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Word centre is misperceived

Martin H Fischer
Department of Experimental Psychology, Ludwig Maximilians University, Leopoldstrasse 13, D 80802 Munich, Germany; e-mail: martin@psy.uni-muenchen.de
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Abstract. Normal readers were asked to mark the middle of visually presented words. They made systematic errors toward the left, indicating an overestimation of the length of the beginning of a word. The number of characters determines the size of this error. The bias extended to pseudowords, letter strings, and symbols, but not to blocks, dashes, and lines. Finally, the bias was sensitive to typographical errors but not to colour cuing. These findings suggest that special cognitive operations determine the perceived spatial extent of words. Implications for our understanding of perceptual and cognitive processes in reading are discussed.

1 Introduction

Our visual perception is not veridical. Numerous visual illusions have been reported, and their ongoing analysis reveals important principles of visual perception and cognition (eg Coren and Girgus 1978; Gregory 1994; Luckiesh 1922). For example, Gregory (1994, chapter 27) proposed a taxonomy of physical, physiological, and cognitive illusions, distinguishing between ambiguities, distortions, paradoxes, and fictions at each of these levels of visual processing. According to this taxonomy, the present paper deals with a new cognitive distortion pertaining to the perception of print. It will be shown that special cognitive operations seem to be involved in the perceived spatial extent of words.

Only few studies have assessed how we perceive the spatial extent of printed material. Biases in letter perception were investigated by Skottun and Freeman (1983) and by Carrasco and Sekuler (1993). Skottun and Freeman reported that the height of letters is overestimated by a constant proportion of about 20% once the spacing between letters is larger than a critical value of about 3 min of arc. Carrasco and Sekuler presented Navon stimuli(1) to their subjects and found that viewers overestimated the horizontal extent of the local letter components, contrary to what one might expect from the well-known horizontal – vertical illusion.

With regard to words, our knowledge about the perception of their spatial properties is mostly indirect. For example, Mapelli et al (1996) suggested that the spatial extent of words is part of their cognitive representation because letter detection times showed a spatial compatibility effect: When asked to press a button with their left hand in response to target letters embedded in horizontally presented words, subjects responded faster to target letters in the beginning of a word, compared to targets in the end of a word, which were responded to faster with the right hand (see also Nicoletti et al 1992).

Several neuropsychological studies assessing the representational consequences of hemispatial neglect have found that words are neglected to a lesser extent than other visual materials. For example, in a line bisection study by Brunn and Farah (1991), prior to each line bisection their patients reported words, pseudowords, or nonwords that

(1) Navon letters are letters that are arranged such that they together form yet another letter. The small letters are then referred to as the local level and the large letter is referred to as the global level of this compound stimulus.

were printed horizontally above the horizontal lines. The patients' line bisection errors improved most in the context of words, suggesting that the words somehow counteracted the neglect for lines. In another study, Sieroff et al (1988) found that both left-parietal and right-parietal stroke patients identified many letters of tachistoscopically presented words correctly, while they showed contralateral extinction of letters in nonwords. Thus, there was no lateralised spatial performance deficit associated with words despite the parietal lesion (see also Fischer and Zihl, submitted). Recently, Ladavas et al (1997) studied word and nonword naming by neglect patients and found a 30% benefit for word over nonword naming.

Despite this rather indirect evidence, there are occasionally strong claims about the nature of the cognitive representation of the spatial extent of words. Caramazza and Hillis (1990a) reported data from a single patient who, after left-parietal damage, always made spelling errors on the last letters of words, irrespective of their physical arrangement on a printed page (left-to-right, right-to-left, rotated, mirrored). The authors proposed that visual word perception in general includes the transformation of the physical stimulus into a canonical left-to-right representation and assumed that this representation is normally veridical. A more cautious conclusion would be that the processing and representation of spatial attributes of words may differ from that of other visual materials.

The only study in which cognitive representation of the spatial extent of printed words has been investigated seems to be the one by Fischer (1996). In that study, Caramazza and Hillis's (1990a) proposal of veridical and canonical word-length coding was tested with a task that required the bisection of words with a pencil. Contrary to their prediction, performance depended on stimulus orientation. An unexpected finding in that study was the consistent bias to the left when subjects attempted to bisect words at their midpoint. This second result contradicts the widely held notion of veridical word-length representations and provides the starting point for the present investigation.

Follow-up studies showed that the word bisection bias is robust: It holds in English and German; for nouns, adjectives, and verbs; for different fonts and type sizes; and in a CRT-screen as well as in paper-and-pencil tests (Fischer 1999). Further, it generalises to pseudowords but not to letter strings and is stronger in subjects who perceive words in their second language compared to their native language (see Fischer 1996, for details). Of interest for the present study, it has been shown that lines of the same spatial extent as the words were bisected quite accurately, suggesting that the word bisection bias might be specifically related to the processing of orthographic materials. Moreover, the bisection bias is reduced in words with more syllables compared to equally long words containing fewer syllables and increases with word length up to about 15 characters (see Fischer 1999, for details).

So far, however, all studies of the word bisection bias confounded physical word length and number of characters: The more characters a word contained, the longer was its physical extent. Thus, it is not clear whether it is the mere spatial extent of a word or the number of letters that induces the systematic misperception of print. If the size of the bisection bias is merely a function of the spatial extent of the word, then it could be accounted for by the fact that an observer's sensitivity generally covaries with absolute stimulus magnitudes (the Weber – Fechner law), although the direction of the bias would still have to be explained with additional assumptions. If, on the other hand, the bias is a function of the number of characters, then it might reflect higher-level cognitive operations related to lexical access. The first experiment tackled this question and provided support for the latter hypothesis.

2 Experiment 1: The role of characters

2.1 *Subjects*

Twelve right-handed subjects responded to local advertising and participated for pay. They were seven women and five men aged between 21 and 64 years (average: 38 years). All subjects had normal or corrected vision, reported to be neurologically healthy, and were naive with respect to the hypotheses of the study. They signed an informed consent form prior to their participation.

2.2 *Apparatus*

Subjects were run individually in a quiet laboratory room with dim background light. They sat on a height-adjustable office chair in front of a Philips 4 CM 2299 Autoscan Professional Colour monitor with 20 inch diagonal screen size. Stimuli were presented in black on white background. An Apple 4400/200 Power-Mac controlled stimulus presentation and response collection. Horizontal and vertical screen resolutions were 1024 and 768 pixels, respectively. Responses were made with the right hand on a one-button Apple Desktop Bus Mouse II.

2.3 *Stimuli*

German nouns were selected from an electronic database (Celex 1995) according to their length (5, 7, 9, 13, and 17 characters) and frequency of occurrence in the printed language (average frequency: 5.3 per 6 million, range 0–19). The number of syllables for a given word length was 2, 2, 3, 4, and 5 syllables for words with 5, 7, 9, 13, and 17 characters, respectively. A total of 15 words were used for each word length. Their interletter spacing was manipulated as follows (see table 1). The 5-character words were shown three times, with either 0, 1, or 2 spaces between adjacent characters; the 7-character and 9-character words were shown twice, with either 0 or 1 space between adjacent characters; and the 13-character and 17-character words were shown once without extra spaces added between adjacent characters. Thus, the total number of stimuli was

Table 1. Conditions of experiment 1 and main results.

Condition	Number of characters	Number of syllables	Number of spaces	Word length (characters)	Sample stimulus (in Monaco font)
1	5	2	0	5	FERSE
2	7	2	0	7	PRANGER
3	9	3	0	9	WAGENBURG
4	13	4	0	13	HAUSVERWALTER
5	17	5	0	17	NERVENHEILANSTALT
6	5	2	1	9	F E R S E
7	7	2	1	13	P R A N G E R
8	9	3	1	17	W A G E N B U R G
9	5	2	2	13	F E R S E

Condition	Response time/ms	Bisection bias/pixels	Bisection variance/pixels
1	2643	−2.60	116
2	2807	−5.18	158
3	2934	−7.17	158
4	3560	−7.55	296
5	3793	−9.76	285
6	2077	−1.25	169
7	2572	−4.12	237
8	2924	−5.09	287
9	2518	−2.43	172

$45 + 60 + 30 = 135$. Letters were presented in non-proportional Monaco font and in uppercase to prevent effects of ascenders or descenders on perceived word centre. This font has no serifs, so letter borders were clearly defined. For the large 45 point type, we used letter size 34×26 pixels or 13 mm $\times$ 10 mm, yielding about 1.3 deg per character at a viewing distance of about 50 cm.

2.4 *Task and procedure*

The words were shown in a random sequence to each subject, one at a time, at randomly chosen locations on the screen (see also footnote 4). When the subject pressed the mouse button, a word appeared horizontally on the screen, together with a 1 mm narrow, 9 mm long vertical bar. Subjects named each word aloud before indicating its perceived midpoint by moving the vertical bar. The vertical cursor moved only horizontally when subjects displaced the mouse, and it did so only about 500 ms after stimulus exposure to emphasise priority of the naming task and to avoid attention capture from the moving cursor. The bar appeared always at the screen centre so that it had to be moved to the left and to the right about equally often. Pressing the mouse button yielded a measure of bisection accuracy, where negative values indicated a shorter distance from the cursor to the beginning of the stimulus than to its end. Pilot testing had shown that observers can localise the beginning and ending of words within ± 2 pixels with this method. Response times were measured from stimulus onset to the mouse button click, which also terminated the stimulus display. Instructions emphasised accuracy but reminded subjects not to dwell on an item to prevent letter counting.

2.5 *Analysis*

Accuracy data were accepted for statistical analyses if responses occurred after 1 s and before 10 s had elapsed since stimulus onset.(2) Naming accuracy was not verified and was thus not a criterion for acceptance because it was assumed that reading was perfect in the absence of time pressure. Because subjects occasionally pressed the mouse button inadvertently, bisection judgments beyond ± 50 pixels (2 characters) from the true word centre were excluded from analysis. On the basis of the criteria outlined above, 4% of the data (60 trials) were discarded. Bisection performance was calculated by subtracting the distance between cursor position and the first pixel of the word from the distance between cursor position and the last pixel of the word. Thus, a negative score indicates an error toward the left, ie toward the word's beginning. Average bisection performance was determined in pixels for each subject, and two major analyses were performed. First, average performance was tested against zero to see if the bias was reliable, by means of two-sided *t*-tests. Second, repeated-measures analyses of variance (ANOVAs) assessed the effects of word length on word bisection accuracy, bisection variability, and response times. A posteriori tests and contrasts were two-sided *t*-tests unless noted otherwise.

2.6 *Results*

Consider first the spatial aspect of word bisection performance. Table 1 shows the average bias per condition, and figure 1 gives an overview of the results. Average bisection performance across all nine conditions was -5.02 pixels (SD 3.0). This score was reliably different from accurate bisection ($t_{11} = 5.79$, $p < 0.001$), replicating the observation of Fischer (1996) of a general bias to the left in perceived word centre.

Consider first spatial performance on words without additional interletter spaces (conditions 1–5). Average bisection performance across all five conditions was -6.45 pixels (SD 3.43). This score was reliably different from accurate bisection ($t_{11} = 6.52$,

(2) Analysis of temporal performance might help understand the origin of the bisection bias. To include only typical performances, the global latency distribution has been inspected and the cut-offs were located at 1 and 10 s because the majority of judgments had clearly occurred by then.

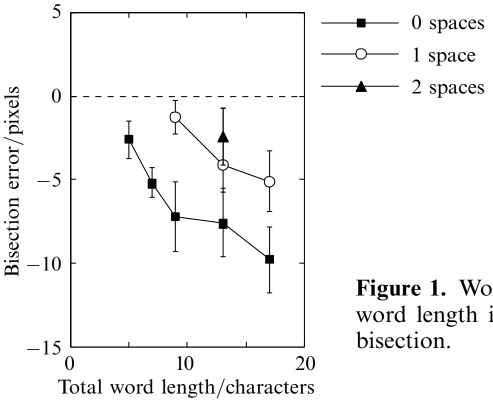

Figure 1. Word bisection error (±1 SEM) as a function of word length in experiment 1. Hatched line represents accurate bisection.

$p < 0.001$). There was a significant main effect of word length across these five conditions ($F_{4,44} = 3.05$, MSE = 28.62, $p < 0.05$). Among adjacent word-length levels, no reliable differences were present (all p-values > 0.23). The first reliable difference in bisection scores emerged between 5-character and 9-character words ($t_{11} = 2.76$, $p < 0.02$). Bisection performance for the 17-character words differed from performance for 5-character and 9-character words ($t_{11} = 3.39$, $p < 0.01$; and $t_{11} = 2.41$, $p < 0.05$, respectively).

Consider now spatial performance on words with a single additional space inserted between adjacent characters (conditions 6–8). For these three conditions with one extra space, there was a marginally significant main effect of word length ($F_{2,22} = 3.38$, MSE = 14.14, $p = 0.05$). The differences between 5-character and 7-character words, and between 7-character and 9-character words were both marginally reliable ($t_{11} = 2.08$, $p = 0.06$; and $t_{11} = 2.18$, $p = 0.05$, respectively).

Consider finally spatial performance on words with the same number of characters but three different levels of spacing (conditions 1, 6, and 9). An ANOVA on these three conditions with 5-character words showed no effect of physical length on perceived word centre ($F_{2,22} = 0.64$, MSE = 10.17, $p > 0.50$).

To further quantify the independent contributions of physical length and of number of characters to the word bisection bias, comparisons were performed on two sets of condition pairs. First, the effect of physical length on bisection accuracy was assessed by contrasting conditions 1 vs 6, 2 vs 7, 3 vs 8, 1 vs 9, and 6 vs 9. Words from these condition pairs have the same number of characters but different physical lengths. Directional t-tests assessed whether the bisection bias increased with physical length. All contrasts were insignificant (p-values > 0.10).

Next, the effect of number of characters was assessed by contrasting conditions 3 vs 6, 4 vs 7, 4 vs 9, 5 vs 8, and 7 vs 9. Words from these condition pairs have the same physical length but different numbers of characters. If number of characters had no impact on bisection accuracy, no significant differences should emerge in these comparisons. If, on the other hand, bisection accuracy decreased with increasing number of characters irrespective of physical length, then significant differences should obtain. Consistent with the second prediction, all but one of the contrasts (condition 7 vs 9) were significant or marginally significant (p-values < 0.07).

Consider now the *variability* of word bisection across conditions, based on the variance of spatial judgments as determined for each subject in each condition. Average variances for all conditions are given in table 1. Consider first spatial performance on words without additional interletter spaces (conditions 1–5). There was a main effect of word length ($F_{4,44} = 12.52$, MSE = 6441, $p < 0.01$), indicating that variability increased with physical word length and/or number of characters. When the three conditions with 5-character words were considered separately, no reliable effect of physical word length emerged ($F_{2,22} = 1.64$, MSE = 7176, $p > 0.22$), suggesting that the number of characters, not physical extent, determines how reliably an observer can perceive the word middle.

The effect of physical length on bisection variability was further assessed by contrasting again the condition pairs with the same number of characters but different physical lengths (1 vs 6, 2 vs 7, 3 vs 8, 1 vs 9, and 6 vs 9). Only the most extreme condition pair (1 vs 9) showed a significant increase in average variance of judgments ($t_{11} = 2.42$, $p < 0.05$), with p-values for all remaining contrasts > 0.07. Next, the effect of number of characters on consistency of responses was assessed by contrasting conditions with the same physical length but different numbers of characters (3 vs 6, 4 vs 7, 4 vs 9, 5 vs 8, and 7 vs 9). The contrasts between conditions 4 vs 9 and 7 vs 9 were both reliable ($t_{11} = 2.98$, $p < 0.02$; and $t_{11} = 2.42$, $p < 0.05$, respectively), indicating less variability with fewer characters.

Consider next the *speed* of word bisection performance. Table 1 shows the average response times per condition. Average response time across all nine conditions was 2870 ms (SD 999). Response times on words without additional interletter spaces (conditions 1–5) showed a significant main effect of word length ($F_{4,44} = 13.41$, MSE = 224 182, $p < 0.001$). Among adjacent word-length levels, the only reliable difference was between 9-character and 13-character words ($t_{11} = 3.1$, $p = 0.01$, all other p-values > 0.06). The remaining contrasts were all significant, with p-values < 0.02.

Consider now temporal performance on words with a single additional space inserted between adjacent characters (conditions 6–8). For these three conditions with 1 extra space, there was a significant main effect of word length ($F_{2,22} = 9.59$, MSE = 226 460, $p < 0.001$). The difference between 5-character and 7-character words was reliable ($t_{11} = 4.34$, $p < 0.001$), while the difference between 7-character and 9-character words was not significant ($t_{11} = 1.86$, $p > 0.08$, respectively). The difference between 5-character and 9-character words was reliable ($t_{11} = 3.33$, $p < 0.01$).

Consider, finally, response speed on words with the same number of characters but three different levels of spacing (conditions 1, 6, and 9). For these three conditions with 5-character words there was a significant effect of word length on response times ($F_{2,22} = 13.48$, MSE = 78 871, $p < 0.001$). The difference between conditions 1 and 6 (0 vs 1 space) and the difference between conditions 6 and 9 (1 vs 2 spaces) were both reliable ($t_{11} = 4.49$, $p < 0.001$; and $t_{11} = 3.3$, $p < 0.01$, respectively). The difference between conditions 1 and 9 was, however, not significant ($t_{11} = 1.66$, $p > 0.12$).

The effect of physical length on response time was assessed by contrasting conditions 1 vs 6, 2 vs 7, 3 vs 8, 1 vs 9, and 6 vs 9. Words from these condition pairs have the same number of characters but different physical lengths. Directional t-tests assessed whether response time increased with physical length. All but one of these contrasts (condition 3 vs 8) were significant or marginally significant, with p-values < 0.06. The effect of number of characters on response times was assessed by contrasting conditions 3 vs 6, 4 vs 7, 4 vs 9, 5 vs 8, and 7 vs 9. Words from these condition pairs have the same physical length but different numbers of characters. All but one of the contrasts (condition 7 vs 9) were significant (p-values < 0.01).

2.7 *Discussion*

The aim of the first experiment was to assess the separate roles of physical stimulus length and number of characters for the word bisection bias. Although the two dimensions must naturally remain confounded to some extent, the insertion of irrelevant spaces between letters allowed an independent assessment of both factors. The results show that the size of the word bisection bias is determined by the number of characters. Figure 1 illustrates how the 1-space conditions are vertically offset from the 0-space conditions of equal length, indicating a constant reduction in bias when given spatial intervals are filled with fewer letters.

Response times increased systematically with word length. The overall increase of errors with longer words compared to shorter words shows that the slower responses to longer words were not due to a simple speed–accuracy trade-off. The result may reflect the fact that an observer's sensitivity is reduced for larger absolute stimulus magnitudes (the Weber–Fechner law): Subjects may have required more time to maintain equivalent subjective-accuracy levels across conditions. However, all but one of the response-time contrasts of condition pairs with equal physical length were significant, indicating that physical length did not alone determine response speed. Also, consistency of judgments decreased to a larger extent when more characters were present.

Alternatively, subjects may have counted the letters in each stimulus to improve their judgments. The overall speed of responses, however, argues against this possibility: It takes clearly more than 4 s to name a 17-character word, then count up to 17, and then again up to 8, and then position the cursor at the corresponding position. In addition, all but one of the response-time contrasts between condition pairs with equal numbers of characters were reliable as well. In summary, then, the latency and error pattern together suggest that some counting was attempted but that subjects did not generally succeed in adopting this strategy.

In summary, the results of experiment 1 constitute a replication of the finding of a general bias to the left in word bisection (Fischer 1996, 1999), thus showing that word length is not veridically perceived by normal readers. Implications of this fact are discussed in section 6. For now it appears that the word bisection bias is a robust phenomenon, but its origin is not clear. Three follow-up experiments addressed the roles of lexical factors (experiment 2), orthographic factors (experiment 3), and attentional operations (experiment 4).

3 Experiment 2: The role of lexical factors

The second experiment replicated the spacing manipulation with words, pseudowords (pronounceable letter strings without semantic content), non-pronounceable letter strings without vowels, and symbol strings. If the bisection bias originates from lexical processes, performance on words should differ from that with the other three stimulus types. If the bisection bias reflects phonological processes, performance on words and pseudowords should differ from performance on non-pronounceable letter and symbol strings. Finally, if the bisection bias originates from letter familiarity, then the symbol strings might show bisection performance that differs from that on stimuli made from letters.

3.1 *Subjects*

Eighteen new right-handed subjects participated for pay. They were eight men and ten women aged between 19 and 38 years (average: 27 years). All subjects had normal or corrected vision. Subjects reported to be neurologically healthy and were naive with respect to the hypotheses of the study. They signed an informed consent form prior to their participation.

3.2 *Apparatus and procedure*

The apparatus and general procedure were not modified, but subjects were not required to name each stimulus, to keep overt task demands comparable across stimulus types.

3.3 *Stimuli*

First, a subset of 10 words each of length 5, 9, and 17 characters was randomly selected from the materials of experiment 1. This set of 30 words was augmented by 30 pseudowords that were derived by exchanging vowels (eg 'JUWEL' became 'JEWUL'). Next, a set of 30 letter strings was generated by exchanging all vowels with randomly selected consonants (eg 'JNWKL'). Finally, 10 symbol strings each of 5, 9, and 17 elements length were derived from random sequences of symbols from the set '&#$%&' and added to the materials, yielding 120 stimuli without interletter spaces. All stimuli with 5-character and 9-character length were also shown with added interletter spaces. This resulted in 80 additional stimuli, and a total of 200 experimental trials per subject.

Stimuli were shown in randomised order. One subject chose to discontinue her participation for undisclosed reasons near the end of the session, resulting in 120 instead of 200 observations for this participant. On the basis of the criteria outlined above, 96% of the data were included in the analyses.

3.4 *Results*

All results were analysed with repeated-measures analysis of variance (ANOVA). The first analysis looked at effects of stimulus length (5, 9, or 17 characters) and stimulus type (word vs pseudoword vs letter string vs symbol string) on spatial performance, excluding the stimuli with added interletter spaces. The main effect of length was reliable ($F_{2,34} = 15.09$, $p < 0.001$, $\mathrm{MSE} = 145.78$). Average bisection error was -2.39 pixels (SE 0.61), -7.10 pixels (SE 1.03), and -13.41 pixels (SE 2.68) for stimuli with the length of 5, 9, and 17 characters, respectively. There was also a significant main effect of stimulus type ($F_{3,51} = 6.24$, $p < 0.001$, $\mathrm{MSE} = 25.49$). Average bisection error was -6.21 pixels (SE 1.44), -7.03 pixels (SE 1.61), -10.13 pixels (SE 1.26), and -7.16 pixels (SE 1.13) for words, pseudowords, letter strings, and symbol strings, respectively. A posteriori t-tests showed that letter strings had a reliably stronger overall bisection bias than the other materials. Finally a significant interaction ($F_{6,102} = 4.23$, $p < 0.001$, $\mathrm{MSE} = 19.10$), indicated that the overall larger bias for letter strings was especially evident at the longest length ($p = 0.02$).

This analysis was complemented by an assessment of the impact of stimulus length (5, 9, or 17 characters) and stimulus type (word vs pseudoword vs letter string vs symbol string) on bisection speed, again excluding the stimuli with added interletter spaces. The main effect of length was reliable ($F_{2,34} = 23.41$, $p < 0.001$, $\mathrm{MSE} = 925\,991$). Average bisection times were 2298 ms (SE 167), 2751 ms (SE 232), and 3390 ms (SE 338), for stimuli with the length of 5, 9, and 17 characters, respectively, and t-tests (5%) indicated that all times differed reliably. There was also a significant main effect of stimulus type ($F_{3,51} = 15.30$, $p < 0.001$, $\mathrm{MSE} = 408\,921$). Average bisection times were 2987 ms (SE 291), 3185 ms (SE 284), 2667 ms (SE 235), and 2416 ms (SE 171) for words, pseudowords, letter strings, and symbol strings, respectively. A posteriori t-tests (5%) showed that all conditions except words vs pseudowords differed reliably. A significant interaction ($F_{6,102} = 8.69$, $p < 0.001$, $\mathrm{MSE} = 226\,510$), indicated that the overall slowing with increasing stimulus length was stronger for words and pseudowords compared to the other materials.

Consider now the effect of the spacing manipulation on spatial accuracy. A new analysis evaluated the effects of stimulus length (5 vs 9 characters), stimulus spacing (0 vs 1 interletter space), and stimulus type (word vs pseudoword vs letter string vs symbol string) on perceived stimulus centre. There was a significant main effect of stimulus length ($F_{1,17} = 24.50$, $p < 0.001$, $\mathrm{MSE} = 54.93$), replicating the stronger bias to the left with longer stimuli. Average bisection bias for short and long stimuli was -2.19 pixels (SE 0.72) and -6.52 pixels (SE 1.23), respectively. Importantly, the main effect of stimulus spacing was not reliable ($F_{1,17} = 1.34$, $p > 0.26$, $\mathrm{MSE} = 32.80$), as was the main effect of stimulus type ($F_{3,51} = 0.51$, $p > 0.67$, $\mathrm{MSE} = 15.29$). The only significant interaction involved stimulus length and stimulus type ($F_{3,51} = 3.79$, $p < 0.05$, $\mathrm{MSE} = 16.10$), with all other p-values > 0.45. Figure 2 depicts this interaction. A posteriori tests showed that short symbols had the largest bisection bias in the short conditions ($F_{3,51} = 3.78$, $p < 0.02$, $\mathrm{MSE} = 6.64$) and the smallest bias in the long conditions. The latter difference was, however, not reliable ($F_{3,51} = 1.77$, $p > 0.16$, $\mathrm{MSE} = 24.75$).

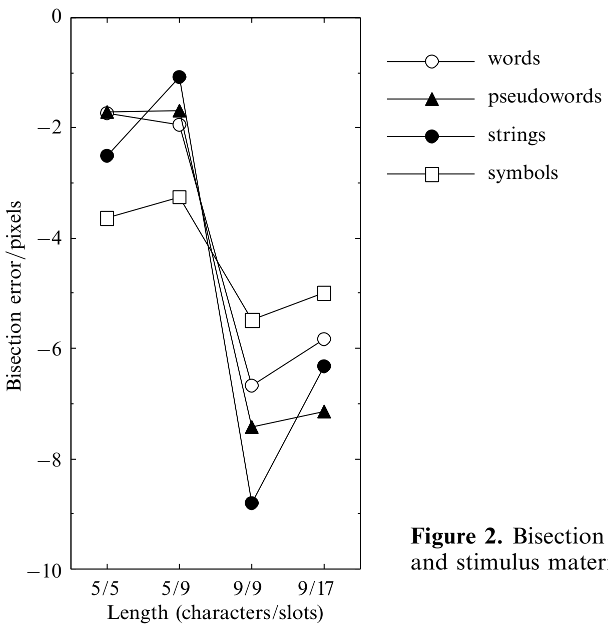

Figure 2. Bisection error as a function of stimulus length and stimulus materials in experiment 2.

Response times were reliably faster for short compared to long strings ($F_{1,17} = 21.92$, $p < 0.001$, MSE = 962 454). Average response times for short and long strings were 2317 ms (SE 173) and 2858 ms (SE 257), respectively. Response times were also reliably faster for unspaced compared to spaced strings ($F_{1,17} = 7.84$, $p < 0.01$, MSE = 143 392). Average response times for unspaced and spaced strings were 2591 ms (SE 219) and 2584 ms (SE 207), respectively. There was also a significant main effect of stimulus type ($F_{3,51} = 10.48$, $p < 0.001$, MSE = 230 189). Average bisection times were 2629 ms (SE 222), 2804 ms (SE 241), 2553 ms (SE 221), and 2363 ms (SE 178) for words, pseudowords, letter strings, and symbol strings, respectively. A posteriori *t*-tests (5%) showed that pseudowords were bisected slower and symbol strings were bisected faster than all remaining stimuli. All higher-order interactions, with the exception of spacing X type, were also significant ($p < 0.05$).

3.5 *Discussion*

Experiment 2 addressed the impact of lexical factors on perceived stimulus centre. Subjects bisected words, pseudowords, letter strings, and symbol strings. There was an increased bias with larger number of characters, and no effect of spacing on perceived centre. This confirms the observations of experiment 1. Moreover, the bias in perceived stimulus centre extended across all stimulus types tested. This new finding suggests that all types of orthographic symbols received similar processing, including letter-like symbols. Symbols were, however, also special in that they were not as sensitive to the manipulation of string length as the remaining stimulus types.

Expanding a familiar pattern by adding spaces to words can affect memory-based performance with words by reducing their familiarity advantage over pseudowords, while sensory processes in word perception (as measured with a probe task) can remain unaffected (Mewhort et al 1982). Thus, added spaces can have both a symbolic and a sensory-perceptual function in visual word recognition. The present finding that added spaces have the same effect on words as on other orthographic materials suggests that their impact does not simply reflect 'natural' interletter spacing in reading. Instead, there is something special about the number of elements that determines the perceived stimulus centre. This interpretation could be strengthened by finding the limiting conditions under which the bisection bias no longer obtains. The next experiment provided such information.

The bisection bias was strongest for letter strings, contrary to a result obtained by Fischer (1996) with English materials and paper and a pencil method. In that older study, pseudowords but not consonant strings exhibited a bisection bias to the left. The finding suggested that phonological or lexical processing may affect perceived word centre, but the present results do not replicate it. However, there are several procedural differences between the two studies that may have contributed to the different outcomes. First, in the older study the different materials were given to different groups of subjects. The results may thus have been due in part to individual differences. Second, the blocked stimulus manipulation of pseudowords and consonant strings may have induced strategic biases. The aim of the present experiment was to investigate bisection performance with randomly mixed stimulus materials and a within-subjects manipulation, thus possibly allowing subjects to apply different strategies. Finally, the consonant strings in Fischer's (1996) study were generated by replacing each consonant with the letter 'X', thus possibly creating a particularly heterogeneous visual pattern, compared to the present study. In any event, the results called for a replication of the present effect of stimulus materials on bisection performance in experiment 3.

The results with regard to bisection times are complex, but can to some extent be attributed to reading strategies. Relatively short bisection times for symbol strings presumably reflect the ability of subjects to quickly distinguish between letters and symbols. Only in the case of letters would they then bother to engage in further processing. Similarly, note that pseudowords had the longest response times. These were shown in the same block as the words from which they were derived. Thus, subjects may have attempted to identify the original words, which required reordering of the vowels and guessing. The possibility of strategic biases in the bisection task was also investigated further in experiment 3.

4 Experiment 3: Orthographic vs graphic stimuli

The third experiment had several objectives. First, it replicated the comparison between words, pseudowords, letter strings, and symbols, to see if the generality of the bisection bias indeed extends across all types of orthographic materials. In addition, line bisection was investigated to obtain a baseline measure demonstrating that the bisection bias does not reflect visuomotor inaccuracy (see also Fischer 1999). Regarding the possibility of strategic or context effects, lines were presented twice to see if their perceived centre is modulated by the presence of words in the same block of trials. Moreover, lines and words differ in various respects: Lines are made from a single element, whereas words are concatenations of letters. Also, a line extends predominantly in one dimension, whereas words are two-dimensional. The third experiment explored the role of visual factors such as one-dimensionality vs two-dimensionality of the stimuli and stimulus segmentation, on bisection accuracy.

4.1 *Subjects*

Twenty-two new right-handed subjects participated for pay. They were eleven men and eleven women aged between 19 and 48 years (average: 26 years). All subjects had normal or corrected vision. Subjects reported to be neurologically healthy and were naive with respect to the hypotheses of the study. They signed an informed consent form prior to their participation.

4.2 *Apparatus and procedure*

The apparatus and general procedure were not modified from experiment 2, except that each subject received a different order of 5 blocks of stimuli, to be described next. Stimuli were displayed, responses collected, and data analysed as before. Subjects were not asked to name any of the stimuli.

4.3 *Stimuli*

There were five different blocks of stimuli to be bisected silently by each subject. In the first block, only lines were bisected to obtain a baseline measure of visuomotor accuracy. 10 lines of 81 mm length and 10 lines of 124 mm length, all 1 mm high, were presented in randomised order.

The second block contrasted line and word bisection to see if line bisection would be affected by the word context. A difference in performance, relative to the first block, would suggest that bisection performance is sensitive to strategic (top–down) or context (bottom–up) effects. 10 lines of 124 mm and 10 German nouns with a length of 12 characters were presented in randomised order. The two types of stimuli had identical physical lengths. Average word frequency was 299 per 6 million according to the Celex (1995) database, and all words had 4 syllables.

The third block involved bisection of lines, dashes, boxes, and bars. This allowed an assessment of the impact of one-dimensionality (lines, dashes) vs two-dimensionality (boxes, bars), as well as the role of stimulus continuity (lines and bars vs dashes and boxes), on bisection accuracy.

The fourth block was designed to assess the impact of letter vs symbol processing and the role of stimulus homogeneity vs heterogeneity on perceived word centre. Letters were D, F, G, H, and J; and symbols were &, #, §, $, and %.

In the fifth block letter strings were presented to assess the role of letter gravity on perceived centre. Strings were made either from the letter I or the letter W, or they contained a mixture, such that there were two Ws at the beginning or at the end of a string of Is. All stimuli were 124 mm long, and 10 replications of each stimulus were presented for bisection. Segmented stimuli all contained 12 elements.

4.4 *Results*

Consider first spatial performance in the *control* conditions. Short lines were bisected with an average bias of -1.34 pixels (SD 5.6), which did not differ reliably from accurate performance ($t_{21} = 1.11$, $p > 0.27$). Long lines were bisected with an average bias of -3.82 pixels (SD 5.9), which differed reliably from accurate performance ($t_{21} = 3.04$, $p < 0.01$). The effect of line length was reliable ($t_{21} = 2.48$, $p < 0.05$). Regarding bisection speed, short lines were bisected with an average response time of 3753 ms (SD 1872), and long lines were bisected with an average response time of 3887 ms (SD 2074). This difference was not reliable ($t_{21} = 0.91$, $p > 0.37$).

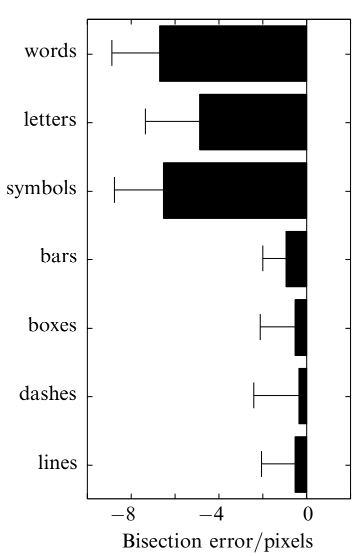

Figure 3. Bisection error (±1 SEM) as a function of stimulus material. Line bisection data are from the condition with word context (see main text).

Consider now the contrast between *line* and *word bisection.* Figure 3 gives an overview of spatial performance in these, as well as some of the remaining conditions. Lines were bisected with an average bias of −0.52 pixels (SD 7.4), which did not differ reliably from accurate performance ($t_{21} = 0.33$, $p > 0.74$). A comparison with bisection performance of the same lines in the first block did, however, show a significant reduction of bias ($t_{21} = 2.44$, $p < 0.05$, two-tailed). Thus, perceived stimulus centre is indeed sensitive to context effects.

Words identical in length with the lines were bisected with an average bias of −6.76 pixels (SD 10.2), which differed reliably from accurate performance ($t_{21} = 3.11$, $p < 0.01$). This effect of stimulus material was highly reliable ($t_{21} = 3.79$, $p < 0.01$), thus replicating previous findings (Fischer 1999).

Regarding bisection speed, lines were bisected with an average response time of 3316 ms (SD 1981), and words were bisected with an average response time of 3716 ms (SD 1860). This difference was reliable ($t_{21} = 2.29$, $p < 0.05$), but the direction of this effect argues against a speed – accuracy trade-off and suggests, instead, involuntary word reading.

Consider now the role of stimulus *dimensionality* and *continuity* on bisection accuracy (see figure 3). Spatial accuracy for lines, dashes, bars, and blocks was −0.69 (SD 7.1), 0.34 (SD 9.7), −0.93 (SD 5.0), and 0.53 pixels (SD 7.4), respectively. There was no reliable difference from accurate bisection either for lines ($t_{21} = 0.46$, $p > 0.65$, two-tailed), or for dashes ($t_{21} = 0.16$, $p > 0.87$, two-tailed), or for bars ($t_{21} = 0.87$, $p > 0.39$), or for blocks ($t_{21} = 0.34$, $p > 0.74$).

A repeated-measures analysis of variance (ANOVA) found no reliable effects of dimensionality ($F_{1,21} = 0.38$, $p > 0.54$, MSE = 17.56), or of continuity ($F_{1,21} = 0.34$, $p > 0.57$, MSE = 33.61). The interaction was also not significant ($F_{1,21} = 0.15$, $p > 0.70$, MSE = 14.11). These results show that the centre of graphic stimuli can be accurately perceived, in contrast to that of orthographic stimuli.

Bisection times for lines, dashes, bars, and blocks were 3397 ms (SD 1218), 3233 ms (SD 840), 3353 ms (SD 1134), and 3360 ms (SD 1227), respectively. A repeated-measures analysis of variance (ANOVA) found no reliable effects of dimensionality ($F_{1,21} = 0.16$, $p > 0.69$, MSE = 235 402) or of continuity ($F_{1,21} = 0.21$, $p > 0.65$, MSE = 644 439). The interaction was also not significant ($F_{1,21} = 1.06$, $p > 0.31$, MSE = 152 745).

Consider next the role of *stimulus type* (letters vs symbols) and *string homogeneity* (homogenous vs heterogeneous) on bisection accuracy. Spatial accuracy for homogenous and heterogeneous letter strings and for homogenous and heterogeneous symbol strings was −5.04 (SD 11.2), −4.72 (SD 12.8), −7.51 (SD 11.6), and −5.55 (SD 11.0) pixels, respectively. Performance differed reliably from accurate bisection for homogenous letter strings ($t_{21} = 2.19$, $p < 0.05$, two-tailed), for homogenous symbol strings ($t_{21} = 3.03$, $p < 0.01$, two-tailed), and for heterogeneous symbol strings ($t_{21} = 2.37$, $p < 0.05$, two-tailed), but not for heterogeneous letter strings ($t_{21} = 1.73$, $p > 0.09$, two-tailed), thus replicating the result of Fischer (1996) for consonant strings.

A repeated-measures analysis of variance (ANOVA) found no reliable effects of stimulus type ($F_{1,21} = 2.84$, $p > 0.11$, MSE = 21.18) or of string homogeneity ($F_{1,21} = 1.15$, $p > 0.30$, MSE = 24.96). The interaction was also not significant ($F_{1,21} = 0.50$, $p > 0.49$, MSE = 29.40). These results show that orthographic stimuli (letters and symbols) are processed differently from graphic stimuli.

Bisection speed for homogenous and heterogeneous letter strings and for homogenous and heterogeneous symbol strings was 3719 ms (SD 1586), 3750 ms (SD 1658), 3610 ms (SD 1500), and 3559 ms (SD 1451), respectively. A repeated-measures analysis of variance (ANOVA) found no reliable effects of stimulus type ($F_{1,21} = 1.99$, $p > 0.17$, MSE = 249 314) or of string homogeneity ($F_{1,21} = 0.03$, $p > 0.87$, MSE = 80 333). The interaction was also not significant ($F_{1,21} = 0.40$, $p > 0.54$, MSE = 94 288).

Consider, finally, the role of *letter gravity* on bisection accuracy. Homogenous strings of W or I, strings of I with W at the beginning, and strings of I with W at the end were bisected with −3.48 (SD 7.0), 1.56 (SD 7.8), and−5.4 (SD 8.5) pixel accuracy, respectively. Performance differed reliably from accurate bisection for homogenous letter strings ($t_{21} = 2.32$, $p < 0.05$, two-tailed) and for strings with W at the end ($t_{21} = 2.97$, $p < 0.01$, two-tailed), but not for strings with W at the beginning ($t_{21} = 0.94$, $p > 0.35$, two-tailed). The difference between the asymmetric strings was reliable ($t_{21} = 5.31$, $p < 0.001$, two-tailed), indicating that subjects overcompensated for perceived centre of gravity.

Bisection times for homogenous strings of W or I, strings of I with W at the beginning, and strings of I with W at the end were 3427 ms (SD 1389), 3528 ms (SD 1616), and 3557 ms (SD 1679), respectively. No reliable differences emerged (all p-values > 0.45).

4.5 *Discussion*

The third experiment replicated the finding of a reliable word bisection bias. The bias cannot be attributed to visual or motor processes, because line bisection requires the same visual and motor processes, but was overall accurate. Stimuli made from graphic symbols (lines, dashes, bars, blocks) were all bisected accurately, whereas stimuli made from orthographic elements (symbols or letters) exhibited a reliable bias. While there was no impact of stimulus dimensionality and stimulus segmentation on perceived stimulus centre, perceived centre of gravity of the stimulus ensemble led to reliable overcompensation of bias. Finally, line bisection was context-sensitive, as indicated by a reduced bisection bias for lines in the context of words. This result provides a possible explanation for the divergent findings between Fischer (1996) and the present experiment 2 (see above) regarding the perceived centre of letter strings.

5 Experiment 4: The role of attention

To account for the bisection bias to the left with orthographic materials, Fischer (1996) proposed an attentional scaling hypothesis: Readers might preferentially attend to the beginning of letter strings, and the length of this part of a word is subsequently overrepresented. This account assumes that allocation of visuospatial attention is part of a lexical access mechanism. It predicts that reflexively induced attention shifts affect the spatial representation of words. Alternatively, the bias may operate on more abstract stimulus representation, such as the matching between the perceived input against lexical representations. If the bias is related to lexical access, then it should be relatively insensitive to arbitrary manipulations of visuospatial attention. The fourth experiment addressed this issue with colour cues. Colour singletons are thought to attract visual attention (eg Theeuwes 1992, 1994). Thus, letters from the beginning, middle, or end of a word were coloured red in the experimental conditions, and the bias in these conditions was compared to the bias in a control condition with all black letters. If the bias reflects the allocation of visuospatial attention, then the bias should covary with the position of the coloured letter.

5.1 *Subjects*

Fifteen new subjects participated for pay. They were six men and nine women aged between 18 and 39 years (average: 29 years). All subjects had normal or corrected vision. Subjects reported to be neurologically healthy and were naive with respect to the hypotheses of the study. They signed an informed consent form prior to their participation.

5.2 *Apparatus and procedure*

The apparatus and procedure were not generally modified. However, because the stimuli were all words, subjects again named each word aloud before indicating its perceived midpoint by moving the vertical bar (as in experiment 1).

5.3 *Stimuli*

A total of 60 nouns were selected from a computerised database (Celex 1995). They were all 15-characters long and had 5 syllables. Word frequency ranged from 1 to 121 per 6 million, with an average frequency of 14.9 per 6 million. Four experimental lists were generated such that each subject saw all 60 words once; but across all four lists a particular word appeared once in black letters, once with its second letter in red, once with its eighth letter in red, and once with its fourteenth letter in red. Words were displayed and responses collected and analysed as before.

5.4 *Results*

There were a total of 900 observations, but owing to typographical errors in 2 stimuli and the exclusion of outliers according to the criteria specified above, only 90% of the data were included in this analysis, and the typos were analysed separately (see below). Average bisection performance in the control condition was −15.2 pixels (SD 10). This word bisection bias deviated reliably from accurate performance ($t_{14} = 5.63$, $p < 0.001$). Contrary to the attentional prediction, however, the bisection bias did not increase when the second letter of these words was shown in red colour: Average bisection performance in this condition was also −15.2 pixels (SD 10) ($t_{14} = 5.88$, $p < 0.001$). Also, contrary to the attentional prediction, the word bisection bias was not reduced when the fourteenth character was coloured red. Average bisection performance in this condition was −15.5 pixels (SD 11) ($t_{14} = 5.68$, $p < 0.001$). Finally, there was a slightly reduced bisection bias when the centre letter was red. Average bisection performance in this condition was −11.1 pixels (SD 11) ($t_{14} = 3.85$, $p < 0.02$). Bisection performance did not vary between these four conditions (all t-values < 1).

Average response time was 3848 ms across all conditions (SD 1430 ms). Response times with none, the second, the eighth, or the fourteenth character in red were 3524 ms, 3914 ms, 4028 ms, and 3927 ms, respectively. The control condition differed reliably from all other conditions ($t_{14} > 4.3$, $p < 0.001$), which did not differ reliably (all p-values > 0.13).

While there was no systematic effect of the intended attentional manipulation on perceived word centres, an unexpected result was obtained from some of the trials in which stimuli with typographical errors had been presented. Specifically, two typos had inadvertently been made in the stimulus files: The second letter ‘n’ had been omitted from the word ‘INSTRUMENTALIST’; and the neighbouring letters ‘n’ and ‘d’ had been reversed in the word ‘GEWALTANWENDUNG’. Average bisection errors were −17.8 pixels (SD 25) for the first stimulus and +21.7 pixels (SD 17) for the second stimulus. Average response times were 3367 ms (SD 1328) for the first stimulus and 4264 ms (SD 1756) for the second stimulus. Spatial performance on the first string exhibited typical bias to the left ($t_{11} = 2.48$, $p < 0.05$). Interestingly, however, performance on the string with the letter reversal indicated a reliable bias to the right ($t_{14} = 4.9$, $p < 0.001$).[3]

To insure that the positive word bisection bias in response to the letter reversal indeed represented an effect of the typographical error and not a bias specific to this letter combination, a control study was run in which the two correctly written words were shown to eleven new subjects (age: 21 – 34 years; average: 26 years; all right-handed; one male) from the same population. The correctly printed words were embedded in a list of 193 other stimuli (Fischer, in preparation). In this new data set, the correctly spelled word ‘GEWALTANWENDUNG’ obtained a bisection score of −10.82 pixels (SD 14), thus exhibiting a reliable bias to the left ($t_{10} = 2.61$, $p < 0.03$). The correctly spelled word ‘INSTRUMENTALIST’ obtained a bisection score of −7.0 pixels (SD 16), exhibiting no reliable bias ($t_8 = 1.31$, $p > 0.22$) (see footnote 3).

[3] Owing to the design of this experiment, every subject contributed only one observation to these statistics. Thus, the degrees of freedom for the t-tests depended on whether response time or bias scores for this particular trial exceeded the adopted cut-offs.

5.5 *Discussion*

The aim of the fourth experiment was to investigate the possible attentional origin of the word bisection bias. Visuospatial attention was manipulated with colour singletons. Response times were reliably faster in the control condition compared to the experimental conditions with red letters, presumably reflecting interference from the attentional distraction, for which subjects needed some time to recover prior to bisecting the stimulus. The expected covariation of the word bisection bias with the position of the red letter did, however, not obtain. Indeed, there was no evidence in the spatial domain of any effect of the colour-based attention manipulation.

An unexpected finding concerns the effect of typographical errors on perceived word centre: The inadvertent reversal of two neighbouring letters induced a reliable shift to the right in word bisection performance. This points to a processing stage related to orthographic or lexical computations, rather than to visual-attentional scanning. Unfortunately, no record was kept of whether or not a subject detected the typographical errors. This information should be obtained in future studies to further clarify the processes involved in the spatial perception of words. The context sensitivity of the bisection task (see experiment 3) suggests that only a few typographical errors should be presented per experiment to insure that subjects are engaged in normal word processing.

6 General discussion

The aim of the present study was to investigate perceptual and attentional contributions to perceived word centre. Subjects were presented with visual stimuli of variable extent made from graphic or orthographic materials. They had to move a narrow vertical line underneath the centre of each stimulus. Four main results obtained. First, the middle of a word is not accurately perceived by normal readers (see also Fischer 1996, 1999). Thus, skilled readers experience a perceptual illusion, or, in terms of Gregory's (1994) taxonomy, a cognitive distortion pertaining to the perception of print. This observation is in conflict with current theories of visual word perception that either implicitly or explicitly (eg Caramazza and Hillis 1990a, 1990b) assume that word length is coded veridically. Instead of perceiving the middle of a word correctly, normal readers overestimate the length of the word's beginning.

Second, the perceptual bias extends from words to pseudowords, letter strings, and even symbols; but not to boxes, dashes, lines, or bars. Thus, it does not depend on the requirement to name the stimulus aloud. It rather seems as if orthographic symbols receive some additional visual processing that graphic stimuli do not receive. This observation is in agreement with the claim of specialised brain areas along the early visual pathway for the processing of text (eg Petersen et al 1988).

Third, it is not the physical extent of the stimuli that determines the size of the bias, but the number of characters that fill the spatial interval. By manipulating the size of interletter spaces it was shown that inserting additional characters increases the perceptual bias for a constant physical string length. This increase in bias when a given spatial interval was filled with more elements is reminiscent of the filled interval illusion. Both temporal (eg Fraisse 1984) and spatial (eg Luckiesh 1922) intervals appear longer when they are filled, compared to empty intervals. This suggests that this type of illusion may tap a very basic perceptual mechanism related to perceived length. On the other hand, there appear to be no previous reports of directional errors when attempting to bisect homogeneously filled intervals compared to empty intervals. Also, subjects were certainly able to discriminate the lengths of strings made of 5 characters vs 5 characters plus 4 spaces. In other words, the increase in perceived length cannot account for the effect (see figure 1). Moreover, continuity vs segmentation alone did not systematically affect the size of bisection bias (experiment 3; see figure 3).

The results rather point to a cognitive operation related to the processing of orthographic stimuli as the source of the bias.

Finally, the word bisection bias was sensitive only to certain attentional manipulations (experiment 4). It did not covary with the position of a red letter among the black letters constituting a word. It is currently under debate whether a colour singleton leads to mandatory attentional capture (see Yantis 1998, for discussion). Thus, other attention manipulations (blinking, onsets, etc) should be applied to the word bisection task to insure attentional insensitivity of the bisection bias. On the other hand, sensitivity of the bisection bias to a letter reversal suggests that attentional manipulations related to lexical access might be more effective means of understanding perceived word centre. The result implies that not visuospatial scanning of the stimulus, but a more abstract stimulus representation provides the computational basis for an evaluation of the spatial extent of words. This interpretation is further supported by recent findings of a sensitivity of the word bisection bias to phoneme distribution (Fischer et al 1998; Fischer and Ziegler, submitted).

Fischer (1996, 1999) proposed an *attentional scaling hypothesis* to account for the directional word bisection bias. According to this hypothesis, lexical access involves attentional focusing on the initial letters of a word to establish a cohort of potential matches with entries in the mental lexicon (Paap et al 1982; see Marslen-Wilson 1989 for review). This attentional strategy would yield an overrepresentation of the word's beginning, resulting subsequently in the bisection bias. The current results suggest that the proposed scaling operation might not be performed early on during visual encoding, but rather at a more abstract representational stage related to lexical access mechanisms. The attentional scaling proposal relies on the notion of sequential left-to-right scanning, as opposed to the widely held assumption of parallel letter processing, but there has recently been some support for this notion (Kwantes and Mewhort 1999).

The bisection bias is relatively small, amounting to less than a character on average. This makes it important to consider possible sources of the artifact. For example, the systematic bias could be due to peculiarities of stimulus presentation, or it could depend on features of the beginning or ending letters, or it may reflect visuomotor problems of the subjects. However, these possibilities can all be ruled out. First, the bias obtains with printed stimuli on paper as well as with stimuli on CRT displays, with proportional as well as non-proportional fonts, and across a range of letter sizes. Second, note that stimuli (and hence, the beginning and end letters) remained identical across several conditions with added interletter spaces (experiments 1 and 2), but still changes in perceived centre emerged.

Pilot work had indicated that the beginning and the end of words was perceived with only ± 2 pixels variability across all stimuli. Moreover, all reported results are averages across several different stimuli, thus diluting any item-specific effects without missing the main effect of bias. Stimuli were presented at randomly chosen screen locations, and the seed input to the random procedure was the interval between trials, as determined by the subjects. Thus, there are no systematic effects of stimulus position in any one condition, and all conditions used the entire screen equally (except for a 55 pixel border between CRT frame and nearest stimulus pixel).[4] On the other hand,

[4] To illustrate how the random placement of stimuli on the screen depended on conditions, the mean (and range) of screen X and Y locations are given for the left lower margin of the first character of a stimulus in the main conditions of experiment 2. 5-character length: $X = 374$ (56 – 714), $Y = 411$ (58 – 716); 9-character length: $X = 309$ (56 – 559), $Y = 426$ (58 – 716); 17-character length: $X = 170$ (53 – 248), $Y = 414$ (58 – 716). Thus, the range of X values (horizontal position) became smaller owing to the requirement to fit longer stimuli on the screen, whereas the range of Y values (vertical position) remained equally large across conditions, indicating that the randomisation of stimulus positions worked.

merely changing the order of two internal letters induced a dramatic reversal of bias in a single stimulus (experiment 4) which cannot be attributed to an averaging artifact. This change occurred to the right of the bisection mark, and did thus presumably not affect perceived interletter spacing at the critical bisection location.

Inspection of individual data sets further revealed that each has a similar, monomodal distribution of judgments. Thus, averaging across subjects is also not the source of the bias. The reported increase of bias with number of letters also rules out an account in terms of visuomotor processes because these processes did not change across conditions. Experiment 3 provided a direct control for visuomotor effects by showing that lines and other graphic stimuli with an identical length to the orthographic strings do not exhibit the bias. Thus the present results cannot be accounted for in terms of procedural artifacts. They rather suggest that words (and other orthographic materials) trigger special brain mechanisms that affect the computation of their spatial extent. Similar observations were made by Carrasco and Sekuler (1993) and by Skottun and Freeman (1983) with single letters and letter strings, respectively.

The present findings with words shed a new light on a regularly observed eye fixation bias in normal reading. Reading researchers who register landing positions of the eyes during reading notice that the eyes tend to fixate in the first half of newly fixated words, rather than at the perceptually more optimal word centre (eg Rayner 1979; McConkie et al 1988; Underwood et al 1988, 1990; O'Regan 1990). McConkie et al provided evidence for an oculomotor contribution to this fixation bias, while the hypothesis of Underwood et al of parafoveal semantic information extraction was not supported by more recent evidence (Rayner and Morris 1992; Radach and Kempe 1993; Hyönä 1995). The present results suggest that the cognitive representation of word length may also contribute to this eye fixation bias. Specifically, word length may be perceived such that a fixation in the first half may be equivalent to a fixation in the subjective centre of that word. Although the word bisection bias is smaller in size than the eye fixation bias, it must be acknowledged that subjects in the present task had ample time for corrections, whereas eye fixations are the result of a fast and ballistic process. Further research should clarify the possible relation between perceived word centre and eye behaviour in reading.

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