Fast and specific access to orthographic knowledge in a case of letter-by-letter surface alexia

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ABSTRACT

A series of experiments assessed priming for single letters and words in a letter-by-letter reader (IH) when primes were displayed briefly (between 100-500 ms) and masked. Consistent with previous claims that letter-by-letter readers have difficulties accessing orthographic letter codes, IH failed to show normal cross-case priming for single letters in a naming task (e.g., *a*/*A*). Nevertheless, IH showed robust cross-case priming for four-letter words that have few if any perceptual features in common between upper and lower case (e.g., *read*/*READ*; the letters *r*/*R*, *e*/*E*, *a*/*A*, and *d*/*D* are visually dissimilar in lower/upper case), even at prime durations that failed to support priming for single letters. Furthermore, priming extended to pseudowords (e.g., *DEAT*), and was highly specific given that no priming was obtained between orthographic neighbors (e.g., *face* did not prime *FACT*). Based on this pattern of results, we argue that IH gains relatively normal access to orthographic representations, and that his letter-by-letter reading reflects a partial disconnection between orthographic and phonological representations. Within the context of a disconnection account, we provide an explanation of the paradoxical finding of robust word priming in the absence of single letter priming.

Dyslexic patients are classified as letter-by-letter readers whenever they exhibit an abnormally large increase in reading reaction times as word length increases. The effect of word length on reading times varies greatly from one case to another, but a typical patient might require three or four seconds to read three letter words, and reading times often increase by 2-3 seconds -- or more -- for every additional letter. This reading deficit can occur in the absence of impaired writing or spelling, and in these cases, patients are referred to as pure alexic. However, letter-by-letter reading is often accompanied by additional language problems, most commonly surface dyslexia and surface dysgraphia.

According to most (if not all) contemporary theories, the reading process in letter-by-letter reading is disrupted in such a way that patients cannot gain normal access to lexical or sub-lexical orthographic representations. The explanation as to why access is disrupted, however, is a point of contention. According to one view, orthographic codes cannot be contacted normally because a low-level perceptual deficit prevents patients from constructing accurate shape descriptions of visual inputs whenever multiple forms must be processed rapidly or in parallel; that is, the patients suffer from *simultagnosia* (e.g., Farah & Wallace, 1991; Kinsbourne & Warrington, 1962; Levine & Calvanio, 1978). On this account, the uptake of all kinds of visual information having to do with stimulus shape is impeded, but the deficit is manifested most clearly in reading because the identification of words is particularly dependent upon the parallel analysis of multiple shapes (i.e., letters; for a related view, see Patterson & Kay, 1982). According to another view, letter-by-letter reading reflects a difficulty in identifying letters, rather than constructing a visual description of the letters (e.g., Arguin & Bub, 1993, in press; see also, Kay & Hanley, 1991; Reuter-Lorenz and Brunn, 1990). These authors note that shape descriptions of letters must be mapped onto abstract letter codes in order to read (e.g., Coltheart, 1981), and on this view, a breakdown in this mapping function prevents normal access to orthographic representations. On a third view, letter-by-letter reading is the consequence of damage to orthographic representations themselves (Warrington & Shallice, 1980). Of course, there is no reason to assume that the same functional impairment is responsible for all cases of letter-by-letter reading (cf. Price & Humphreys, 1992), and it is possible that all of the above theories correctly characterize specific sub-sets of patients.

What we want to emphasize, however, is that all of the above accounts share the assumption that access to orthographic representations is impaired in letter-by-letter reading, and this in turn leads to slow reading. Accordingly, we will introduce the term *orthographic-access* theory to refer to this general view. Another possibility that is rarely considered, however, is that some instances of letter-by-letter reading reflects an impairment in the reading process after the appropriate orthographic codes are contacted. In particular, a partial disconnection between orthographic representations on the one hand, and phonological and semantic codes on the other, might underlie some cases of the reading disturbance by delaying access to the phonological codes required for naming. Since this interpretation is reminiscent of the early disconnection theories (Dejerine, 1892; Geschwind, 1965), we will adopt the term *disconnection* account to refer to patients who read in a letter-by-letter fashion after gaining relatively normal access to orthographic knowledge.

Despite the widespread acceptance of the orthographic-access view, two recent sets of results suggest that a sub-set of letter-by-letter readers do indeed access orthographic knowledge relatively normally. First, some patients process words surprisingly well when reading is tested *covertly*. For example patients have been reported who carry out lexical decisions (word/pseudoword discriminations) and semantic classifications of words (e.g. living/nonliving) at exposure durations too brief for them to explicitly identify the target items (e.g., Shallice & Saffran, 1986, Coslett and Saffran, 1989; Coslett, Saffran, Greenbaum, & Schwartz, 1993). Similarly, Bub and Arguin (1995) reported that a pure alexic patient (DM) was able to distinguish between high frequency words and legal pseudowords in a lexical decision task when reaction times were measured, and his responses were relatively quick (approximately 800 ms) and insensitive to word length. More interestingly, DM continued to make fast lexical decisions when items were presented in mixed case letters (e.g., tAbLe vs. jAbLe). Since upper and lower case letters are treated as functionally equivalent within the orthographic system (e.g., Besner, Coltheart, & Davelaar, 1984; Bowers, submitted; Coltheart, 1981; McClelland, 1976), this latter finding provides rather direct evidence that orthographic codes mediated his performance. Taken together, these covert reading results pose somewhat of a challenge to orthographic-access theories of letter-by-letter reading, because it might have been expected that abnormally long reading times would accompany long lexical decisions and long semantic categorizations -- performance on all of these tasks requires access to orthographic codes.

Second, it has become clear that letter-by-letter reading does not invariably abolish the word superiority effect (WSE; Bub, Black & Howell, 1989; Reuter-Lorenz & Brunn, 1990; Friedman & Hadley, 1992; Bowers, Bub & Arguin, in press). For example, Bowers et al. reported a WSE in a letter-by-letter surface alexic (IH) that was equally large when words and pseudowords were displayed in upper case letters (e.g., CAME was better identified than HANE) and in mixed case letters (CaMe was better identified than HaNe), as is the case with normal subjects (McClelland, 1976). This WSE was obtained despite the fact that the pseudowords were very "word-like" (pseudowords were matched with words in terms of bigram frequency and neighborhood density), and despite the fact that items were displayed briefly (83 ms for upper case items, 133 ms for mixed case items) followed by a post-stimulus mask. According to the standard interpretation of this finding, the advantage of words over pseudowords depends upon words gaining <u>specific</u> access to appropriate lexical-orthographic representations, while pseudowords can only access sub-lexical codes and lexical neighbors (e.g., Adams, 1979; McClelland & Rumelhart, 1980). So as long as this analysis is accepted, then the WSE obtained with IH indicates that he continues to gain specific access to orthographic knowledge, despite his reading disorder.

Of course, the above results do not provide unimpeachable evidence against orthographic-access theories. It is possible, for example, that a mild deficit in accessing orthographic codes is sufficient to impair explicit reading, whereas covert reading and the WSE may continue under these conditions (e.g., Arguin & Bub, 1993; Bub & Arguin, 1995; Farah & Wallace, 1991; Shallice & Saffran, 1986; but see Bowers et al., in press). For instance, if we assume that words activate more orthographic codes than pseudowords in some letter-by-letter readers, then this subset of patients might make fast and relatively accurate lexical decisions by monitoring the overall activity of their orthographic representations, and responding "yes" if the activation is above some threshold, and "no" if activation is below. Alternatively, these preserved reading skills may reflect processing mechanisms that are functionally and anatomically separate from those that normally mediate reading; namely reading mechanisms in the right hemisphere (e.g., Coslett et al., 1989, 1993; Reuter-Lorenz & Baynes, 1991; but see Bowers et al., in press). Still, these preserved reading skills should temper the strong conclusion that the underlying deficit in letter-by-letter reading invariably impairs access to orthographic knowledge. In some cases, these reading abilities may reflect relatively normal access to orthographic representations, as is supposed by disconnection accounts of letter-by-letter-reading.

In the present paper, we report a series of experiments that attempt to provide a further assessment of the claim that a letter-by-letter reader (IH) does in fact gain relatively normal access to orthographic knowledge (also see Bowers et al., in press). In all the experiments reported below, we employed a masked priming paradigm in which briefly displayed primes were presented prior to target which IH had to name as quickly as possible (cf. Arguin & Bub, 1994, in press; Forster & Davis, 1991). Consistent with previous work with DM (Arguin & Bub, 1994), IH showed severely impaired priming for single letters when primes and targets were presented in lower/upper case, respectively, suggesting that IH also has difficulty in accessing abstract letter codes. However, IH showed robust priming for words (and pseudowords) when primes and targets were displayed in lower and upper case format, even though these latter primes were presented for the same durations that failed to support letter priming. Furthermore, word priming reflected highly specific access to orthographic knowledge, given that no priming was obtained between orthographic neighbors (e.g., *face* did not prime *FACT*). Taken together, these results provide support for a disconnection account of IH's letter-by-letter reading. In the General Discussion, we outline a disconnection model that helps to reconcile the paradoxical finding that access to letter codes seems impaired in IH whereas access to higher order orthographic knowledge is intact.

CASE HISTORY

IH was a forty-five year old right-handed male at the time he suffered from a subarachnoid hemorrhage which was drained surgically in September 1983. No CT-scan is available to us, however, the neurological case report indicates that IH suffered a left temporo-occipital hematoma. Following the hemorrhage, IH's main behavior complaints were of a complete right-homonymous hemianopia, anomia, surface agraphia, and reading problems. A WAIS indicated an IQ in the low normal range (90) with no asymmetry between the verbal (89) and performance (92) scales. IH's anomia was verified with the Boston Naming test, on which he obtained a score of 6/60. Testing was discontinued on trial 19 after six consecutive errors. In that test, the patient could provide clear indications that he did recognize the stimuli presented but often failed to find the appropriate name even with substantial phonemic cueing. In order to document IH's dysgraphia, we asked him to spell a set of 144 words with ambiguous spellings that were read aloud along with a context to specify the word we had in mind. IH correctly spelled 26/144 on his first attempt, and six additional items on a second try. In all cases, his spellings were phonologically plausible, for example, spelling DIRT *d-u-r-t,* and hazy *h-a-z-e*. Based on our conversations with IH, we would also suggest that he comprehends and produces speech at a normal rate. With one exception noted below, the present set of experiments were performed with IH between August 1993 and May 1994.

EXPERIMENTAL TESTS

(1) The Effect of Word Length and Word Frequency on Reading

Bowers et al. (in press) documented IH's letter-by-letter reading by presenting him with a list of 160 words that included an equal number of four-, five-, six-, and seven-letter words. For each word length, 20 words were high frequency (greater than 100 occurrences per million), and 20 were low frequency (less than 10 occurrences per million). Items were presented in a random order, and were displayed in upper case 24--point Geneva bold font. During the reading task, IH was asked to name each word as quickly as possible, and his reaction times were measured by a voice trigger. As can be seen in Figure 1, IH's reading times were long and increased by approximately 500 ms for each additional letter, a pattern indicative of letter-by-letter reading. It should be pointed out that this reading rate is somewhat faster than that of most other cases of letter-by-letter reading reported in the literature. However, a number of patients read at a similar rate, including DM (Arguin & Bub, 1993, 1994; Bub & Arguin, 1995) and RAV (Warrington & Shallice, 1980).

Insert Figure 1 about here.

As can be seen in Table 1, IH also misread many of the above words, especially the longer ones. As is common in letter-by-letter readers, his errors were predominantly visual in nature (e.g., Patterson & Kay, 1982). For example, IH read SUSPEND as SUSPECT and THEORY as THERE. In addition, a number of his errors were also phonological regularizations, such as pronouncing TIGER with a short "i" sound, as in "fig", an error indicative of surface dyslexia. Consistent with this diagnosis, Bowers et al. (in press) reported a second experiment in which IH correctly read 69% of high frequency irregular words, whereas he only read 31% of low frequency irregular words (all words were between 4 and 6 letters in length). By contrast, his reading performance on regular words was independent of frequency, with 86% and 82% accuracy rates for high and low frequency items, respectively. This pattern of performance has been reported previously in surface dyslexic patients (Behrmann & Bub, 1992; Patterson & Hodges, 1992), and accordingly, it appears that IH he suffers from a combination of letter-by-letter reading and surface dyslexia, so-called *letter-by-letter surface alexia* (Friedman & Hadley, 1992).

Insert Table 1 about here.

(2) Masked Letter priming.

According to most current theories of normal reading, shape descriptions of letters map onto abstract letter codes in a parallel manner, and these abstract letter codes map, in turn, onto higher level orthographic knowledge (e.g., Adams, 1979; McClelland, 1976). Recently, a number of authors have accounted for letter-by-letter reading within this general framework, and argued that the functional impairment is located in mapping function between the shape descriptions of letters and the abstract letter codes (e.g., Arguin & Bub, 1994; Reuter-Lorenz & Brunn, 1990; Kay & Hanley, 1991). One key source of evidence in support of this claim is that a pure alexic patient (DM) failed to show priming in a naming task when lower case letters served as primes for upper case target letters (e.g. "*a*" did not prime "*A*"), whereas robust priming was obtained when primes and targets were presented in the same case (e.g. "*A*" primed "*A*") (Arguin & Bub, 1994). In fact, the authors failed to obtain cross-case priming when primes were displayed for 500 ms, whereas, Arguin & Bub (in press) reported robust cross-case priming in normal subjects with 50 ms primes, and equivalent cross-case/within-case priming with 150 ms primes (for additional evidence that alexic patients have difficulties accessing abstract letter codes, see Reuter-Lorenz & Brunn, 1990; Kay & Hanley, 1991). Based on this pattern of results, Arguin and Bub argued that DM's letter-by-letter reading was the product of his inability to gain access to abstract letter codes. In the following experiment, we attempted to replicate this finding in IH.

Materials. The materials included eight letters that were perceptually dissimilar in upper and lower case conditions according to a visual similarity matrix computed by Boles and Clifford (1989); namely, the letters *A/a, B/b, D/d, E/e, G/g, L/l, N/n, R/r* . All letters were displayed in 24-point Geneva font. A masking stimulus, which took the form of a checkerboard with sides of 10 mm was presented before and after the prime, and an outline of a square with sides of 10 mm acted as a frame around target letters in order to unambiguously mark the target letter (see below). All stimuli were presented in the middle of the display screen.

Design and Procedure. Three conditions defined the relation between prime and target: 1- Physical Identity (PI), where the prime was identical to the target, with both items displayed in upper case (e.g., prime = *A*; target = *A*). 2- Nominal Identity (NI), where the prime had the same name as the target, but was structurally different (e.g., prime = *a*; target = *A*). All NI primes were presented in lower case, targets in upper case. 3- Different Identity (DI), where the prime and target were both nominally and structurally different (e.g. prime = *a*; target = *D*). The DI primes were selected from the above set of eight letters and were randomly paired with targets. Half of the DI primes were displayed in lower case and half in upper case; all targets were displayed upper case. In order that primes and targets shared the same name on half of the trials (e.g. *a/A* or *A/A*) and had different names on half of the trials (e.g. *a*/*D* or *A*/*D*), twice as many DI trials were included compared to PI or NI trials. PI, NI, and DI trials were randomly intermixed and were presented in blocks of 96 trials. Note, Arguin & Bub (1994) included a neutral prime (blank character) as the baseline condition in order to compute priming in the various experimental conditions. However, the inclusion of a DI baseline condition in the present experiment should not compromize a comparison across studies, given that Arguin & Bub (in press) found that normal subjects' reaction times to name target letters were equivalent in Neutral and DI conditions when primes were displayed for 100, 200, or 500 ms -- the prime durations included here.

At the beginning of each trial, the masking stimulus was presented in the center of the screen for 500 ms. It was then replaced by the prime, which remained on for a duration of either 100, 200, or 500 ms, encompassing the prime durations of 200 and 500 ms that Arguin & Bub (1994) included with DM. At the offset of the prime, the mask was presented again for a duration of 33 ms (i.e. two video frames). It was then replaced immediately by the target surrounded by the square frame, which remained visible until IH responded. In order to construct a fully counterbalanced design, each letter was presented in the PI, NI, and DI conditions, as well as the 100, 200, and 500 ms prime duration conditions. This yielded a set of 96 trials. In order to increase the number of observations per condition, IH was tested four times on the list.

Results and Discussion. IH's correct naming latencies in the various experimental conditions are listed in Figure 2, and his corresponding error rates in Figure 3. As can be seen in Figure 2, robust PI priming was obtained at all prime durations, whereas NI priming was absent at the shortest delay. Consistent with this description of the results, an ANOVA that treated prime type (NI vs. PI vs. DI), prime duration (100, 200, 500 ms), and list repetition (1-4) as between subject factors revealed a main effect of prime type, [$F(2, 335) = 36.22$, $p < .001$], list repetition, [$F(3,335) = 16.58$, $p < .001$], as well as an interaction between prime duration x prime type, [$F(4, 335) = 4.23$, $p < .01$]. List repetition did not interact with any factor [all F values < 1]. A series of contrasts revealed significant PI priming at all prime durations, [all $F(1, 335)$ values > 6.47, p values < .05], whereas the NI priming failed to reach significance when primes were displayed for 100 ms, [$F(1,335) < 1$], and only reached significance following 200 or 500 ms primes, [both $F(1, 335)$ vales > 5.52, p values < .05]. Furthermore, NI priming was reduced compared to PI priming at 200 ms, [$F(1, 335) = 11.26$, $p < .001$], although this difference was not significant following a 500 ms prime, $F(1,335) = 1.12$, $p = .28$. Error rates in all conditions were low (all below .06), and there was no evidence of a speed-accuracy trade-off, as the correlation between average RTs and error rates across conditions was slightly positive and insignificant [$r = +.14$; $F(1,7) < 1$].

Insert Figure 2 & 3 about here.

Based on this pattern of results, it appears that IH shows a pattern of priming that parallels the recent findings reported with DM (Arguin & Bub, 1994). Like DM, IH showed robust PI priming at all durations, and similarly, IH showed reduced NI priming compared to what has previously been found in normal subjects. Given these results, it appears that both IH and DM have difficulties accessing abstract letter codes, consistent with the orthographic-access approach. It should be emphasized, however, that IH did show robust NI priming when primes were displayed for

500 ms, whereas DM failed to show priming in this condition. Accordingly, IH's deficit in accessing abstract letter codes seems less severe than DM's impairment.

(3) Masked word priming.

Given the standard assumption that word identification depends upon the prior identification of letters, it might be expected that a deficit in processing letters should produce a corresponding deficit with words. Indeed, it is often argued that letter-by-letter readers have particular difficulty in identifying letters when several of them must be processed in parallel -- i.e., they suffer from simultagnosia (e.g., Farah & Wallace, 1991; Kay & Hanley, 1991). Accordingly, it might be expected that these patients would have more difficulty in accessing orthographic word codes compared to single letters. Thus, it is interesting to note that the only evidence that some patients gain fast access to orthographic representations has been obtained with words rather than individual letters. For example, DM was able to make relatively fast and accurate lexical decisions when words and pseudowords were displayed in mixed case letters, and his reaction times were largely insensitive to word length (Bub & Arguin, 1995). At the same time, however, he failed to show NI priming for single letters when primes were displayed for 500 ms. Similarly, IH was better able to identify words compared to matched pseudowords in a word superiority experiment, even when items were displayed in mixed case letters for 133 ms and a post-stimulus mask was included (Bowers et al., in press). At the same time, however, his NI priming for single letters was absent or grossly impaired when primes were displayed for 100 and 200 ms. Based on these results, it appears that DM and IH gain better access to orthographic word compared to letter codes, a surprising conclusion given standard models of reading. Of course, different tests were employed to characterizing the letter and word processing skills of DM and IH, and thus it is difficult to make any strong conclusion based on these results.

In order to more directly compare letter and word processing in letter-by-letter reading, we assessed priming for words with a procedure as similar as possible to the letter priming task. If NI priming for words is obtained under conditions that fail to support letter priming, then the conclusion that IH has a difficulty accessing orthographic codes will have to be reconsidered.

Materials. In order to evaluate whether orthographic codes are contacted within a priming experiment, it is important that the primes and targets are structurally dissimilar in their upper and lower case formats -- otherwise, any priming effects obtained may reflect the repetition of low-level perceptual information rather than the repeated access to abstract orthographic codes. This concern was easily addressed in the letter priming experiment, because it is a straightforward matter to select letters that are perceptually unrelated in upper and lower case. Fortunately, it is also possible to select a set of words that are perceptually dissimilar in upper and lower case, because some words are composed of letters that are dissimilar in upper and lower case (e.g. *READ/read; R/r, E/e, A/a, D/d*). For descriptive purposes, this class of words is labeled *high shift*.

The experiment included a set of 60 four-letter high shift words that were composed of 3 or 4 letters judged to be the visually dissimilar in upper and lower case; namely, *A/a, B/b, D/d, E/e, G/g, L/l, Q/q*, (Boles and Clifford, 1989). This list was composed of 30 high frequency high shift words (median frequency 123, range 24-1156 occurrences per million), and a set of 30 low frequency high shift words (median frequency 6, range 1-13 occurrences per million) from the Francis and Kucera (1982) norms. See Appendix A for complete list of items.

As in the letter priming experiment, a masking stimulus was presented before and after the prime. In this case, the mask took the form of an elongated checkerboard with sides of 10 x 40 mm. In addition, the outline of a rectangle with sides of 10 x 40 mm acted as a frame around the target words. Once again, all stimuli were presented in the middle of the display screen, in 24-point Geneva font.

Design and Procedure. The design of this experiment paralleled the letter priming study. In the PI condition, primes were identical to targets, with both items displayed in upper case (e.g., prime = *BABY*; target = *BABY*). In the NI condition, primes had the same name as targets, but both were structurally different (e.g., prime = *baby*; target = *BABY*). NI primes were always presented in lower case, targets in upper case. In the DI condition, primes and targets were both nominally and structurally different (e.g. prime = *read*; target = *BABY*). DI Primes were selected from the set of high and low frequency words, and were randomly paired with targets from the same condition. The DI primes were displayed in lower case format on half the trials and upper case on half of the trials; targets were displayed in upper case. As before, twice as many DI primes were included compared to PI and NI trials, and they were randomly mixed in blocks of approximately 100 trials.

As was the case with the letter priming experiment, the masking stimulus was first presented in the center of the screen for 500 ms. It was then replaced by the prime, which remained on for a duration of either 100 or 200 ms. At the offset of the prime, the mask was presented again for a duration of 33 ms, and it was then immediately replaced by the target surrounded by the rectangular frame. In order to construct a fully counterbalanced design, each word was presented in the PI, NI, and DI conditions, as well as the 100 and 200 ms prime duration conditions. Accordingly, 480 trials were required in order to rotate items through the various conditions. In order to increase the number of observations within each condition, IH was tested on the list twice. Testing took place once a week, for several weeks.

Results and Discussion. IH's correct naming latencies for high shift words in the various experimental conditions are listed in Figure 4, and the corresponding error rates are listed in Figure 5. As can be seen in Figure 4, similar PI and NI priming was obtained in the various conditions, except for the reduced NI compared to PI priming when low frequency words were tested with 200 ms primes. A series of contrasts confirmed this description of the results: Robust PI and NI priming was obtained in all conditions [$\underline{F}(1, 709)$ values > 6.29, $\underline{p}$ values < .05)], except for NI priming when low frequency words were preceded by 200 ms primes [$\underline{F}(1, 709) < 1$]. Furthermore, apart from this anomalous case, IH's latency to name targets in the PI and NI conditions did not differ [$\underline{F}(1, 709)$ values < 1]. An overall ANOVA carried out on the priming data revealed a main effect of frequency, [$\underline{F}(1, 709) = 84.38$, $\underline{p} < .001$], a list repetition effect that approached significance [$\underline{F}(1, 709) = 3.16$, $\underline{p} = .08$], and an interaction between prime type x frequency x prime duration that also approached significance [$\underline{F}(2, 721) = 2.67$, $\underline{p} = .07$]. This latter result reflects the anomalous lack of NI priming for low frequency words at 200 ms. No other interaction approached significance.

The error rates in the various conditions were higher than in the letter priming task (mean error rate = .21, range from .13-.29), but again, there was no evidence of a speed-accuracy trade-off, given that correlation between average RTs and error rates across conditions was positive and insignificant [$\underline{r} = + .53$, $\underline{F}(1,10) = 3.93$, $\underline{p} > .05$]. Note, the error rates in this experiment (and the following experiments) are higher than that obtained with the 4 letter words used to assess IH's letter-by-letter reading (.08), as listed in Table 1. We presume this higher error rate reflects IH’s attempt to name words more quickly in the priming tasks, and in addition, the preceding mask and prime may have interfered with his naming of targets to some degree.

Insert Figure 4 & 5 about here.

The failure to obtain priming in one condition -- namely, for low frequency words preceded by 200 ms primes -- complicates the interpretation of the present pattern of results. In order to clarify the situation, we re-tested IH with the low frequency words at both prime durations, and his reaction times and error rates in the various conditions are displayed in Figures 6 and 7, respectively. As can be seen in Figure 6, the NI and PI priming in this case were equivalent at both prime durations , suggesting that the initial failure to observe NI priming at 200 ms was incorrect. An ANOVA carried out on the latter data revealed a main effect of prime type, [$F(2, 386) = 3.71$, $p < .05$], no effect of prime duration $F(1, 386) < 1$, and no interaction between these factors, $F(2\ 399) < 1$. Neither the main effect of list repetition [$F(1,386) = 1.78$, $p = .18$] nor its interaction with other factors approached significance [all F values < 1]. Furthermore, IH's latency to name words in the PI and NI conditions did not differ, both $F(1, 399)$ values < 1, indicating that priming was equivalent in both conditions. It should be noted that the overall size of the priming effect for low frequency word, collapsed across prime duration, is somewhat smaller (85 ms) compared to priming for high frequency words (166 ms) in the former experiment, suggesting that IH gains better access to high compared to low frequency words.

Insert Figures 6 and 7 about here.

One additional finding that merits some comment is that the magnitude of the NI and PI priming was larger in some conditions than the duration of the prime itself. For example, a PI priming effect of 172 ms was obtained for high frequency target words preceded by a 100 ms prime. This finding suggests that priming in the PI conditions (and presumably NI conditions as well) reflected, at least in part, an *inhibition* in naming targets in the DI condition. This follows, because the largest possible priming attributable to facilitatory processes is only 133 ms, which is the SOA between prime and target. Thus, when considering the PI and NI priming, it is important to note these results may partially reflect a protection from the interference associated with the DI primes, rather than a true facilitatory effect. But even if all of the priming is the product of this interference, it is important to emphasize that naming in both the PI and NI conditions were protected -- even though there is no similarity in the perceptual properties of the primes and targets in the NI condition. Thus, we would argue that this protection account of priming is consistent with the view that IH gains fast access to orthographic knowledge.

In summary, it appears that robust NI and PI priming is obtained with both high and low frequency words even when primes are only presented for 100 ms. This result must be considered surprising given that NI priming for single letters was completely absent when primes were displayed for 100 ms, and was greatly reduced compared to PI priming following 200 ms primes. One possible interpretation of this result it that IH gains fast access to orthographic word codes without contacting letter codes, contrary to the common assumption that letter identification precedes word identification (McClelland, 1976). An alternative hypothesis, however, that we outline in more detail in the General Discussion, is that the letter priming task is simply a poor measure of letter processing within the *orthographic system*. That is, it is possible that IH gained fast access to both orthographic letter and word codes, and the absence of NI priming for single letters reflects an insensitivity of this task to orthographic processes.

Whatever the proper interpretation of the contrasting letter and word results, we want to emphasize that the NI priming results for words indicate that IH's reading impairment does not preclude him from gaining rapid access to orthographic representations. Thus, this finding provides a challenge to the orthographic-access theory of letter-by-letter reading.

One way to reconcile orthographic-access theories with the present results would be to argue that orthographic codes are contacted quickly but <u>non selectively</u> in letter-by-letter reading (Arguin & Bub, 1993). According to this interpretation, normal access to abstract letter and word codes depends on activating correct targets, and inhibiting incorrect neighbors. For example, in order to identify the word *GAME*, it is necessary to selectively access the code(s) for *GAME* and inhibit its neighbors -- simultaneously accessing *GAME, DAME, TAME, SAME*, etc. would obviously impair reading. Therefore, if the activation and/or inhibition processes are disrupted in letter-by-letter reading, reading would be compromised because selective access to the appropriate orthographic code would not be achieved. Indeed, Arguin & Bub (1993, Bub and Arguin, in press) have argued that this hypothesis is consistent with many of the findings reported in the literature, including the covert reading skills of DM. Note, this account is also compatible with the present data as long as non selective access to orthographic codes can support repetition priming. That is, the presentation of the prime *game* to IH may lead to the simultaneous activation of the codes *GAME, DAME and TAME*, etc., and this diffuse activation may be sufficient to accelerate the naming of the target *GAME* relative to a condition (DI) where the prime shares no letter with the target (also see Shallice & Saffran, 1986).

In order to provide a direct test of this latter possibility, we decided to compare repetition priming (e.g., *face/FACE*) to priming between orthographic neighbors (e.g., *face/FACT*) -- so-called *form-priming* (Forster, Davis, Schoknecht, & Carter, 1987). On the view that orthographic-access is abnormally diffuse in letter-by-letter reading, it might be expected that form-priming might be more prevalent in IH compared to normal subjects.

(4) Masked repetition and form-priming in IH.

Form-priming has been the focus of a number of studies with normal subjects (e.g., Evett & Humphreys, 1981; Forster et al., 1987; Humphreys, Evett, & Quinlan, 1990; Segui & Grainger, 1990; see Forster, 1993, for review). One key finding that has emerged from this literature is that different priming tasks provide very different priming results. For example, priming on some tasks is constrained by the *neighborhood density* of words whereas priming on other tasks is not. Neighborhood density refers to the number of words that can be constructed from a target by changing one letter of the target (Coltheart, Davelaar, & Jonasson, & Besner, 1977). The word *BANK* , for example, is in a high density neighborhood, because many words differ from *BANK* by one letter -- e.g., *TANK*, *SANK*, *BARK*, *BAND*, etc. (12 in all), whereas the word *BABY* is in a low density region, because only one word can be constructed by changing a single letter from *BABY* -- *BABE*. In the lexical decision task, Forster et al. (1987) reported form-priming for targets in low density neighborhoods but not for targets in high density neighborhoods. So, little priming should be expected in the lexical decision task between BANK and BAND, because the items have many neighbors. In the identification task introduced by Evett & Humphreys (1981), however, form-priming is not constrained by neighborhood density, and is obtained for words that have few or many neighbors (e.g., Humphreys et al., 1990; Davis, 1990). The same has been reported for the naming task as well (Manso de Zuniga et al., 1988, cited in Humphreys, Besner, & Quinlan, 1988).

If in fact form-priming is ubiquitous in the naming task, then it is a poor vehicle to test the hypothesis that access to orthographic codes is non selective in letter-by-letter reading: Robust form-priming would reflect normal rather than abnormal access. However, Forster and Davis (1991) also failed to observe form-priming in the naming task when target items were <u>high frequency</u> words with many neighbors. That is, the naming task is subject to the same density constraint as the lexical decision task, as long as high frequency target words are tested. So again, no priming should be obtained between *BANK/BAND* in the naming task, because *BAND* is a high frequency word with many neighbors. This specific priming in normal subjects presumably reflects specific access to orthographic word codes for high frequency words. Therefore, if IH shows robust form-priming for this set of items, then there would be reason to argue that orthographic-access in IH is abnormally diffuse (at least in the sense that common words are not sufficiently activated to produce the specificity of priming observed in intact readers).

Materials. The materials included 128 pairs of orthographic lexical neighbors, with an equal set of neighbors differing in positions one through four: e.g., *fear/DEAR*, *male/MILE*, *fire/FINE*, *fact/FACE*. One item in each pair served as the prime, the other the target. An additional set of 128 words unrelated to the targets served as baseline primes (see below). Another set of 128 pseudoword/word neighbors were included, with an equal number of pairs differing on each of the 4 positions: e.g., *gisk/RISK*, *fope/HOPE*, *teft/TEXT*, *slir/SLIP*. A corresponding set of 128 pseudowords unrelated to the targets served as baseline primes. Finally, a set of 32 word-pairs that shared the same name, i.e., *king/KING*, and 32 words unrelated to the targets that served as baseline primes, were included. Thus, a total of 576 stimulus-pairs were included in the experiment.

In all conditions, primes were displayed in lower case, targets in upper case. Items were four letters in length, and all words had a frequency greater than 50 (median frequency = 153, range from 50-7289 occurrences per million; Francis & Kucera, 1982), and targets had an average of 4.4 neighbors. These words were not high shift, and therefore the selection of items was not restricted to a small set of words composed of specific letters. As above, a checkerboard mask was presented before and after the prime, and the outline of a rectangle acted as a frame around targets. Words and pseudowords were presented in 24-point Geneva font.

Design and Procedure. In the overall experiment, 18 conditions defined the relation between prime and target. For exposition purposes, however, the various conditions can be organized into two categories, and considered separately. The first 10 conditions comprised the basic experiment. In these conditions, the primes and targets were both words, organized as follows: Condition 1. Name Identity (NI), where prime had the same name as target (e.g., prime = next, target = NEXT). Conditions 2-5. Form-Similar (FS), where prime was one letter different from target. The letter change occurred equally often in positions 1-4, making four separate conditions (e.g., FS prime = talk, FS target = WALK). Conditions 6-10. Different Identity (DI), where the prime and target shared no letters (e.g., DI prime = deep, DI target = WALK). The targets from conditions 1-5 were included in this condition; accordingly, each target was preceded by a related and unrelated prime . DI primes served as baselines in order to determine priming effects in the NI and FS conditions.

The remaining 8 conditions assessed form-priming between pseudoword primes and word targets, as follows: Conditions 11-14. Form-Similar (FS), where the prime was one letter different from target, differing on positions 1-4 (e.g., FS prime = boof, FS target = BOOK). Conditions 15-18. Different Identity (DI), where the prime and target shared no letters, and targets were the same as in conditions 11-14 (e.g., DI prime = thid, DI target = BOOK). Again, the DI primes acted as controls for the FS primes.

As in the previous experiments, the masking stimulus was presented in the center of the screen for 500 ms. It was then replaced by the prime, which remained on for 100 ms, and at the offset of the prime, the mask was presented again for a duration of 33 ms. It was then immediately replaced by the target surrounded by a rectangular frame. The complete design resulted in 576 trials, and in order to increase the number of observations within each condition, IH was tested on the list twice. Testing took place over several weeks.

Results and Discussion. IH's correct naming latencies in the ten conditions that included word primes are displayed in Figure 8, and the corresponding conditions with pseudoword primes are displayed in Figure 9. The associated error rates are listed in Figure 10. The data for word and pseudoword primes are analyzed separately.

Insert Figures 8-10 about here.

As can be seen in Figure 8, the priming results with word primes are clear cut: NI priming was robust, [$F(1, 516) = 8.04$, $p < .01$], whereas FS priming did not approach significance in any condition, [all $F(1, 516)$ values < 1]. Thus, priming with word primes is very specific, contrary to the hypothesis that orthographic-access is diffuse in IH. A similar conclusion might be drawn when pseudowords act as primes, given that a series of contrasts failed to show significant FS priming in any position, [all $F(1, 408) < 1.86$, p values > .17]. As can be seen in Figure 9, however, there is a general trend to show FS priming for pseudowords, and in an overall ANOVA, the main effect of FS priming approached significance, [$F(3, 408) = 3.03$, $p = .08$]. Accordingly, pseudoword primes provide some evidence of diffuse access to orthographic codes. It should also be noted that the effect of list repetition was significant for word primes [$F(1, 516) = 9.39$, $p < .001$], but not for pseudoword primes [$F(1, 408) < 1$]. In neither case did list repetition interact with other factors [F values <1]. Error rates across conditions was similar to Experiment 3 (mean error rate = .17, range .13-.26), and again, no evidence of a speed-accuracy trade-off was seen, as the correlation between average RTs and error rates across all conditions was positive and insignificant [$r = +.39$., $F(1,16) = 1.95$, $p > .1$].

As noted above, form-priming in normal subjects differs widely across tasks and conditions. In order to determine "normal" performance in the present procedure, we tested six undergraduate students from McGill University as controls. For three subjects, primes were displayed for 100 ms (as was the case with IH), and for three subjects, primes were displayed for 50 ms[3]. For the sake of displaying the results in a simple format, we present priming scores for words (as opposed to the naming latencies) in Figure 11, and the corresponding priming results for pseudowords in Figure 12. As can be seen in the Figure 11, all subjects showed robust NI word priming, and like IH, priming was highly specific: no form-priming was obtained when primes were displayed for 100 ms, and two of the three subjects failed to show any form-priming when primes were displayed for 50 ms. Only subject BR showed evidence of form priming in position 4, [$F(1, 1073) = 5.9$, $p < .05$]. Thus, of 24 comparisons (six subjects x four positions), only one reached significance. With a confidence level of .05, we would expect 1 comparison out of 20 to be significant by chance alone. Interestingly, control subjects showed more evidence of form-priming with pseudoword primes, as was the case with IH (see Figure 12). With 100 ms primes, two subjects (SB & SD) failed to show any form-priming, but one subject (LG) showed form-priming in positions two, three, and four, [all $F(1, 1076)$ values > 5.38, p values < .05]. In addition, form-priming was obtained when primes were displayed for 50 ms with subject FF who showed priming in positions three and four, [$F(1, 1089)$ values > 3.56, p values < .05], and subject LS who showed form-priming in position 2, [$F(1, 1110) =5.20$. $p < .05$]. Thus, the slightly "diffuse" priming that was observed with pseudoword primes in IH is also obtained in normal control subjects, and therefore this priming seems to reflects normal rather than abnormal access to orthographic representations. It should also be noted that similar priming results were obtained when primes were displayed for 50 ms and 100 ms, suggesting that similar mechanisms mediated priming in both cases.

Insert Figures 11 and 12 about here

Finally, we should briefly mention a second version of this experiment that IH completed in which the mask interposed between the prime and target was displayed for 500 ms rather the 33 ms. In all other respects, the experiment was identical. Once again, FS priming effects were nonsignificant, but more interestingly, a 47 ms trend for NI priming was also nonsignificant, $\underline{F}(1,975) < 1$. The implication of this latter result is two-fold. First, it appears that the primes only activated orthographic representations for a very short period of time, i.e., less than 500 ms. This finding parallels previous work in normal subjects that have found masked priming effects to be very short-lived (e.g., Humphreys et al., 1988). Second, and more importantly, this pattern of results suggests that the NI priming reflects automatic rather than strategic processes, because if strategic processes mediated the effects, then IH would have had more time to organize his responses following a 500 ms mask, and thus more (or at least equal) priming should have been obtained in this latter condition. But given the absence of priming following a 500 ms mask, it appears that NI primes activate orthographic codes in a short-term automatic fashion.

(5) Repetition and form-priming for pseudowords.

The combination of robust NI word priming and severely reduced (if not null) FS word priming suggests that IH gains relatively specific access to orthographic representations. But still, it is not clear what type(s) of orthographic information are contacted. One possibility is that IH gains relatively normal access to sub-lexical representations -- such as abstract letter, bigram, and trigram codes -- and these codes mediated priming. Humphreys and colleagues endorse this account of masked priming in normal subjects (Humphreys et al., 1988, 1990). Another possibility is that IH gains relatively normal access to lexical-orthographic representations, and the priming reflects repeated access to a given orthographic word code by a prime and the target. Forster and colleagues endorse this latter view (Forster et al., 1984, 1987, 1991). Of course, a third possibility is that the these priming effects reflect a combination of lexical and sub-lexical factors.

Although we have no direct evidence regarding the type of orthographic codes that mediate priming in IH, there is reason to suspect that sub-lexical codes play an important role. In previous work, we argued that IH has selectively lost orthographic codes for low frequency words (Bowers et al., in press). This conclusion was based on the finding that IH shows a large WSE for high frequency words but not low frequency words, and the symptoms of his surface dyslexia are more severe for low compared to high frequency words. In the present experiment, however, IH showed repetition priming with low frequency primes and targets. If indeed we are correct and low frequency words are not represented within IH's orthographic system, then the priming obtained with low frequency words must be mediated by sub-lexical representations.

In order to provide a more direct test of this proposal, we assessed repetition priming for a stimulus material that does not have a lexical-orthographic representation; namely, pseudowords. If priming is obtained for these items, it would be necessary to conclude that sub-lexical representations can indeed mediate priming, at least for pseudowords, and presumably for words as well. By contrast, if null priming results are obtained, it would suggest that lexical-orthographic codes mediate priming in IH.

However, even if robust pseudoword priming is obtained, it is important to note that there is a problem in concluding that sub-lexical orthographic codes mediated the priming in IH. The problem is that Forster and Davis (1991) have argued that priming for low frequency words (and presumably pseudowords) can be mediated by a so-called onset effect in the naming task, an effect that is non-orthographic in nature. More specifically, the authors argue that priming can occur when subjects prepare to pronounce the prime word prior to the encoding of the target, which facilitates target naming when prime and target share the initial phoneme, and inhibits target naming otherwise. For example, subjects are faster to name the target *DART* preceded by the prime *dart* compared to the prime *bang*, because the partial naming of the prime *dart* is compatible with the naming of *DART*, facilitating a response, whereas the partial naming of *bang* is incompatible with the naming of *DART*, causing interference. So on this analysis, priming is obtained for *DART*, but this priming reflects the phonological properties of the word, or the procedures for articulating the word, rather than properties of its orthography. The authors go on to show that this onset effect is eliminated when high frequency target words are employed (presumably because high frequency words are read lexically rather than sub-lexically). But given that the present experiment assesses priming for pseudowords, any obtained priming could be the product of sub-lexical orthographic codes or an onset effect.

In order to assess the contribution of an onset effect to any pseudoword priming, we included a form-similar condition in which pseudoword primes and targets differed in the fourth position (e.g., prime = *reeb*, targt = *REET*). If we obtain pseudoword priming in IH, and if these effects are mediated by an onset effect, then priming should be obtained both in the repetition and the form-similar conditions -- in both cases, IH would begin to pronounce the initial phoneme(s) of the target before the target was displayed (e.g., “*r*” in “*reeb*” or “*reet*”), facilitating target naming compared to a DI condition. By contrast, if repetition but no form-similar priming is obtained, then the priming cannot reflect an onset effect. In this case, we would conclude that priming reflects repeated access to sub-lexical orthographic knowledge.

Materials, Design and Procedure. This experiment assessed repetition priming for a set of 30 *high-shift* four-letter pseudowords, and form-priming for another set of 30 *high shift* four-letter pseudowords. As before, these high shift target items contained three or four letters judged to be highly dissimilar (Boles & Clifford, 1989; see Appendix 2 for list of pseudowords). Four conditions defined the relation between prime and target: 1 (NI), where the prime had the same name as the target, but both items were structurally different (e.g., prime = *bame*; target = *BAME*), 2 (FS), where the prime was one letter different than target (e.g., prime = *reeb*; target = *REET*), and 3-4 (DI), where the prime and target were unrelated. Conditions 3 and 4 served as baseline for the NI and FS conditions, respectively (e.g., prime = *dall*; target = *BLAP*). Primes were displayed for 100 ms, and the procedure was the same as above. In order to increase the number of observations per condition, IH was tested on the list four times.

Results and Discussion. IH's correct naming latencies for pseudowords in the various experimental conditions are displayed in Figure 13, and his corresponding error rates are displayed in Figure 14. As can be seen in Figure 13, NI priming was obtained for the pseudowords, [$F(1, 354) = 4.22$, $p < .05$], and no FS priming was obtained, $F(1,354) < 1$. Thus, pseudoword priming, like word priming, is both robust and highly specific. The main effect of list repetition did not approach significance [$F(3, 354) = 1.17$, $p = .34$], and it did not interact with the other factors [F values < 1]. Error rates for pseudowords in the various conditions was comparable to the word error rates in the earlier experiments (mean of .23, range .17-.31), and again there is no evidence of a speed-accuracy trade-off, given the correlation between average RTs and error rates across conditions was positive and insignificant [$r = +.87$, $F(1,2) = 6.24$, $p = .12$]. Given that pseudowords are not represented as lexical-orthographic codes, sub-lexical representations must have played a role in the NI priming results, consistent with the view of Humphreys et al. (1988).

Insert Figures 13-14 about here

One aspect of the present results that might be considered surprising is the absence of FS pseudoword priming in IH, given that Forster and Davis (1991) reported robust FS priming with normal subjects as long as the target items were not high frequency words. In order to verify that FS priming is the standard result in the present experimental procedure, we tested three undergraduates from McGill university on the same task under identical display conditions. Consistent with the Forster & Davis (1991) finding, all three subjects showed significant FS-priming, with an average priming effect of 34 ms [all F values > 4.06, p values < .05.] In addition, the NI priming effects were significant, with an average effect of 68 ms [all F values > 22.13, p values < .001], and the interaction between priming condition x position reached significance in all cases, [F values = 3.7, p values < .06], indicating that NI priming was significantly greater than FS priming.

Clearly, then, pseudoword priming in the present paradigm is subject to an onset effect in normal subjects, and for some reason, IH is immune to this effect. Our explanation for this discrepancy follows directly from the Forster & Davis (1991) analysis of the onset effect. According to these authors, the onset effect reflects the prime's fast access to phonological codes, which facilitates target naming when prime and target share the same onset, and interferes otherwise. Given that IH does not gain fast access to phonological codes from orthography, he would not be expected to show an onset effect. Accordingly, any priming observed with IH likely reflects access to orthographic knowledge, uncontaminated by partial access to phonological knowledge. Since the pseudowords in the above experiment are in relatively high density lexical neighborhoods (median number of lexical neighbors was eight), the aforementioned density constraint that operates with high frequency words would predict no form priming for the pseudowords as well -- as was observed. Accordingly, the specific pseudoword priming in IH may reflect normal access to sub-lexical orthographic knowledge, and poor access to the phonological knowledge that mediates the onset effect in normal subjects.

One final point should be made with regards to the present set of results. As noted above, Humprheys et al. (1990) argue that priming is mediated by sub-lexical orthographic codes, and in support of this claim they note that priming extends to pseudowords in a masked identification task, and the same is true for the naming task (Masson, 1991). By contrast, Forster et al. (1984, 1987) argue that orthographic priming is lexical in nature, and in support of this conclusion, they note that priming in the masked lexical decision task is robust for words, but it is absent for pseudowords. Furthermore, they argue that the robust pseudoword priming in the identification task is in fact an artifact of a low-level perceptual phenomena (upper and lower case versions of the same word fuse together in a legible format when both primes and targets are presented briefly; Davis & Forster, 1994), and pseudoword priming in the naming task could be attributed to an onset effect that they have observed with low frequency words (Forster & Davis, 1991). Humphreys et al. (1990) reply that the task demands of making lexical decisions may be responsible for the lack of pseudoword priming in the lexical decision task. For example, pseudoword primes may increase the perceptual fluency for both words and pseudowords, but in the lexical decision task, this increased fluency produces a bias to respond "Yes". For pseudowords, this bias conflicts with the correct response, and may overcome the facilitation produced by pre-lexical priming.

We would suggest that the present findings speak to this debate. In our view, the combination of robust repetition priming for pseudowords and the absence of form-similar priming for these items in IH is most compatible with the view that sub-lexical orthographic codes supported his priming, because as noted above, the lack of form-similar priming rules out an onset effect as a source of the repetition priming. To the extent that the same orthographic mechanisms mediate priming in IH and normal readers, our results support the view of Humphreys et al. (1990). Indeed, it is important to emphasize that normal subjects in our study showed much larger pseudoword priming in the repetition compared to the form-similar condition, suggesting that the onset effect cannot account for all of their pseudoword priming. Of course, we recognize that our results can only be taken as preliminary evidence in favor of a pre-lexical account of masked priming, and there are undoubtedly ways in which the present data can be accommodated within the lexical account. Nevertheless, we consider a pre-lexical account to provide the most straightforward account of IH’s, and by extension, normal subjects’ results.

General Discussion

The present set of studies have yielded two main results. First, in a replication of some recent work with the pure alexic patient DM (Arguin & Bub, 1994), IH showed reduced priming in a naming task when lower case letters served as primes for letters in upper case (e.g., "a" did not prime "A"), and robust priming when primes and targets were presented in the same case (e.g., "A" primed "A"). This failure to observe robust cross-case letter priming in the naming task has now been reported in four separate cases of letter-by-letter reading (Arguin & Bub, 1992), and congruent results have been reported in two studies that showed patients to be abnormally slow in matching letters displayed in upper and lower case formats on name identity (Reuter-Lorenz & Brunn, 1990; Kay & Hanley, 1991). Thus the present results, in combination with these previous findings, seems to support the view that letter-by-letter readers have difficulty accessing abstract letter codes within the orthographic system.

However, the second main result, that contrasts sharply with the above finding, is that IH showed robust NI priming in the naming task when lower case words served as primes for upper case targets (e.g., *read/READ*). These robust effects were obtained even when primes were displayed for 100 ms, a prime duration that failed to support NI priming for single letters. Importantly, this priming was highly specific, given that little or no priming was obtained between orthographic neighbors (e.g., *face* did not prime *FACT*), and it also extended to pseudowords. Based on these latter results, it appears that IH is able to gain quick and specific access to orthographic knowledge, in spite of his failure to show priming for single letters.

It is important to emphasize that the present set of priming results are not the only demonstration that letter-by-letter readers gain relatively normal access to orthographic knowledge. As noted in the introduction, there are now a number of reports of patients performing lexical decisions and semantic categorizations much more quickly and accurately than they are able to name items (e.g., Bub & Arguin, 1995; Coslett & Saffran, 1989), and reports of a preserved word superiority effect when words and "word-like" pseudowords are randomly intermixed (Bowers et al., in press; Reuter-Lorenz & Brunn, 1990). In our view, this combination of results considerably strengthens the conclusion that some patients gain relatively normal access to orthographic knowledge, and that the reading impairment in these patients reflects a deficit *after* orthographic-access. With regards to IH, we would argue that the present results support the view that he gains relatively normal access to *sub-lexical* orthographic information, given that priming extended to words and pseudowords. Furthermore, given that IH showed a WSE for high frequency words intermixed with pseudowords matched in terms of bigram frequency and neighborhood density

(Bowers et al., in press), we would also argue that he is able to gain relatively normal access to *lexical* orthographic knowledge for high frequency words. But as a consequence of an orthographic-phonological disconnection, IH is unable to name words quickly.

The paradox of robust word and pseudoword priming with severely reduced letter priming

The present set of experiments provide clear evidence that priming extends to words and pseudowords in IH. Still, there remains one striking anomaly in the priming data that is yet to be fully addressed; namely, that IH failed to show comparable priming for single letters.

One interpretation of the letter-word discrepancy that has been suggested to us on a number of occasions is that IH does in fact have a difficulty in identifying single letters, which in turns leads to degraded access to higher order orthographic knowledge. In order to account for the greater amount of priming for words compared to single letters, it is argued that there are greater internal constraints within the orthographic system at the word-level compared to letter-level , and this acts to "clean-up" word representations compared to letter codes. That is, a difficulty in processing letters prevents robust letter priming in letter-by-letter readers, but nevertheless, the orthographic system is able to interact with degraded letter codes in such a way that high-level orthographic codes can support priming for words and pseudowords. Although this version of the orthographic-access theory cannot be rejected outright, two comments regarding this explanation are in order. First, it is important to note that this account is difficult to reconcile with the common view that letter processing is most impaired when multiple forms must be identified simultaneously (e.g., Farah & Wallace, 1991). In order to maintain this latter view, it would have to be argued that although a letter identification deficit is most pronounced when multiple forms must be processed, the orthographic system is able to counter this simultagnosia to such an extent that multiple letters are better identified than single letters -- an unmotivated position at best. Second, it is important to realize that this account fails to explain the most basic feature of letter-by-letter reading; namely, that latencies to name words are a function of word length in these patients. If it is argued that the orthographic system can act to "clean-up" messy word information but not letter information, and this is put forward as the explanation for the difference in letter and word priming, then it is not at all clear why naming should show the dramatic discrepancy in latencies between words and letters -- after all, this "clean-up" should also facilitate the naming of words compared to single letters.

In contrast with this approach, we would like to argue that IH does gain relatively normal access to both letter and word codes within the orthographic system, and that the contrasting priming results reflect the different types of representations that mediate priming for letters and words; namely, phonological codes in the case of letters, and orthographic codes in the case of pseudowords and words. That is, we assume that word identification involves the prior and parallel identification of the component letters of words, and in order to account for the present results, we assume that word priming reflects repeated access to orthographic knowledge, whereas priming for letters depends upon repeated access to phonological representations. So the absence of letter priming is not thought to be indicative of poor access to orthographic knowledge, as is generally assumed, but rather reflects poor access to phonological codes.

Consistent with the claim that qualitatively different representations support word and letter priming, a recent study by Arguin & Bub (in press) found letter priming in normal subjects to be constrained in a way that differs markedly from word priming. As noted earlier, these authors observed robust NI priming for single letters using the naming task that was similar in magnitude to PI priming following a short prime duration. However, using the same prime durations, they failed to obtain NI priming in an alphabetic decision task in which subjects classified targets as being either a letter or a non-alphabetic character, i.e.: !, $, %, &, +, ?, #, <, >, and =. For example, subjects were no faster in making alphabetic decisions to the target "A" when it was preceded by the matching prime "a" compared to the nonmatching prime "b". Thus, NI letter priming is restricted to some conditions (naming), but not others (alphabetic decision). In contrast with these results, numerous studies have reported robust NI priming for words in both the naming and lexical decision task. This dissociation provides at least suggestive evidence that different underlying representations are responsible for the two priming effects.

Additional evidence that different mechanisms underlie letter and word priming has recently been collected by the first author in collaboration with Richard Haan and Gabriella Vigliocco, who directly compared letter and word priming in two additional tasks. First, we compared NI priming for letters and words in two categorization tasks; in the letter task, subjects decided whether high shift letters were vowels or consonants, and in the word task, they decided whether high shift four-letter words were nouns or verbs. For example, subjects were required to press the right shift key of a computer keyboard as quickly as possible when the target letter *A* was presented (vowel), and press the left shift key when the letter *N* was displayed (consonant). Similarly, they pressed the right shift key when the noun *TREE* was displayed, and left shift key when the verb *EARN* was displayed. On each trial, a pattern mask of one pound key (#) or four pound keys (####) was displayed for 500 ms prior to the presentation of the prime that was displayed in lower case for 60 ms, and then finally the target letter or word was presented in upper case until subject responded. The critical finding was that a robust NI priming effect of 31 ms was obtained for words in a group of 26 subjects, whereas a NI priming of 2 ms for single letters was not significant in another group of 26 subjects.

In a second study, we assessed letter and word priming in an identification task in which a mask of one or four pound keys preceded a brief display of a lower case letter or word that acted as prime, followed by a brief display of an upper case letter or word that acted as target, which in turn was followed by a post-mask of one or four pound keys (cf. Evett & Humphreys, 1981). All letters and words were classified as high shift, and the subjects' task was to identify the briefly displayed target letter or word. For example, an individual trial in the letter priming task might include the following four symbols each overwriting each other: #aA#, and a trial in the word priming task might include the sequence: ####readREAD####. Priming is obtained when target identification is greater in the repeated condition (e.g., prime = a, target = A) compared to the baseline condition (e.g., prime = b, target = A). Two undergraduates from McGill were tested on both versions of the task, with the pre- and post-masks displayed for 500 ms, and the prime and target each displayed for 17 ms. As above, word priming was obtained, with subject 1 identifying 35/60 high shift words in the repeated condition and only 17/60 of the baseline items, and subject 2 identifying 35/60 and 12/60 of the repeated and baseline items, respectively. However, no priming was obtained for single letters, with subject 1 identifying 22/72 and 27/72 of the repeated and baseline letters, respectively, and subject 2 identifying 6/24 and 3/24 of the repeated and baseline items, respectively. Interestingly, IH showed the same pattern of results on this task, with robust priming for words and no priming for single letters.

To summarize, normal subjects showed robust NI priming in the naming, lexical decision, noun/verb decision, and identification tasks, but in the case of letters, only the naming task supported NI priming. Thus, the striking finding that word priming was obtained in IH in the absence of letter priming is not a paradoxical result that must be accounted for in the context of the letter-by-letter reading syndrome, but rather seems to be a result that extends to normal subjects under a variety of test conditions. Indeed, the combination of robust word priming and null letter priming was obtained in all but the naming task in normal subjects, and the only respect in which IH's performance differed qualitatively from that of normal subjects is that IH failed to show NI priming for letters in the naming task. Thus, the key question that needs to be asked with regards to normal subjects is: How can word priming occur in the absence of single-letter priming in a number of tasks? and in regards to IH is: Why does he fail to show NI letter priming in the naming task?

In fact, there may be a single answer to both of these questions. In the case of normal subjects, it is interesting to note that NI priming occurred in the one task that emphasizes the phonological processing of the target; namely, the letter naming task. In the alphabetic and vowel/consonant tasks, subjects can respond, at least in principle, on the basis of their orthographic and conceptual knowledge of the letters, and in the case of the identification task, the challenge for subjects is to identify the letters visually not phonologically. Accordingly, the phonological properties of the letters may play little or no role in performing these tasks. By contrast, in the naming task, the target letter is displayed clearly, and the challenge for the subject is to name the item as quickly as possible, which requires a quick encoding of the phonological properties of the target. Thus NI priming is only obtained in the naming task that requires quick access to phonological knowledge, suggesting to us that NI letter priming is mediated by phonological rather than orthographic representations. In contrast with the letter results, NI word priming appears to be mediated by orthographic representations, since priming was obtained in all of the tasks, all of which require access to orthographic codes. If indeed this is a correct characterization of letter and word priming, then the robust word priming in the absence of letter priming does not contradict the common view that word identification depends upon the prior identification of component letters, but rather, it reflects the fact that different priming tasks engage different representational systems.

Note, this characterization of letter and word priming in normal subjects fits nicely with the priming data obtained with IH. It is clear that IH gains slow access to phonological knowledge from printed letters and words, and therefore as long as NI letter priming is mediated by phonological codes, then it should be expected that IH would fail to show normal letter priming. Therefore, the absence of NI letter priming in IH may not reflect poor access to orthographic codes. Indeed, we assume that IH gains fast access to orthographic letter codes given the robust and specific NI priming that was observed for words.

A preliminary account of IH's Letter-by-Letter Reading

Thus far, we have reviewed evidence that IH gains fast and specific access to orthographic information, and summarized data that indicate that NI letter priming is mediated by phonological rather than orthographic codes. Thus, the failure to obtain letter priming in IH cannot be used as evidence that he has a difficulty accessing orthographic knowledge. Given this combination of results, we would like to suggest that IH gains relatively normal access to orthographic representations, contrary to so-called orthographic-access theories of letter-by-letter reading.

If this conclusion is accepted, then the functional locus of the reading deficit in IH is greatly constrained. By our hypothesis, orthographic codes are contacted normally, and given that IH understands and produces speech at normal rates, his phonological representations of words must also be intact. Thus, some form of disconnection between orthographic and phonological representations must underlie his reading deficit, what we labeled a *disconnection* account of letter-by-letter reading. On this view, IH cannot name words quickly, or gain access to meaning quickly, because orthographic codes do not interact with phonological and semantic systems in a normal fashion.

At present, however, we cannot provide a detailed account of the orthographic-phonological disconnection, and further work will be needed in order to characterize this dissociation more fully. One key theoretical issue that must be addressed in future work is why the translation time between orthography and phonology should be a function of the length of the orthographic representation. One possibility is that a partial orthographic/phonological disconnection leads to "messy" phonological outputs given specific orthographic-access, and this phonological pattern must be "cleaned-up" before naming can proceed. As long as it is assumed that longer orthographic strings are associated with more complicated phonological patterns, then it might be expected that this "clean-up" would be more extensive for longer words, leading to longer naming times for these items. Of course, additional explanations are possible, and they will have to be considered in more detail if disconnection accounts of letter-by-letter reading are pursued.

In our view, the primary empirical challenge to our claim that IH gains relatively normal access to orthographic representations is that IH makes many visual errors in naming longer words. As noted earlier, IH is very accurate in reading 4 letter words, as well as high frequency 5 letter words, but his reading accuracy drops off greatly with longer words, at least when he is encouraged to read quickly (see Table 1). One interpretation of this finding, that we cannot rule out unequivocally, is that IH has a mild deficit in accessing orthographic codes that manifests itself as robust and specific priming for 4 letter words and pseudowords, slow naming that is a function of word length, and in the case of longer words, poor reading accuracy. However, without any theoretical explanation as to why robust and highly specific priming should be obtained in the face of poor orthographic-access, we find this position unsatisfactory as well as unmotivated. Another explanation, that we are more tempted to adopt, is that access to complex orthographic patterns (i.e., longer words) is supported by partial access to phonological information that feeds back onto orthographic knowledge, whereas orthographic-access for simple orthographic patterns (i.e., short words) does not rely on feedback from phonological codes to the same extent. Therefore, IH's visual errors with longer words may be a by-product of his slow access to phonological patterns, rather than to his poor access to orthography from print.

Consistent with the claim that phonology plays a role in orthographic-access, there is a variety of evidence that the mapping between orthography and phonology is bi-directional (e.g., Dijkskra, Frauenfelder, & Schreuder, 1993; Stone & Vanhoy, 1994), and a number of models of word identification include feedback from phonology that functions to facilitate orthographic-access (e.g., Grainger & Ferrand, 1994). Indeed, it is interesting to note that patients who have difficulties in accessing phonological patterns from orthography, such as deep dyslexic patients, make visual errors when reading. Furthermore, Seidenberg (1992) has speculated that phonological recoding facilitates the recognition of longer words because these words are recognized in terms of subunits that are recovered from left to right. On this account, phonological recoding facilitates the retention of parts of words while attention shifts to subsequent parts. Seidenberg makes an analogy to the work in sentence processing, in which word-level phonology is thought to be relevant to the use of working memory in sentence parcing (e.g., Waters, Caplan, & Hildebrandt, 1987), and he suggests that phonology may be relevant to the parsing of longer words as well. Whatever the exact role phonology plays in accessing orthographic codes, we just want to emphasize that a number of authors assume that phonological analysis plays an important role in orthographic-access, and thus orthographic errors might in fact be the product of a partial disconnection between orthography and phonology rather than a deficit in the orthographic system itself (cf. Farah, 1994, for discussion of the logic of inferring a deficit in function X given poor performance in function X). Thus, we do not believe that the many visual errors that IH produces when reading long words are incompatible with the view that an orthographic-phonological disconnection underlies IH's letter-by-letter reading.

Before concluding, we want to emphasize that our claim that an orthographic-phonological disconnection underlies IH's reading problem is not a general claim about letter-by-letter reading. The reading performance of letter-by-letter readers often differs dramatically from one to another, and accordingly, there are good reasons to argue that patients often suffer from different underlying deficits (cf. Price & Humphreys, 1992). Perhaps the most striking difference among patients is their reading speed. IH is a relatively mild letter-by-letter reader, in that his reading times only increased about 500 ms per letter. By contrast, some patients read more than an order of magnitude slower than IH (e.g., patient CH from Patterson and Kay, 1982). Given the great differences in the reading speeds among patients, there is no reason to assume that our characterization of IH will provide insights into the reading disturbance of patients who are much slower readers. But when a patient is able to read relatively quickly (DM showed reading times comparable to IH), then it is possible that the present account will hold.

Conclusions

Based on the present set of data, we have argued that IH gains relatively normal access to orthographic representations, and a partial disconnection between orthography and phonology is responsible for his slow reading. Even if this conclusion turns out to be incorrect, the present data also contribute two important results to the literature. First, the robust NI priming for words and pseudowords indicates that a pure alexic patient gains better access to orthographic codes than has previously been assumed. This conclusion is greatly strengthened by the finding that priming is highly specific -- i.e., no priming is obtained between orthographic neighbors such as "face"/"FACT" -- and therefore it is difficult to argue that NI word priming reflects diffuse access to orthographic knowledge. Second, the finding that NI priming extends to words but not single letters in IH (as is the case with normal subjects) undermines the claim that poor performance on letter priming tasks reflects poor access to orthographic knowledge, as has been previously claimed (Arguin & Bub, 1993, in press; Bub & Arguin, 1995; also see Kay & Hanley, 1991, Reuter-Lorenz & Brunn, 1990). In our view, the present set of results challenge the orthographic-access theories of letter-by-letter reading, and suggest a need to reconsider disconnection accounts.

Acknowledgments

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Footnotes

1. This experiment was carried out in 1992, whereas all other experiments were carried out during the 1993-1994 academic year.

2. Jacobs and Grainger (1991) claimed to obtain NI priming for single letters in the alphabetic decision task. However, Arguin & Bub (in press) argued that some of this effect may have reflected the physical similarity between some of the primes and targets (e.g., prime = c, target = C). When Arguin and Bub corrected for this and some other problems, no NI priming was obtained for single letters in the alphabetic decision task.

3. Note, the prime duration of 50 ms is similar to the prime duration that Forster & Davis (1991) used with normal subjects using a similar paradigm. Thus, a comparison of priming following 50 and 100 ms prime should provide some indication as to whether the different mental operations underlie priming in these two conditions.

Table 1

Proportion of Reading Errors as a Function of Word Length and Word Frequency

Word Length	High Freq.	Low Freq.
4-Letter Words	.08	.08
5-Letter Words	.09	.43
6-Letter Words	.38	.53
7-Letter Words	.43	.53

Figure Captions

Figure 1. IH's reading latencies for high and low frequency words as a function of word length.
Figure 2. IH's reading latencies for single letters as a function of prime condition (PI vs. NI vs. DI) and prime duration (100 vs. 200, vs. 500 ms).
Figure 3. IH's error rates in naming single letters as a function of prime condition (PI vs. NI vs. DI) and prime duration (100 vs. 200, vs. 500 ms).
Figure 4. IH's reading latencies for high shift words as a function of frequency (high vs. low), prime condition (PI vs. NI vs. DI) and prime duration (100 vs. 200 ms).
Figure 5. IH's error rates in naming high shift words as a function of frequency (high vs. low), prime condition (PI vs. NI vs. DI) and prime duration (100 vs. 200 ms).
Figure 6. IH's reading latencies for high shift, low frequency words, as a function of prime condition (PI vs. NI. vs. DI) and prime duration (100 vs. 200 ms).
Figure 7. IH's error rates in naming high shift, low frequency words, as a function of prime condition (PI vs. NI. vs. DI) and prime duration (100 vs. 200 ms).
Figure 8. IH's reading latencies for high frequency words as a function of prime condition (NI vs. DI) and letter position change (P0-P4).
Figure 9. IH's reading latencies for pseudowords as a function of prime condition (NI vs. DI) and letter position change (P1-P4)
Figure 10. IH's error rates in naming words and pseudowords as a function of prime condition (NI vs. DI) and letter position change (P1-P4)
Figure 11. Priming for high frequency words in normal subjects as a function of prime duration (50 vs. 100 ms), and letter position change (P0-P4).
Figure 12. Priming for pseudowords in normal subjects as a function of prime duration (50 vs. 100 ms), and letter position change (P1-P4).
Figure 13. IH's reading latencies for high shift pseudowords as a function of prime condition (NI vs. DI) and letter position change (P0 vs. P4).
Figure 14. IH's error rates in naming high shift pseudowords as a function of prime condition (NI vs. DI) and letter position change (P0 vs. P4).

Figure 1

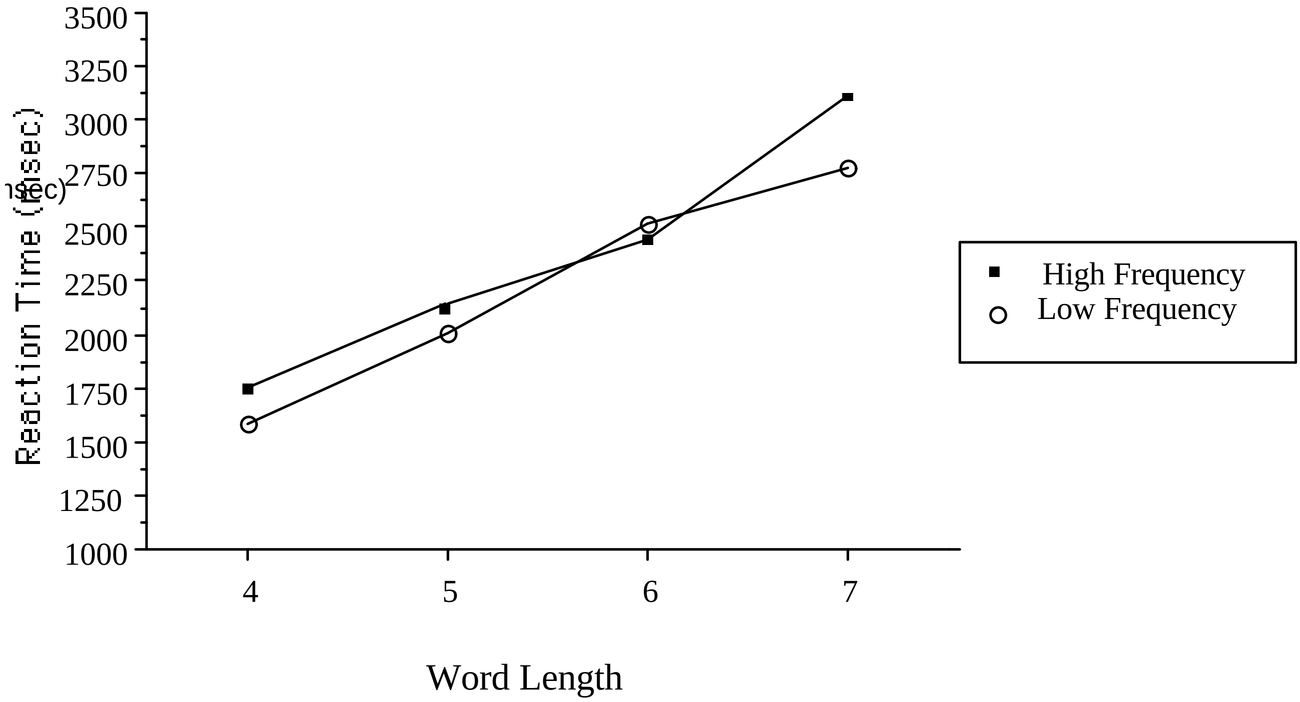

3500
3250
3000
2750
2500
2250
2000
1750
1500
1250
1000
Reaction Time (msec)
nsec)
4
5
6
7
Word Length
High Frequency
Low Frequency

Figure 2

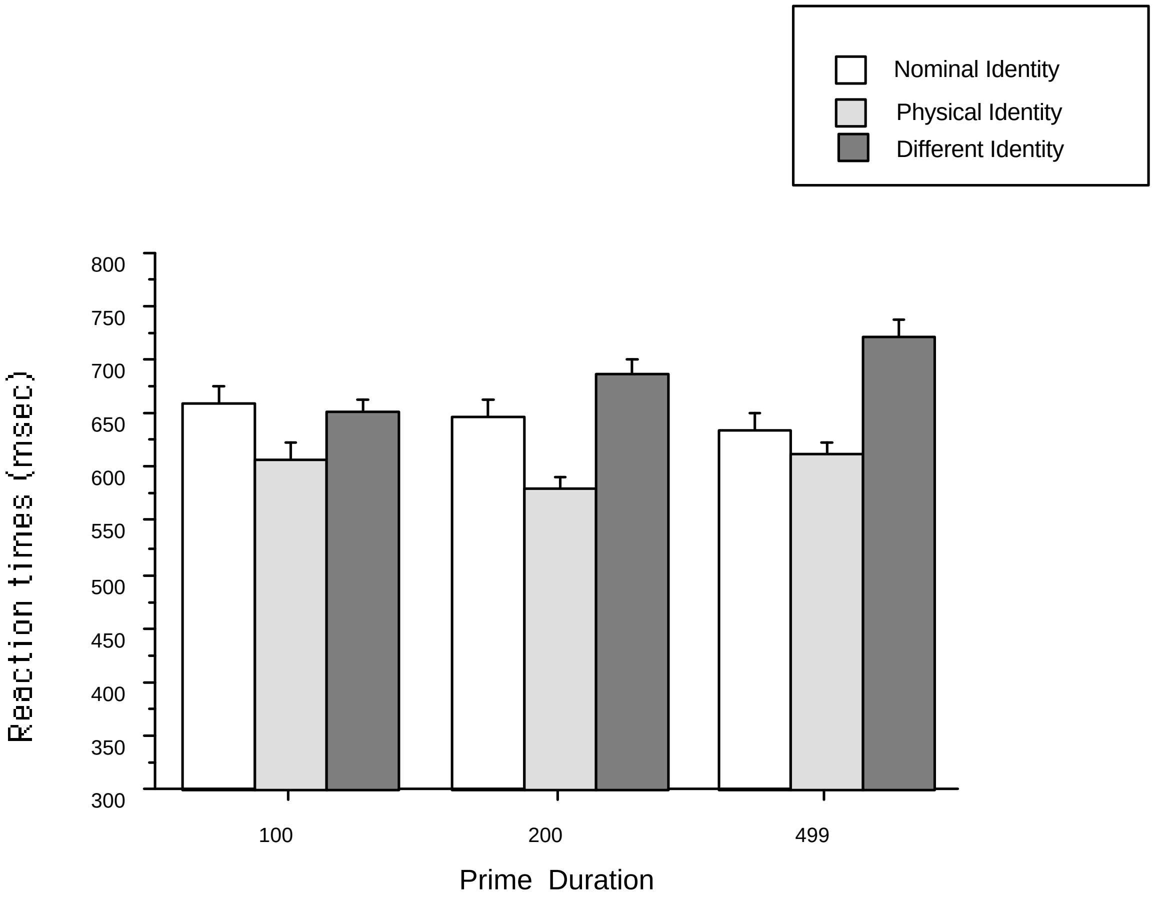

Nominal Identity
Physical Identity
Different Identity
800
750
700
650
600
550
500
450
400
350
300
Reaction times (msec)
100
200
499
Prime Duration

Figure 3

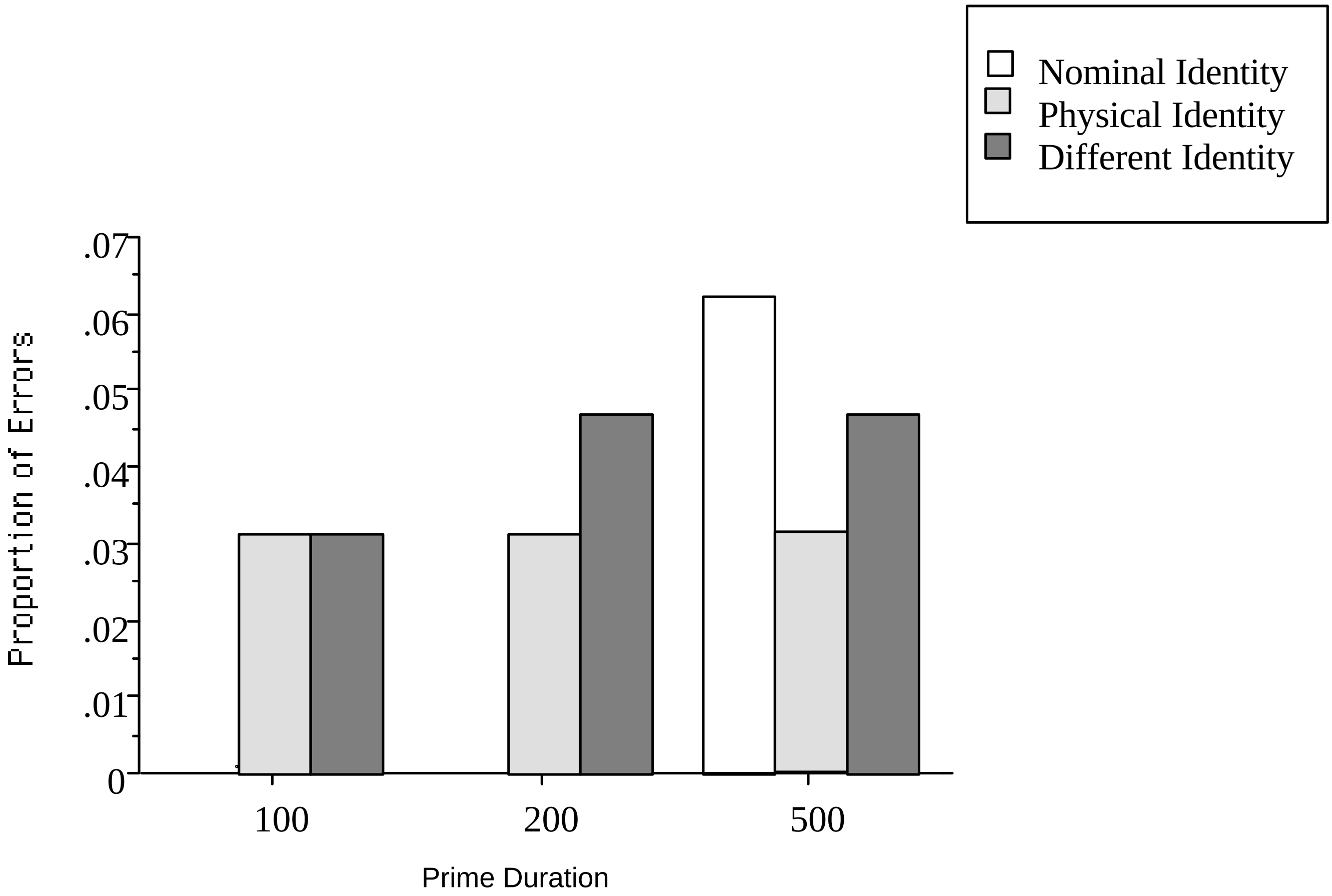

Nominal Identity
Physical Identity
Different Identity
Proportion of Errors
.07
.06
.05
.04
.03
.02
.01
0
100
200
500
Prime Duration

Figure 4

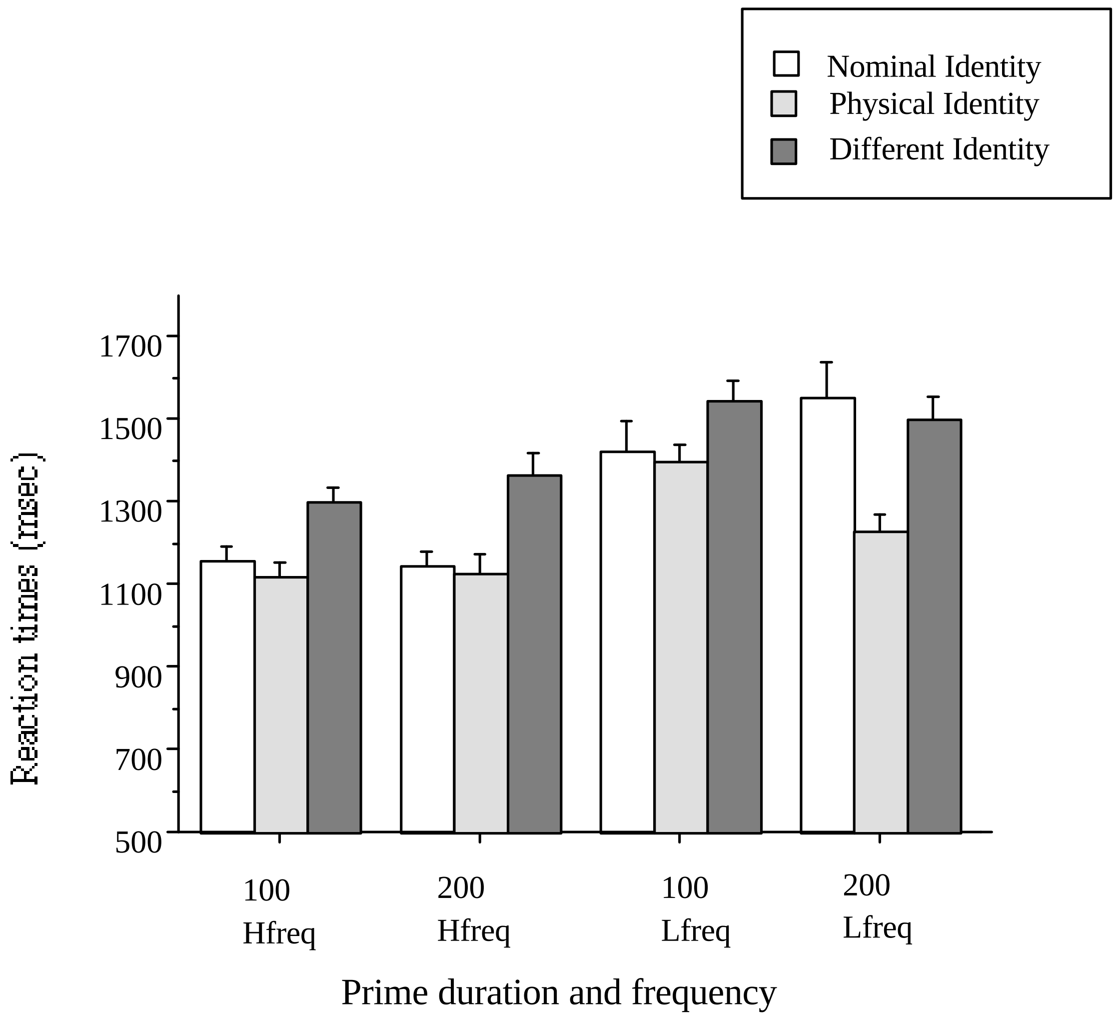

Nominal Identity
Physical Identity
Different Identity
Reaction times (msec)
1700
1500
1300
1100
900
700
500
100
Hfreq
200
Hfreq
100
Lfreq
200
Lfreq
Prime duration and frequency

Figure 5

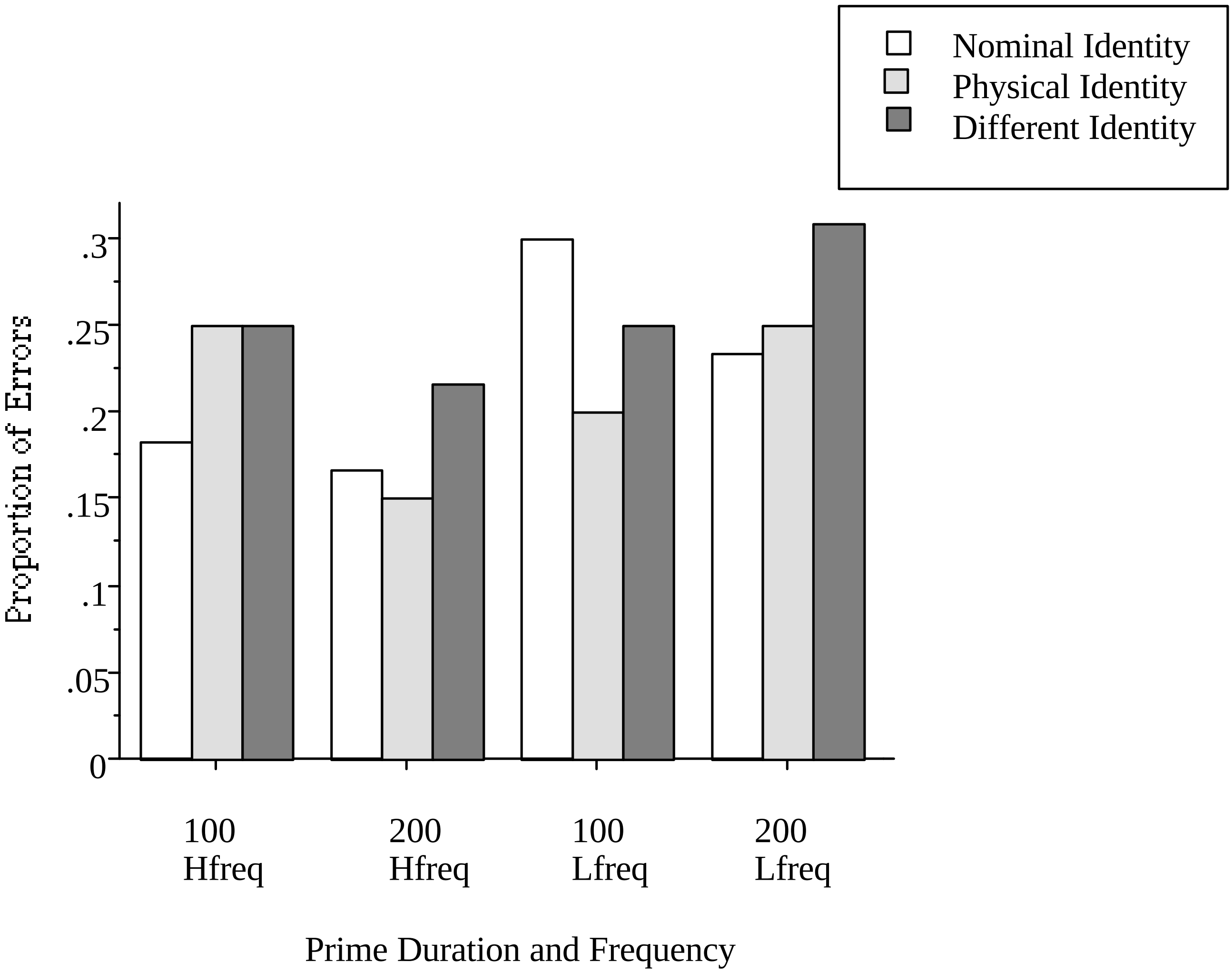

Nominal Identity
Physical Identity
Different Identity
Proportion of Errors
0
.05
.1
.15
.2
.25
.3
100 Hfreq
200 Hfreq
100 Lfreq
200 Lfreq
Prime Duration and Frequency

Figure 6

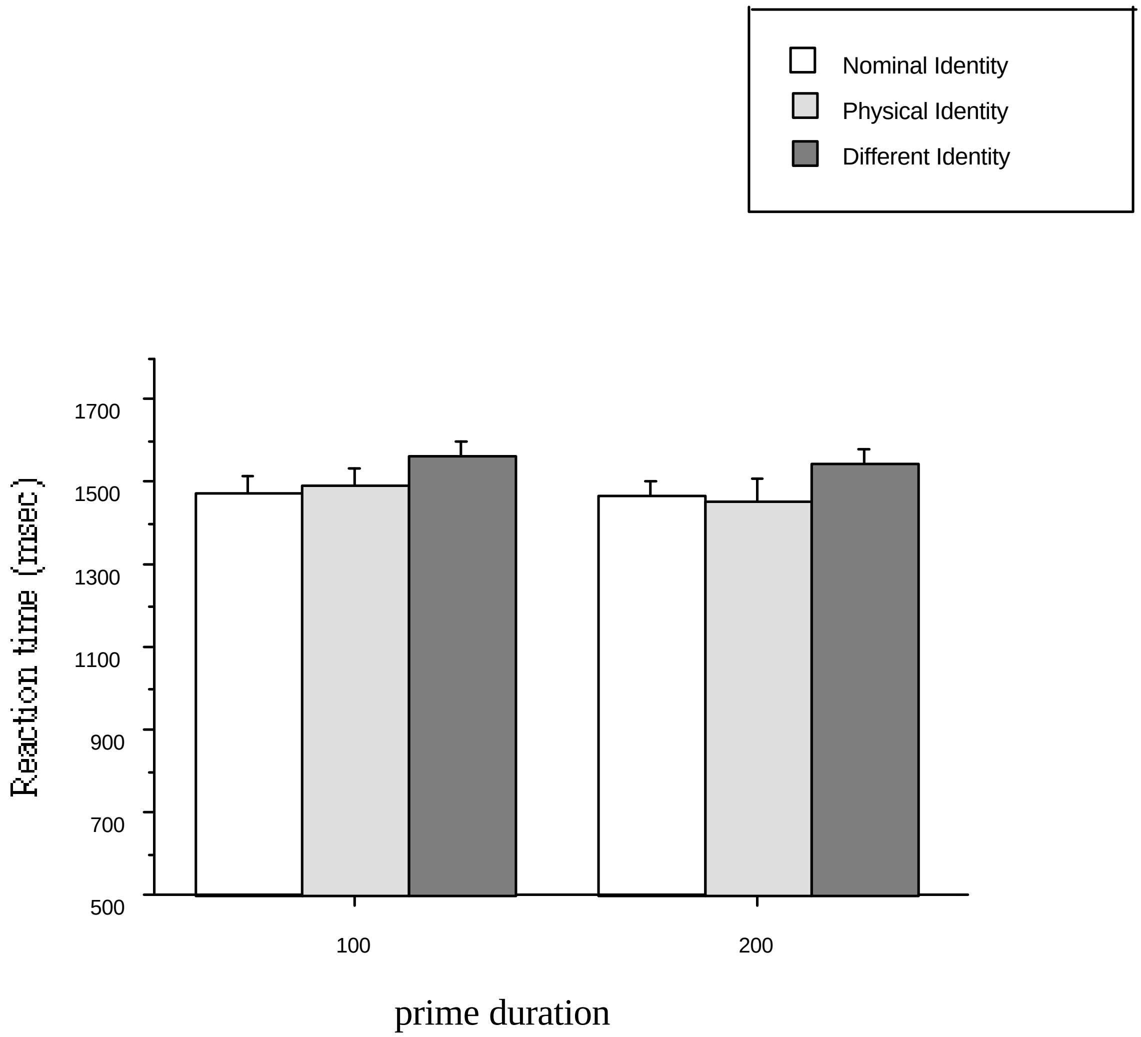

Nominal Identity
Physical Identity
Different Identity
Reaction time (msec)
1700
1500
1300
1100
900
700
500
100
200
prime duration

Figure 7

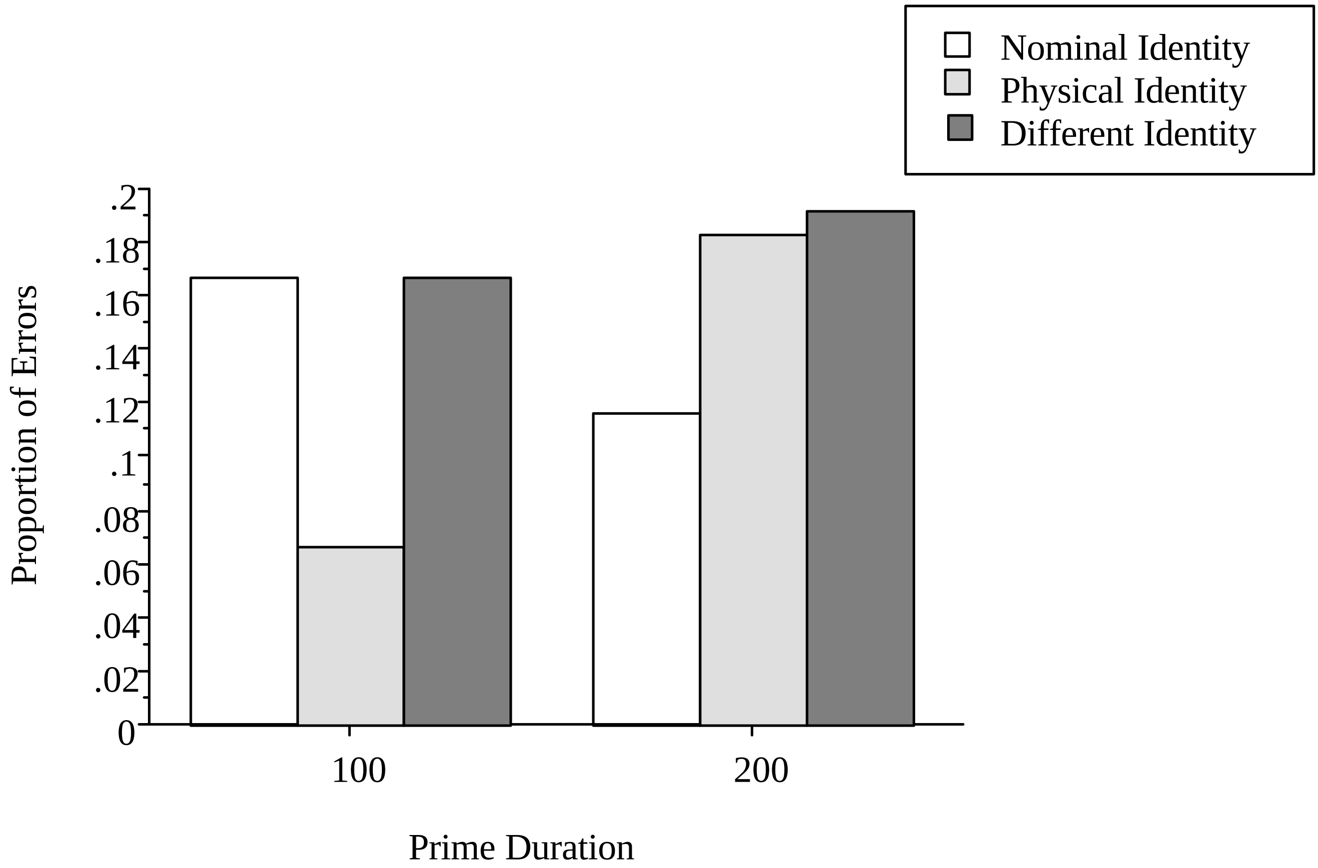

Nominal Identity
Physical Identity
Different Identity
.2
.18
.16
.14
.12
.1
.08
.06
.04
.02
0
Proportion of Errors
100
200
Prime Duration

Figure 8

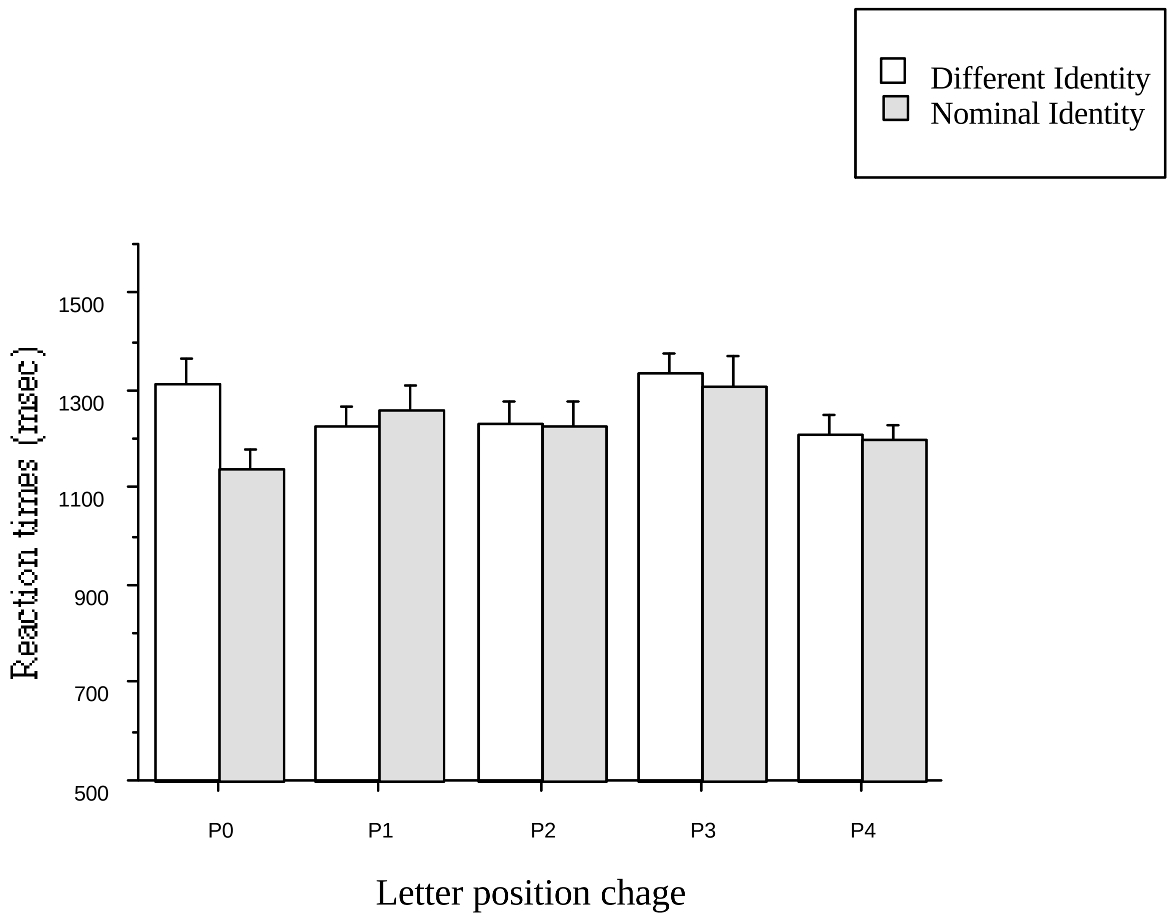

Different Identity
Nominal Identity
Reaction times (msec)
1500
1300
1100
900
700
500
P0
P1
P2
P3
P4
Letter position chage

Figure 9

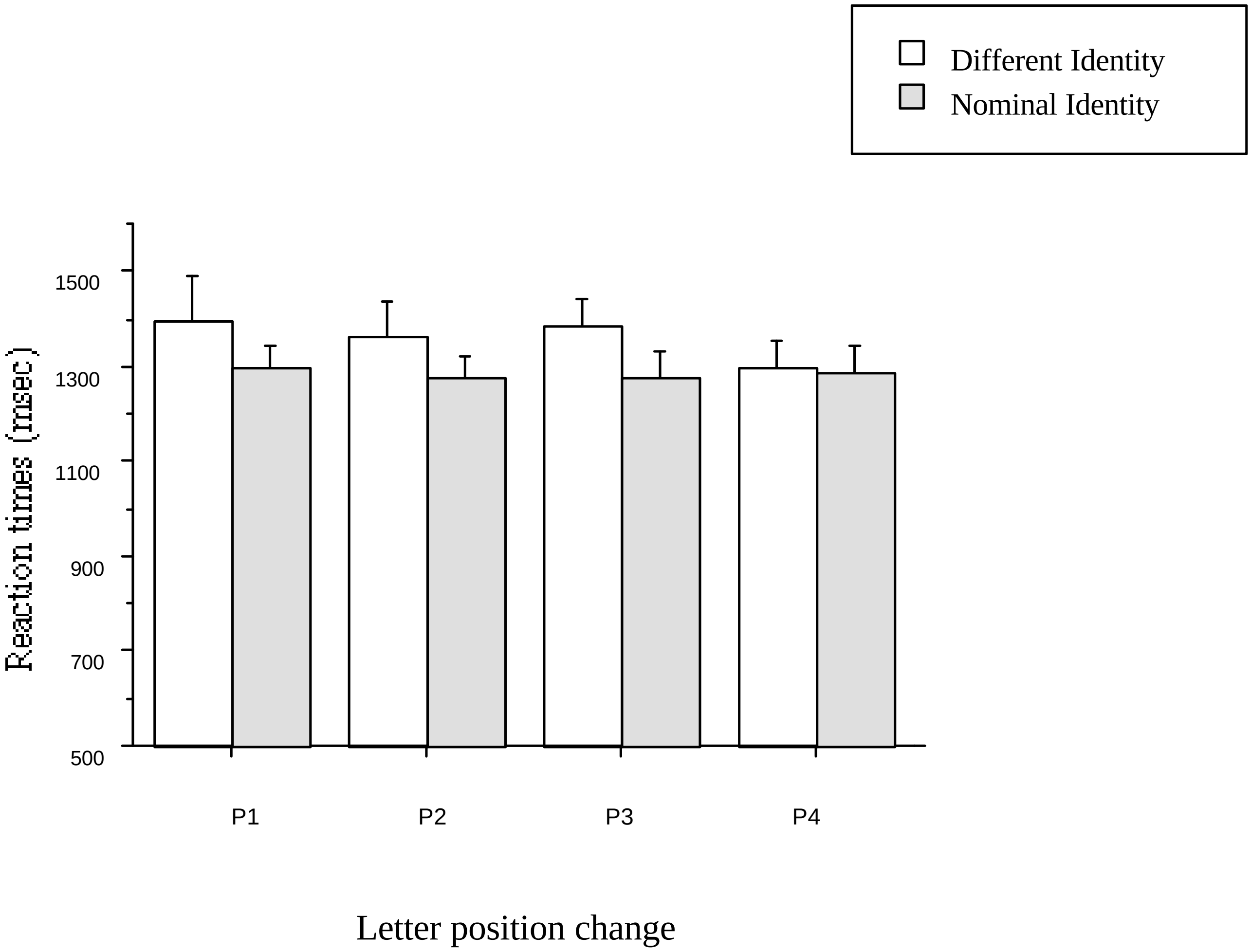

Different Identity
Nominal Identity
Reaction times (msec)
1500
1300
1100
900
700
500
P1
P2
P3
P4
Letter position change

Figure 10

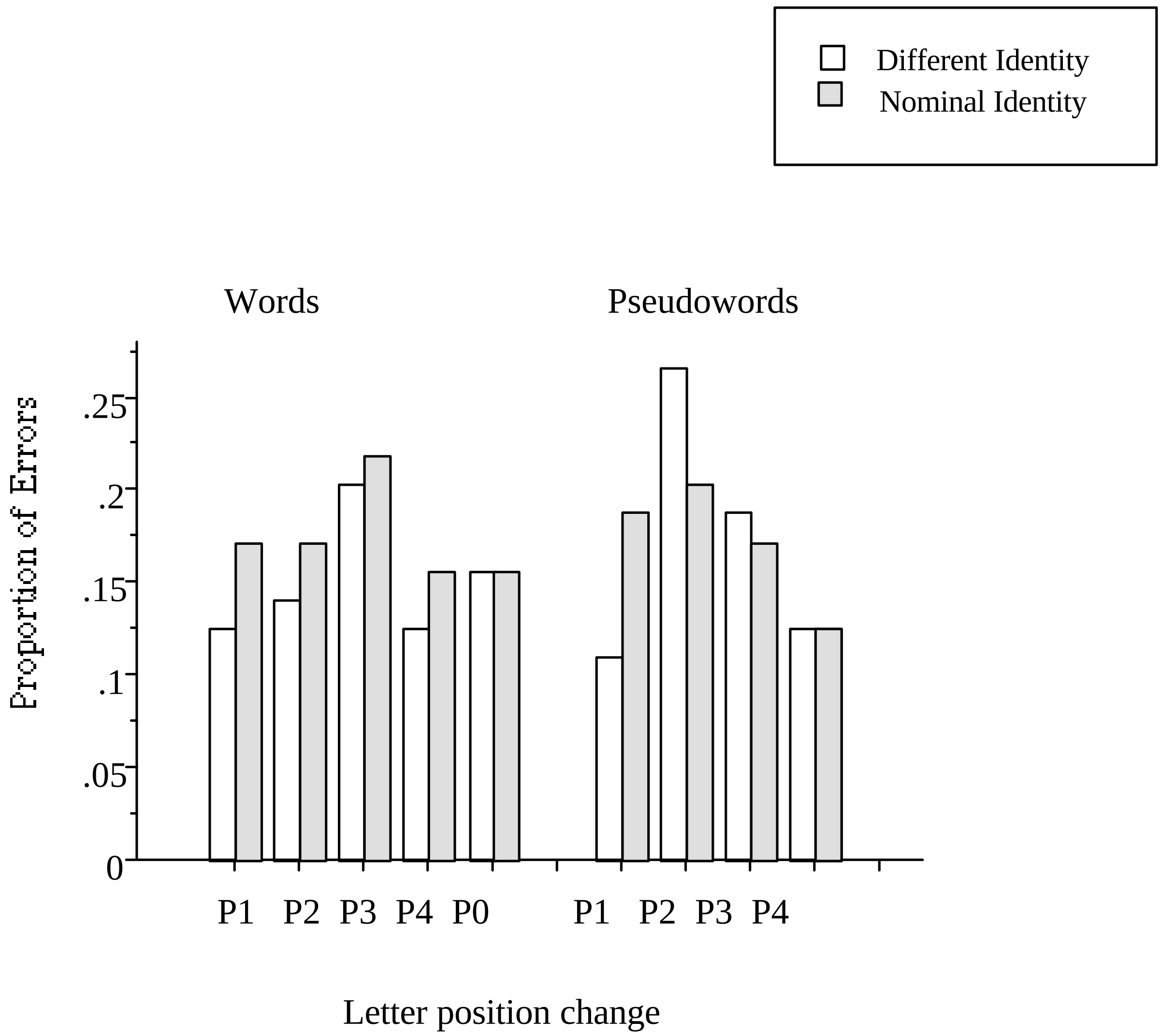

Different Identity
Nominal Identity
Words
Pseudowords
Proportion of Errors
.25
.2
.15
.1
.05
0
P1 P2 P3 P4 P0
P1 P2 P3 P4
Letter position change

Figure 11

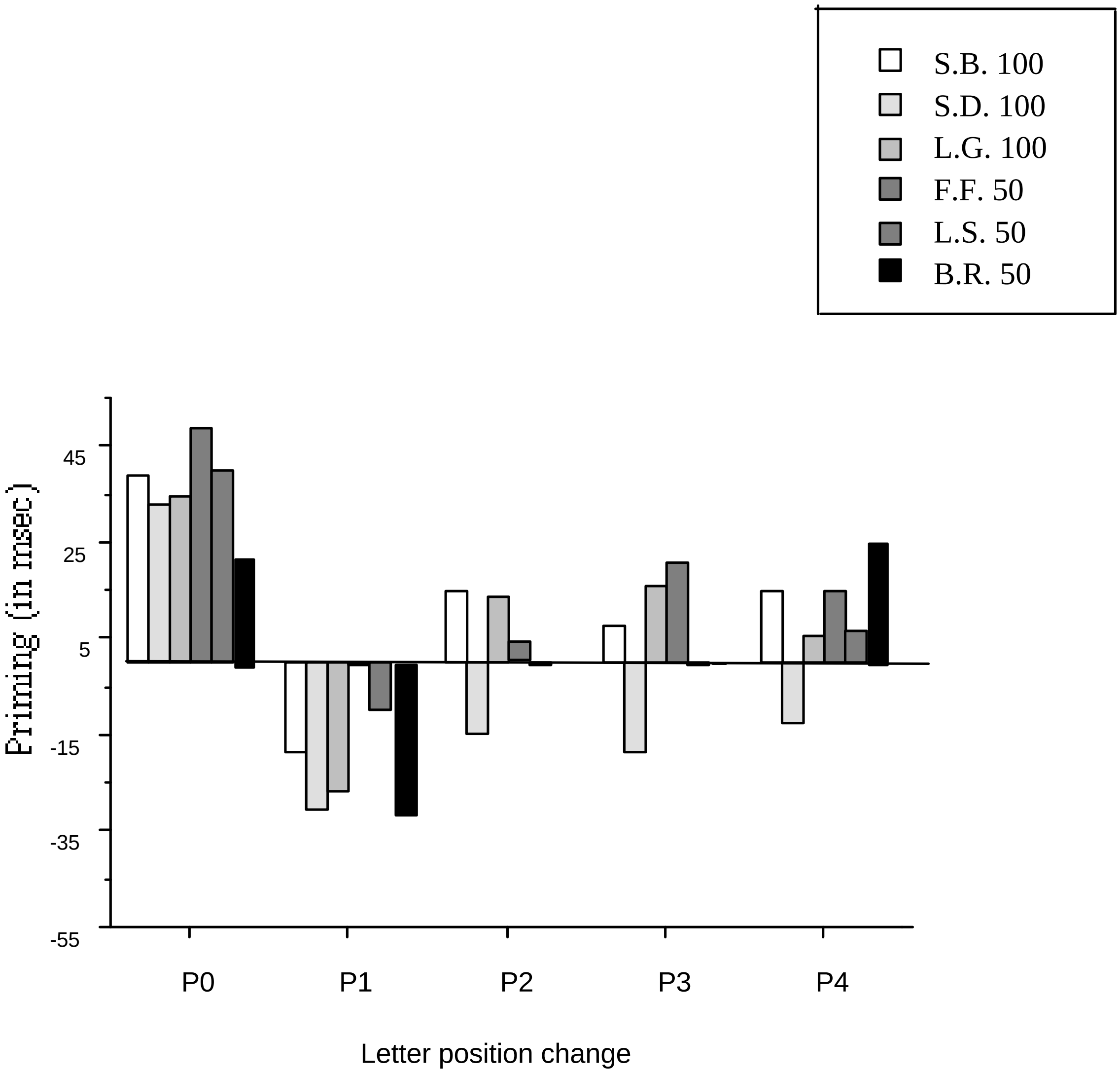

S.B. 100
S.D. 100
L.G. 100
F.F. 50
L.S. 50
B.R. 50
Priming (in msec)
45
25
5
-15
-35
-55
P0
P1
P2
P3
P4
Letter position change

Figure 12

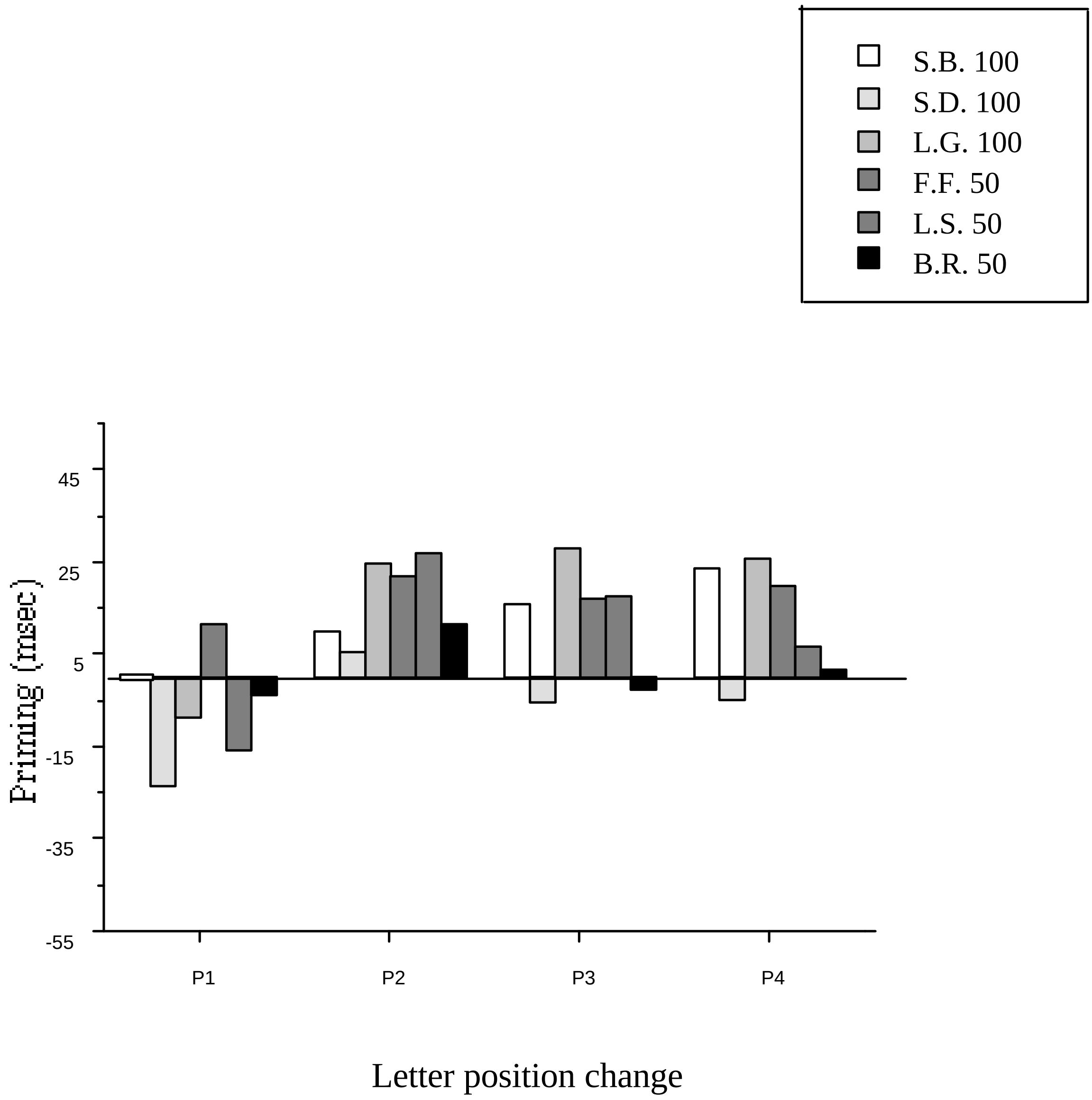

S.B. 100
S.D. 100
L.G. 100
F.F. 50
L.S. 50
B.R. 50
Priming (msec)
45
25
5
-15
-35
-55
P1
P2
P3
P4
Letter position change

Figure 13

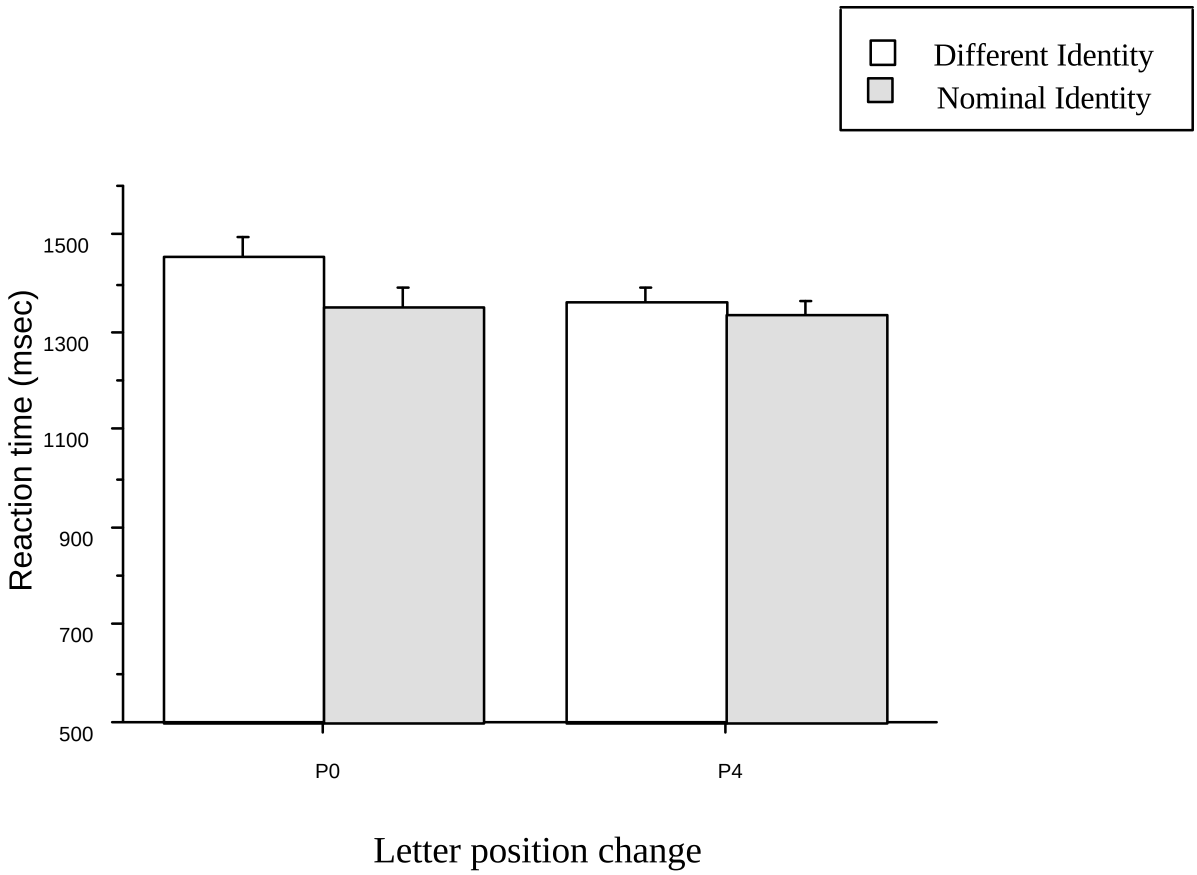
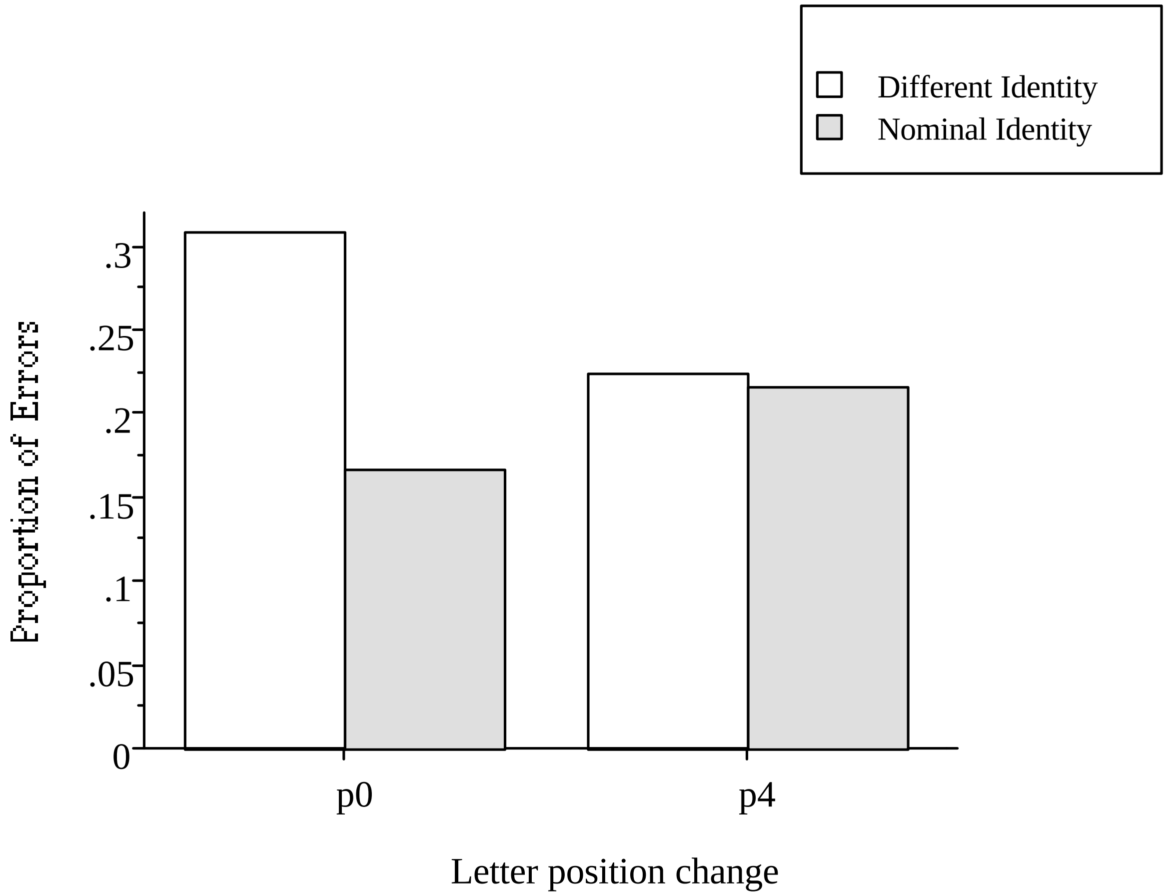

Different Identity
Nominal Identity
Reaction time (msec)
1500
1300
1100
900
700
500
P0
P4
Letter position change

Figure 14


Different Identity
Nominal Identity
Proportion of Errors
.3
.25
.2
.15
.1
.05
0
p0
p4
Letter position change

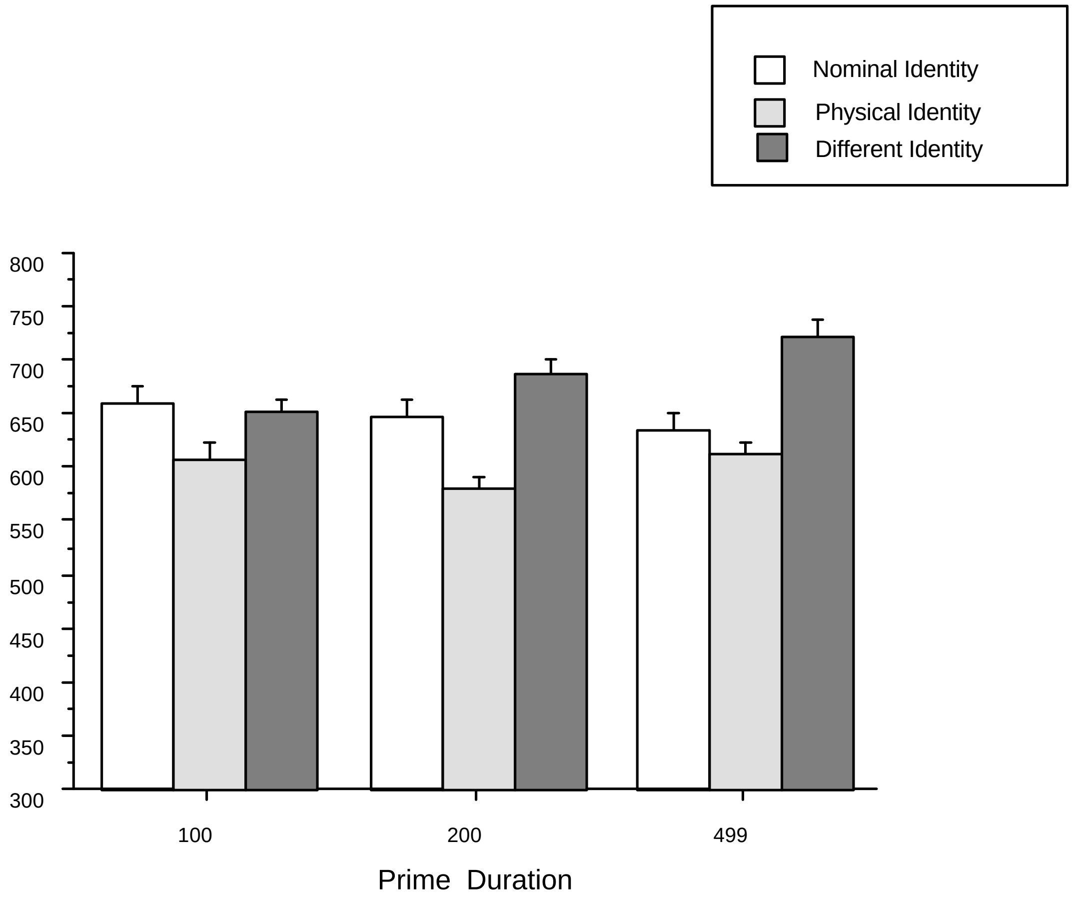
Appendix A

High Frequency	Low Frequency
ABLE	ARAB
AREA	BABE
BABY	BALD
BALL	BANG
BAND	BEAN
BEND	BLED
DATA	BRAG
DATE	BRAN
DEAD	DAME
DEAL	DARN
DEAR	DART
EDGE	DEED
GAME	DEER
GATE	DRAB
HALL	DREG
HARD	EDDY
HEAD	EDEN
HELL	GALA
LADY	GALE
LAND	GARB
LATE	GERM
MADE	GLEE
MEAL	GREY
NEED	HEAL
RATE	HEED
READ	HERB
REAR	LAMB
TALL	LAME
TELL	LARD
YARD	MALL

Appendix B

Prime	Target	Position	prime	Target	Position
alar	ALAR	p0	aman	AMAR	p4
alta	ALTA	p0	beeb	BEEL	p4
bame	BAME	p0	belb	BELD	p4
bebt	BEBT	p0	dagg	DAGE	p4
blap	BLAP	p0	dain	DAIL	p4
blid	BLID	p0	deag	DEAT	p4
bram	BRAM	p0	fagg	FAGE	p4
dalf	DALF	p0	fraa	FRAB	p4
dall	DALL	p0	freb	FREG	p4
deet	DEET	p0	gann	GAND	p4
frad	FRAD	p0	glan	GLAG	p4
garm	GARM	p0	glar	GLAT	p4
gart	GART	p0	glar	GLAW	p4
gire	GIRE	p0	harl	HARG	p4
graw	GRAW	p0	jear	JEAL	p4
gree	GREE	p0	lall	LALE	p4
jerb	JERB	p0	larl	LARB	p4
lage	LAGE	p0	leab	LEAT	p4
lare	LARE	p0	meeq	MEED	p4
larn	LARN	p0	narr	NARD	p4
lart	LART	p0	rala	RALD	p4
lert	LERT	p0	ralb	RALL	p4
nade	NADE	p0	ramd	RAME	p4
pabe	PABE	p0	reeb	REET	p4
pard	PARD	p0	rele	RELL	p4
parl	PARL	p0	tald	TALA	p4
rean	REAN	p0	teab	TEAD	p4
rild	RILD	p0	teag	TEAL	p4
rill	RILL	p0	teeq	TEEL	p4
tade	TADE	p0	tern	TERB	p4

Figure 2


Nominal Identity
Physical Identity
Different Identity
800
750
700
650
600
550
500
450
400
350
300
100
200
499
Prime Duration