
Albrecht W. Inhoff
State University of New York at Binghamton

Ralph Radach
Technical University at Aachen

Brianna M. Eiter and Michael Skelly
State University of New York at Binghamton

Potential sources for the discrepancy between the letter position effects in T. R. Jordan, S. M. Thomas, G. R. Patching, and K. C. Scott-Brown’s (2003) and D. Briihl and A. W. Inhoff’s (1995) studies are examined. The authors conclude that the lack of control over where useful information is acquired during reading in Jordan et al.’s study, rather than differences in the orthographic consistency and the availability of word shape information, account for the discrepant effect pattern in the 2 studies. The processing of a word during reading begins before it is fixated, when beginning letters occupy a particularly favorable parafoveal location that is independent of word length. Knowledge of parafoveal word length cannot be used to selectively process exterior letters during the initial phase of visual word recognition.

In their continuation of a programmatic line of research, Jordan, Thomas, Patching, and Scott-Brown’s (2003) recent work provided additional data indicating a privileged role of exterior letters during visual word recognition. The novel aspect of their study is that the exterior letter effect was obtained under relatively typical passage reading conditions and across a wide range of natural language variation. We concur with Jordan et al. insofar as this type of overarching evidence should provide a powerful impetus for theoretical developments in the domain of visual word recognition. We do not concur, however, with the view that their results are in empirical disagreement with Briihl and Inhoff’s (1995) earlier findings, according to which the beginning letters rather than the exterior letters of a parafoveally visible word assume a privileged role. In the following, we first explore potential sources for the discrepancies between earlier work that examined parafoveal information use and Jordan et al.’s results. Then, we present our view concerning letter usage during fluent reading.

Sources for the Discrepancies Between Briihl and Inhoff’s (1995) and Jordan et al.’s (2003) Letter Position Effects

Jordan et al.’s (2003) and Briihl and Inhoff’s (1995) studies are similar in that both use relatively natural reading tasks and both examine readers’ use of exterior, beginning, and center letters during visual word recognition. The two studies differ in a number of key aspects, however. Briihl and Inhoff controlled precisely when and where useful letter information was available, continuously monitored readers’ eye movements to obtain fine-grained on-line measures of letter usage, and manipulated carefully selected target words.

Specifically, eye-movement-contingent visual display changes were used to present a selected segment of a target word (e.g., its exterior, beginning, or center letters, or none of its letters) while it was visible to the right of fixation (i.e., when it was projected at a left parafoveal retinal location) and to present the intact target when the eyes subsequently moved onto the target location (i.e., when it was brought into foveal vision and fixated). A partially visible target was thus available in the parafovea in the experimental conditions, and the intact target was visible when the word was fixated. The viewing durations on the intact target were then used to determine the usefulness of the previously (parafoveally) available partial target preview. The ordering of the different types of partial target previews was randomized, such that readers could not form any expectations about the informativeness of a particular preview, and the effectiveness of every parafoveal preview manipulation was measured immediately after the parafoveal preview manipulation was applied (i.e., during subsequent target processing). Item properties were carefully controlled. All targets were seven-letter bisyllabic content words that began and ended with a consonant. None of the targets was affixed, and none contained a morphological or grammatical marking. Furthermore, all targets were embedded in neutral sentence context.

Under these conditions, comparisons of the different types of parafoveal target previews with the control and full parafoveal...
target masking condition showed a distinct ordering of letter location effects. Parafoveally visible beginning bi- and trigrams were particularly effective, and center letters were virtually ineffective. Parafoveal visibility of the target’s exterior letter pair was of intermediate usefulness, presumably because the beginning letter but not the last letter of this configuration yielded useful information. These results are in harmony with a large number of studies on parafoveal word recognition during reading (see Rayner, 1998, for a review).

Jordan et al.’s method did not distinguish between parafoveally and foveally available information, as a partially degraded word was visible in parafoveal vision and when it was subsequently fixated. Although Jordan et al. controlled letter identities across manipulated word locations in one of their experiments, there was no attempt to control the properties of manipulated words themselves that varied in length, frequency of occurrence, word type, syllabic and morphological structure, and contextual constraint. The experimental measure, passage reading time, indexed the cumulated effect of a particular experimental manipulation after passage reading was completed, and this global measure required that experimental manipulations were blocked such that the same position-specific letter degradation was applied throughout passage reading.

Under these conditions, Jordan et al.’s passage reading durations differed from Briihl and Inhoff’s (1995) word viewing durations in two important aspects. First, degradation of exterior letters was more deleterious to passage reading than was degradation of either beginning or center letters. Second, degradation of beginning letters was as disruptive as degradation of center letters. Exterior letters were thus particularly effective, and there was no difference in the usefulness of beginning and center letters.

Because the methods of Briihl and Inhoff (1995) and Jordan et al. differed dramatically, various accounts for differences in the effect pattern between the two studies can be advocated. Jordan et al. focused on differences related to the means by which position-specific letter information was implemented. In Briihl and Inhoff, position-specific information was created by revealing selected letters of a target and by replacing all other letters with lowercase xs such that informative letters would stand out among a sequence of xs (Inhoff, 1989b). Jordan et al. noted that this manipulation of letter position has two unintended consequences: It introduces potentially incongruous orthographic content into a parafoveal target preview, and it diminishes (but does not eliminate) word shape and other configurational information. A critical point is that in this manipulation, the degree of orthographic incongruity is confounded with letter position. When beginning letters are visible (e.g., thxxxxx), only one letter transition is incongruous (ux in the example); when exterior or center letters are visible (e.g., thxxxxx and xxndxx), two letter transitions are incongruous in each case (hx and xr for exterior letter previews and xu and dx for center letter previews). Hence, parafoveally visible beginning letters could have been particularly useful in Briihl and Inhoff’s study, because they introduced a relatively small degree of orthographic incongruity and/or because beginning letters are particularly informative when word shape and other configurational cues are obscured.

Jordan et al. sought to avoid the two potential pitfalls through the use of an elegant manipulation that revealed the full target word in all letter position conditions. This was achieved by merely degrading the visibility of letters at designated word locations, via low-pass filtering, such that identification of these letters was somewhat hampered. Because the orthographic structure of the manipulated word and its configurational properties remained intact, this manipulation was assumed to yield an uncontaminated inhibitory effect of letter degradation for different word locations.

In spite of its elegance, the position-specific degradation of letters is not immune to orthographic consistency concerns. It may well be that more orthographic uncertainty is created when the word contains two transitions between a degraded and a nondegraded letter, as occurs in the exterior and center letter conditions, than when it contains only one transition between a degraded and a nondegraded letter, as occurs in the beginning letter condition. Orthographic uncertainty could have exaggerated inhibitory effects in the exterior and center letter conditions, thus inflating the informative value attributed to these letter positions in Jordan et al.’s study. In principle, Briihl and Inhoff’s (1995) facilitation-from-letter-preview paradigm and Jordan et al.’s inhibition-from-letter-degradation paradigm are subject to the same potential confound of letter position and orthographic integrity, except that the confound must manifest itself in complementary ways: an overestimation of beginning letter effects in Briihl and Inhoff’s paradigm and an underestimation of these effects in the inhibition-from-degradation paradigm.

Whether this provides an account for the discrepancies in the effect pattern of the two studies could be determined experimentally, via orthogonal manipulation of exterior, beginning, center, and other letter positions and manipulation of orthographic consistency. We are inclined to predict that effects of orthographic consistency will be small or negligible and that Jordan et al.’s orthographic consistency hypothesis will have little explanatory value. A detailed examination of Humphreys, Evett, and Quinlan’s (1990) influential experiments supports our contention.

Humphreys et al. (1990) used a letter identification task in which participants were asked to identify the letters of a briefly presented uppercase target word that followed a briefly presented lowercase pseudoword prime. All primes and targets were foveally presented and contained relatively few (3–5) letters. Primes and targets contained matching and mismatching letter identities, the spatial location of which was systematically varied. In Experiment 1b, for instance, a four-letter prime revealed either the beginning, exterior, center, or ending two letters of a four-letter target. The prime’s remaining letter locations were occupied by mismatching letters. Primes in the beginning- and ending-letter condition thus contained one orthographically discrepant transition, between the second letter and the third letter, and primes in the exterior and interior prime condition contained two orthographically discrepant transitions, one between the first letter and the second letter and another one between the third letter and the fourth letter. In spite of this orthographic consistency confound that corresponds precisely to the orthographic consistency confound of Briihl and Inhoff’s (1995) study, Humphreys et al.’s data and Briihl and Inhoff’s data do not match. Instead, Humphreys et al.’s effect pattern is virtually identical to that of Jordan et al., indicating that orthographic consistency cannot account for the discrepancies between Briihl and Inhoff’s and Jordan et al.’s results.

Humphreys et al.’s (1990) findings also demonstrate that the availability of word shape and other configurational cues does not
determine the expression of letter position effects. As noted before, primes and target were presented in different letter cases. Nevertheless, exterior letters were consistently more effective than beginning letters, as occurred in Jordan et al.’s study where configurational cues were present in all letter position conditions.

How can the discrepancies between Briihl and Inhoff’s (1995) and Jordan et al.’s key findings be reconciled? Citing Woldorf and Hollingsworth (1974), Jordan et al. acknowledged the influence of retinal location on letter identification, although this factor did not assume explanatory power. In our view, effects of retinal location are pivotal for the understanding of letter position effects. Recall that Woldorf and Hollingsworth showed that a beginning letter is relatively easy to identify even when a letter string is shown in parafoveal vision. The perceptibility of the ending letter, in contrast, decreased dramatically for parafoveal letter string presentations. This implies that only one of the two members of a parafoveally visible exterior letter pair, the beginning letter, is likely to yield discriminating information.

Confirmatory effects have been obtained during natural reading. In their ingenious experiment, McConkie and Zola (1987) asked participants to read sentences while their eye movements were recorded. Each sentence contained a critical region that could be occupied by one of two critical words whose identity changed from fixation to fixation. For instance, during the reading of the sentence John does not store his tools in the shed anymore because it [leaks/leans] too much, the presentation of leaks and leans alternated over successive fixations. In all instances, the two members of each critical word pair differed by a single position-specific letter. After each trial, readers were instructed to select a previously read word from a set of four forced-choice alternatives that included the two critical words and two orthographically similar alternatives. Discriminating letter information that determined the choice of a particular critical word was obtained from a relatively small area of text under these conditions. To be selected, a word’s discriminating letter had to be within approximately four letter spaces to the left of fixation or 6–8 letters to the right.

During natural reading, the ending letter of a parafoveally visible word will yield discriminating information in relatively few cases (i.e., only when the fixated word and the next parafoveally visible word do not extend farther than 6–8 letter spaces to the right of fixation).\textsuperscript{1} The beginning letters of a parafoveally visible word, in contrast, are much more likely to occupy a favorable location and to yield discriminating information.

Moreover, the retinal location of beginning letters, but not of ending letters, is relatively immune to effects of word length. As the length of a parafoveally visible target increases, its last letter will occupy a retinal location with an increasingly poor visual resolution. All target previews in Briihl and Inhoff’s (1995) study contained seven letters (i.e., they were relatively long), such that the ending letter of the preview was likely to occupy an unfavorable retinal location.

Because the retinal location of a visible letter string is known to have a powerful influence on effects of letter position, we maintain that it is the difference in the retinal location of manipulated letter positions that led to discrepant letter position effects in Briihl and Inhoff (1995) and Jordan et al. As noted before, Briihl and Inhoff manipulated the information available at different letter positions only when a target item was available in parafoveal vision. Effects of letter position were thus examined as a function of a particular retinal location. In Jordan et al.’s experiments, all manipulated target words were visible prior to, during, and after their fixation, such that letter position could have influenced the acquisition of useful information prior to a target word’s fixation and during its subsequent reading. The one available comparison of parafoveal and foveal processing effects (Balota & Rayner, 1991) concluded that foveal word processing effects are substantially larger and more robust than corresponding parafoveal effects. Particularly effective use of exterior letters during the foveal processing of a visual target (e.g., Humphreys et al., 1990) is thus likely to dominate the particularly effective use of beginning letters in parafoveal vision when parafoveal and foveal information use cannot be discriminated.

The distinction between the parafoveal and foveal processing of words is of theoretical significance. The effective acquisition of useful information from a parafoveally visible word during reading is one of the hallmarks of fluent reading that develops with reading skill (Rayner, 1986). Mature readers skip between 10% and 30% of the words in a text (i.e., these words are not directly fixated), presumably because they can be identified in parafoveal vision. Information is also obtained from a parafoveally visible word for use when it is subsequently fixated, and the overall rate of fluent reading is approximately one third higher when useful parafoveal word previews are available than when they are denied (see Rayner, 1998, for a review). Effective use of parafoveal information appears to be a universal component of skilled reading, as it occurs in qualitatively different writing systems, including European scripts, Hebrew (Pollatsek, Bolozy, Well, & Rayner, 1981), Japanese (Ikeda & Saida, 1978), and Chinese (Inhoff & Liu, 1998).

Because a significant part of the early phase of the visual word recognition process begins before a word is fixated, we favor the view that beginning letters, rather than the exterior letter pair, assume a pivotal role during this phase.

Letter Processing During the Early Stage of Visual Word Recognition in Reading

In support of a privileged role of exterior letters during the early phase of the visual word recognition, Jordan et al. (2003) argued that these letters are easy to locate and are therefore processed before other letters in a word. A processing conception is developed in which exterior letters and coarse-scale word cues, notably word length, determine the success of the initial phase of visual word recognition.

We disagree with some of these claims on theoretical and empirical grounds. Exterior letters admittedly occupy perceptually distinct word locations, but the beginning letters of a word are also prominent, and they may be just as easy to locate. Furthermore, beginning letters are spatially adjacent, and the beginning letters of a parafoveally visible word occupy a particularly favorable retinal location. Of importance, the retinal location of the beginning letters of a parafoveally visible word—but not of the word’s

\textsuperscript{1} The number of letter spaces to the right or to the left of fixation, rather than the retinal distance measured in degrees of visual angle, appears to determine the visibility of individual letters during reading (Morrison & Rayner, 1981). We use the foveal–parafoveal distinction as it is used in the reading literature (e.g., Rayner, 1998).
ending letters—does not change as a function of word length. Hence, identification of the beginning letter pair may well precede identification of the exterior letter pair when a word is visible in the parafovea during reading, and beginning letters may yield a more stable orthographic code.

Empirical data from our laboratory support the attribution of a somewhat different role to the use of word length during reading. Although word length does offer information that can be obtained relatively early during reading, when words are parafoveally available, word length is used to direct the eyes toward an optimal landing position rather than to support the initial phase of visual word recognition. Specifically, large-scale examinations of landing positions on words showed that readers direct the eyes toward the center of a parafoveally visible word, although a number of oculomotor constraints result in a shift of the actual landing position toward the left of the word center, especially when the word is long (McConkie, Kerr, Reddix, Zola, & Jacobs, 1989; Radach & McConkie, 1998; Rayner, 1979).

Because short, spatially distinct letter strings often correspond to a monomorphemic word (or to a root morpheme plus affixation) in English and because the length and morphological complexity of a word are typically confounded in natural texts, Inhoff and Radach (2002) sought to dissociate the effects of spatial and lexical properties of a targeted word. They took advantage of orthographic conventions according to which some compound words can be written as spatially unified letter strings or as spatially distinct (hyphenated) strings (e.g., firestation and fire-station; the actual experiment was conducted in German, in which similar orthographic conventions apply). Figures 1 and 2 show the landing positions of the first fixation and the second fixation, respectively, relative to the center position of the full compound (indicated by a 0). First fixation on the spatially unified version clustered around Letter Position −2; that is, the preferred landing position was slightly to the left of the center of the spatially unified compound, as would be expected from prior corpus data (Radach & McConkie, 1998). The location of the second fixation did not reveal a distinct spatial selectivity. Spatially segmented compound versions revealed a different effect pattern. The first fixation location was closer to the compound onset, at Letter Positions −4 and −3, and second fixations revealed spatial selectivity, being primarily directed toward Letter Position 3. Consistent with prior corpus data, the eyes thus landed near the center of each one of the two relatively short constituent words, again demonstrating the effective use of parafoveal word length for saccade targeting.

The use of parafoveally available word length for the selection of a fixation location was not accompanied, however, by the two-pronged use of word length and exterior letters during the initial stage of visual word recognition in a recent experiment by Inhoff, Radach, Eiter, and Juhasz (2003). Four parafoveal viewing conditions were created, two that provided accurate parafoveal word length information and two in which the length of a parafoveal word preview was altered by deleting a center or near-center letter. For instance, preview of the target word subject consisted of sub ect in an accurate-length condition and of sub ect in an inaccurate-length condition. (The blank target space in the inaccurate-length preview condition was occupied by an uninformative letter in the accurate-length preview condition, to provide an identical sequence of useful letters in the two conditions.) Exterior letter identities were thus left intact when parafoveal word length was accurate but not when it was inaccurate, as the insertion of a blank space created a pseudoexterior letter, b in the example. Orthogonal to the length of the target preview, Inhoff et al. also

![Figure 1. The relative frequency and location of the first fixation on compound words (unified and hyphenated) with 11–13 characters relative to the compound center (indicated by 0).](image-url)
manipulated the letter content of the target preview by creating two conditions, one that revealed all the letters of the target except its center letter, as shown in the prior examples, and one that replaced all target letters with visually dissimilar letters that were linguistically uninformative (e.g., viptasp and vip asp). If knowledge of parafoveal word length—and of length-dependent exterior letters—engendered the particularly effective use of orthographic information, then parafoveal preview of target letters should have been more useful in the accurate-length than in the inaccurate-length condition. Statistically, this should have yielded an interaction of preview length (accurate vs. inaccurate) and preview content (useful vs. nonuseful letters). Table 1 shows three oculomotor measures that are commonly reported in the literature (Inhoff & Radach, 1998; Inhoff & Weger, 2003).

The saccade data show effective use of parafoveal word length for saccade targeting. As expected, saccades that positioned the eyes onto the intact target were shorter when they had been directed at an inaccurate-length preview, as the reaching of the center of a relatively short preview required the execution of a shorter saccade. In addition, less time was spent viewing the target in the accurate-length than in the inaccurate-length condition, and less time was spent when useful letter information was available prior to the target’s fixation than when it was denied. A critical point is that parafoveally visible target letters were equally useful in the accurate- and inaccurate-length conditions, thus arguing against the privileged use of word length and exterior letters during the initial (parafoveal) stage of visual word recognition.

Although beginning letters of a parafoveally visible word are likely to yield sizable preview benefits, we do not claim that a particular configuration of beginning letters constitutes a lexical access code (Inhoff, 1989a). In several experiments (Briihl & Inhoff, 1995; Lima & Inhoff, 1985; Inhoff, 1989a, 1989b, 1990), parafoveal preview of the full target word was consistently more effective than parafoveal preview of beginning bi- or trigrams (see, however, Rayner, McConkie, & Zola, 1980), and the ending trigram of a six-letter word yielded small preview benefits when its informative value was clearly marked (Inhoff, 1989b). In concert with adjacent letters, the ending letter of a parafoveally visible word may thus contribute to processing, in spite of the sharp decrease in visual acuity toward the parafovea. It is unlikely, however, that an isolated ending letter of a parafoveally visible word can yield lexically discriminating information. Together, theoretical considerations and empirical results cannot be reconciled with the hypothesis that the ending letter of a word, the

Table 1
First Fixation Durations and Corresponding Gaze Durations as a Function of the Length of a Parafoveal Preview and the Availability of Useful Letter Information

<table>
<thead>
<tr>
<th>Measure</th>
<th>Matched length</th>
<th>Mismatched length</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Letter preview</td>
<td>No preview</td>
</tr>
<tr>
<td>Saccade to word</td>
<td>8.8</td>
<td>9.0</td>
</tr>
<tr>
<td>First fixation</td>
<td>199</td>
<td>217</td>
</tr>
<tr>
<td>Gaze duration</td>
<td>271</td>
<td>307</td>
</tr>
</tbody>
</table>

Note. All values are in milliseconds. First fixation duration is the duration of the first fixation on a fixated target word; gaze duration is the cumulated time spent viewing a word until another word is fixated.

Figure 2. The relative frequency and location of the second fixation on compound words (unified and hyphenated) with 11–13 characters relative to the compound center (indicated by 0).
second member of its exterior letter pair, assumes a privileged role in the early stage of visual word recognition during reading.

References


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