almost **touch** | **grope** the singer.
LF-HP | HF-LP	The boss would lose his job. His secretary had reported him [lb] after he had tried to **grope** | **touch** her in the stationary cupboard.
HF-HP | LF-LP	After dessert, they ordered some **coffee** | **brandy** and took it through [lb] to the bar so that Jean could have a cigarette.
LF-HP | HF-LP	Dinner in the Paris bistro was superb. They agreed to finish [lb] their meal with a luxury **brandy** | **coffee** as they were on holiday.
HF-HP | LF-LP	Kyle knew he would go to prison. He had been caught outside [lb] the club selling ecstasy-laced **drugs** | **mints** to undercover police.
LF-HP | HF-LP	The smell of garlic was on his breath. Before going out, he [lb] thought he should take some **mints** | **drugs** in case he met a girl.

HF-HP | LF-LP	John's bank manager would not give him the loan because [lb] he hadn't brought a valid **document** | **passport** for identification.
LF-HP | HF-LP	The immigrant was sure he would be deported. He had been [lb] caught with a fake **passport** | **document** by customs officers at the port.
HF-HP | LF-LP	Dave's birthday was usually an event to remember. This year [lb] he and his friends were having a huge **party** | **disco** to celebrate.
LF-HP | HF-LP	My parents met in the Seventies, when every Saturday night [lb] they would go into town to a **disco** | **party** and dance the night away.
HF-HP | LF-LP	Gillian was on the last mile of the women's marathon. She [lb] grabbed a bottle of **water** | **lager** from a spectator and drank it.
LF-HP | HF-LP	Although a rugby player, Clive struggled through the crowd [lb] at the bar carrying glasses of **lager** | **water** and bags of crisps.
HF-HP | LF-LP	George had been raised to be kind to everyone in his life [lb] and was undoubtedly the nicest **person** | **waiter** Angela had ever met.
LF-HP | HF-LP	The starters had not yet arrived. Annoyed, Peter decided to [lb] stop the next **waiter** | **person** he saw and complain about the service.
HF-HP | LF-LP	When Colin needed refuge from the pressures of everyday [lb] life, he would go to the **church** | **quarry** to sit alone and reflect.
LF-HP | HF-LP	The children were warned about throwing stones and playing [lb] in the abandoned **quarry** | **church** as they could get seriously injured.
HF-HP | LF-LP	The boss and foreman argued. Feeling awkward, the workers [lb] thought it was best to **leave** | **drill** and let them argue in private.
LF-HP | HF-LP	They knew the other area had much more oil, but their bosses [lb] wouldn't allow them to **drill** | **leave** until the current job was done.
HF-HP | LF-LP	At school, Nigel enjoyed painting with wild brush strokes. [lb] He covered every inch of his **paper** | **easel** with untidy smears.
LF-HP | HF-LP	In art class, the first thing that Phillipa did was ensure [lb] that she had correctly set up her **easel** | **paper** before painting.
HF-HP | LF-LP	The noise from next door was outrageous. No one could get [lb] any sleep because of the loud **music** | **siren** that went on all night.
LF-HP | HF-LP	The civil defence drill had been a great success. Everyone [lb] had been able to hear the **siren** | **music** that would signal an attack.
HF-HP | LF-LP	Simon was stressed. His had to e-mail his coursework to his [lb] tutor but his **computer** | **keyboard** had broken and he couldn't fix it.
LF-HP | HF-LP	Rachael was finishing typing in the report when she spilled [lb] her tea, getting her desk and **keyboard** | **computer** completely soaked.
HF-HP | LF-LP	Sheila's son had been involved in a fight at school. Before [lb] deciding what to do, she would talk to her **husband** | **nephews** tonight.
LF-HP | HF-LP	Mary loved toyshops at Christmas. Although she did not have [lb] children, she would buy gifts for her **nephews** | **husband** instead.
HF-HP | LF-LP	The storm had come unexpectedly. The tarpaulin would have [lb] to be stretched to provide a **cover** | **quilt** for everyone caught out.
LF-HP | HF-LP	After purchasing a new mattress and pillows, it made sense [lb] to buy a new **quilt** | **cover** and cotton sheets for their new bedroom.

HF-HP | LF-LP   Mr. Bain had the flu. Being a busy man, he made an emergency [lb]
appointment with his **doctor** | **banker** before rushing to the office.
LF-HP | HF-LP   Fiona was interested in finance. After obtaining a degree in [lb]
Accounting, she hoped to become a **banker** | **doctor** and live in London.

HF-HP | LF-LP   Gardening is a very rewarding hobby. I enjoy being able [lb]
to feel the **earth** | **filth** between my fingers when planting bulbs.
LF-HP | HF-LP   The youth hostel hadn't been cleaned in months. Maria had [lb]
never seen so much **filth** | **earth** on one floor in her whole life.

HF-HP | LF-LP   Jamming all my laundry into the washer, I ignored the fact [lb]
that it could **break** | **erupt** because I had overloaded its capacity.
LF-HP | HF-LP   The geologists hurried to get away from the volcano. Their [lb]
measurements suggested that it could **erupt** | **break** at any moment.

HF-HP | LF-LP   Their day at the zoo was certain to be good. The children [lb]
looked forward to seeing the **animals** | **giraffe** and having a picnic.
LF-HP | HF-LP   On safari, we witnessed the upper leaves of the acacia tree [lb]
being eaten by the hungry **giraffe** | **animals** and we took a picture.

HF-HP | LF-LP   Callum was having trouble with his homework. He asked his [lb]
uncle who was a **teacher** | **plumber** to help him with the assignment.
LF-HP | HF-LP   Ingrid's boiler had suddenly broken down. Fortunately, her [lb]
neighbour's father was a **plumber** | **teacher** and would be able to help.

HF-HP | LF-LP   Little Joey loved the story his father told about the cowboy [lb]
and his faithful **horse** | **puppy** and the adventures they had together.
LF-HP | HF-LP   Emma prayed for a cute pet every Christmas. Her heart leapt [lb]
when she saw a beautiful **puppy** | **horse** waiting outside in the pen.

HF-HP | LF-LP   Sitting outside at his barbecue, Brian got so drunk that he [lb]
almost fell off his **chair** | **patio** and was very embarrassed indeed.
LF-HP | HF-LP   As a kid, when summer came, I spent my days playing in the [lb]
park and my nights out on my Grandad's **patio** | **chair** reading comics.

HF-HP | LF-LP   Arranging tables in the cafe was difficult. Some were oblong [lb]
and others were **square** | **chrome** and they differed in height as well.
LF-HP | HF-LP   The tenants liked the look of their new bathroom. All the [lb]
fixtures were **chrome** | **square** and fit the modern design of the house.

HF-HP | LF-LP   Nowhere was safe for the prime suspect. A national manhunt [lb]
was underway as the **murder** | **thefts** had caused public outcry.
LF-HP | HF-LP   Locals were advised to lock all doors and especially their [lb]
windows. There had been reports of **thefts** | **murder** in the town.

HF-HP | LF-LP   Unusually, the children weren't home yet. Their parents [lb]
hoped they would be home for **dinner** | **sunset** as they were worried.
LF-HP | HF-LP   Living on the coast meant that Jane and Dan could enjoy a [lb]
beautiful **sunset** | **dinner** before going for a stroll along the beach.

HF-HP | LF-LP   The police had been on Wayne's tail for a long time. He was [lb]
well known to be a **criminal** | **hooligan** but they had little evidence.
LF-HP | HF-LP   Sid was not allowed into Austria to watch his favourite [lb]
football team. He was a known **hooligan** | **criminal** and troublemaker.

HF-HP | LF-LP   After the war, there was much rebuilding to do. To maintain [lb]
order, British **troops** | **cadets** had visible presence as peacekeepers.
LF-HP | HF-LP   The young men all wanted to be in the army. Until they were [lb]
old enough, they would serve as **cadets** | **troops** in local forces.

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