Research Article

How to Make the Word-Length Effect Disappear in Letter-by-Letter Dyslexia

Implications for an Account of the Disorder

Daniel Fiset,[1] Martin Arguin,[1] Daniel Bub,[2] Glyn W. Humphreys,[3] and M. Jane Riddoch[3]

[1]Centre de Recherche en Neuropsychologie et Cognition, Département de Psychologie, Université de Montréal, Montreal, Quebec, Canada, and Centre de Recherche, Institut Universitaire de Gériatrie de Montréal, Montreal, Quebec, Canada; [2]Department of Psychology, University of Victoria, Victoria, British Columbia, Canada; and [3]Behavioural Brain Sciences Centre, School of Psychology, Birmingham University, Birmingham, United Kingdom

ABSTRACT—*The diagnosis of letter-by-letter (LBL) dyslexia is based on the observation of a substantial and monotonic increase of word naming latencies as the number of letters in the stimulus increases. This pattern of performance is typically interpreted as indicating that word recognition in LBL dyslexia depends on the sequential identification of individual letters. We show, in 7 LBL patients, that the word-length effect can be eliminated if words of different lengths are matched on the sum of the confusability (visual similarity between a letter and the remainder of the alphabet) of their constituent letters. Additional experiments demonstrate that this result is mediated by parallel letter processing and not by any compensatory serial processing strategy. These findings indicate that parallel processing contributes significantly to explicit word recognition in LBL dyslexia and that a letter-processing impairment is fundamental in causing the disorder.*

In modern society, the cognitive faculty of reading is clearly a domain of expertise. The average English reader will have read more than 100 million words at 25 years of age (Geisler & Murray, 2003). This practice allows people to extract the diagnostic visual information (Gosselin & Schyns, 2002) needed to identify words in less than 250 ms (McCandliss, Cohen, & Dehaene, 2003) and to read words of different lengths at an invariant rate (approximately 530 ms for words of three to six letters; Weekes, 1997); this stability of latencies across word lengths suggests that skilled readers have the capacity to recognize several letters simultaneously. However, a lesion within the temporo-occipital region of the left hemisphere can impair this parallel processing of letters and dramatically affect reading capacities (Binder & Mohr, 1992; Damasio & Damasio, 1983). The resultant reading impairment, called pure alexia or letter-by-letter (LBL) dyslexia, was described for the first time by Dejerine in 1892 (Bub, Arguin, & Lecours, 1993; Dejerine, 1892) and is characterized by an abnormally large effect of length on word reading latencies (frequently more than 300 ms per letter). This abnormally large word-length effect is usually taken to indicate that reading in LBL dyslexics is based on sequential letter processing (Warrington & Shallice, 1980).

Despite 100 years of investigation, there is still no clear and coherent functional account of why patients abandon parallel letter processing to use a sequential strategy. In the present article, we uncover a fundamental factor, namely, the visual similarity among letters, that almost completely accounts for the word-length effect that is diagnostic of LBL dyslexia (see Arguin, Fiset, & Bub, 2002, for prior evidence regarding the particular sensitivity of LBL dyslexics to this factor). We also show that this factor influences performance only under conditions permitting parallel letter processing and that it has no impact on single-letter processing. The abolition of the word-length effect under the appropriate conditions provides definitive evidence for residual parallel letter processing in these patients.

There is prior evidence suggesting that parallel letter processing still occurs in LBL dyslexics (Arguin et al., 2002; Howard, 1991; Osswald, Humphreys, & Olson, 2002). For

Address correspondence to Martin Arguin, Département de Psychologie, Université de Montréal, C.P. 6128, Succ. Centre-ville, Montreal, Quebec, H3C 3J7, Canada; e-mail: martin.arguin@umontreal.ca.

example, such individuals can read more efficiently when words are presented letter by letter than when all the letters appear simultaneously (Osswald et al., 2002). This suggests that parallel letter processing may be disruptive. Other evidence, however, points to a favorable contribution of parallel processing to word recognition in LBL patients (Arguin & Bub, in press; Arguin et al., 2002; Fiset, Arguin, & McCabe, in press). The positive contribution of parallel processing appears to occur with words made of letters with low confusability (based on the visual similarity between a target letter and the remaining letters of the alphabet—see the General Method section for further details), but not with words made of letters with high confusability (Arguin & Bub, in press; Fiset et al., in press).

In the present article, we examine whether letter confusability, through its apparent impact on parallel processing, is the cause of the protracted word-length effect that is diagnostic of LBL dyslexia. Indeed, as word length increases, so does the sum of the confusability of constituent letters. If letter confusability acts upon the probability of effective parallel processing, this probability should normally decline as word-length increases because of longer words' increased summed letter confusability. This hypothesis implies, however, that the effect of word length would be canceled if one were able to equate summed letter confusability across word lengths. In contrast, effects based on length per se would remain.

In Experiment 1, we compared the reading of words that were matched on the average confusability of their constituent letters (the situation that occurs spontaneously when letter confusability is left uncontrolled) and words that were matched on their summed letter confusability. There should be a substantial effect of word length on reading latency when words are matched for the average confusability of their letters, because the summed confusability will increase with word length. However, the word-length effect may be eliminated when summed letter confusability is equated across word lengths. Indeed, note that the average confusability of all the letters in a word must decline when the summed confusability of letters is matched across word length. Experiments 2 and 3 are control studies showing that matching for summed letter confusability eliminates the word-length effect only when a parallel processing mode is adopted. These results rule out the possibility that performance in Experiment 1 can be explained by effects on serial letter identification.

GENERAL METHOD

Case Reports

Six of the 7 patients described here have taken part in other published or submitted studies. Table 1 reports the localization of the patients' lesions, as well as the patients' word-length and letter-confusability effects, and indicates the publications to which readers can refer for additional clinical details.

Stimuli

Two word lists were created for use in Experiments 1, 2b, and 3. Both were made of five-, six-, and seven-letter words (for L.H., 60 items/condition; for I.H. and W.R., 50 items/condition; for the other patients, 40 items/condition) matched across lengths on bigram and lexical frequencies and on orthographic neighborhood size. In addition, in one list, words of different lengths were matched on the average confusability of their constituent letters (so that summed confusability increased linearly with word length), whereas matching for the other list was based on summed letter confusability. Letter confusability was determined from empirical letter-confusion matrices obtained in previous studies with neurologically intact observers (Gilmore, Hersh, Caramazza, & Griffin, 1979; Loomis, 1982; Townsend, 1971; Van Der

TABLE 1
Short Description of the 7 Patients

Patient	Word-length effect (ms/letter)	Letter-confusability effect (ms)[a]	Localization of the lesion	Publication reporting details on patient
D.K.	400	280	Left occipital lobe (CT scan)	Behrmann, Plaut, & Nelson (1998)
D.M.	410	500	Left medial and inferior occipitotemporal gyrus (magnetic resonance imaging)	Osswald, Humphreys, & Olson (2002)
E.L.	405	480	Left peristriate infero-temporal, postero-lateral temporal, and dorsal parietal cortices (CT scan)	Montant & Behrmann (2001)
H.J.A.	600	1,300	Inferior temporal, lateral occipitotemporal, fusiform, and lingual gyri, all affected bilaterally magnetic resonance imaging	Humphreys & Riddoch (1987)
I.H.	550	500	Left temporo-occipital area (neurosurgery report)	Arguin, Bub, & Bowers (1998)
L.H.	550	600	Left temporo-occipital encephalomalacia (magnetic resonance imaging)	Fiset, Arguin, & McCabe (in press)
W.R.	750	850	Left temporo-occipital area (neurological examination)	No publication

[a]This effect was measured for four-letter words.

Heijden, Malhas, & Van Den Roovaart, 1984) and ranged from .24 (letter *L*) to .73 (letter *B*), with an average of .48.

EXPERIMENT 1

Method

In Experiment 1, subjects were required to read aloud the words from the lists. They were asked to read as rapidly as possible while avoiding errors. On each trial, a fixation star appeared for 500 ms at the center of the computer screen and was followed by a word, which remained visible until the subject responded. All stimuli appeared in black against a white background and were printed in Geneva 24-point bold font (Courier New 24-point bold for L.H.). The experimenter registered each response and triggered the next trial by a key press. Each reaction time (RT) was measured from stimulus onset by a voice key triggered by the subject's oral response. The two word lists (one with words matched for average confusability and one with words matched for summed confusability) were intermixed in a single list to avoid any effects of strategic control that might mediate reading performance.

Results

The results for each patient were analyzed individually. All patients showed a significant interaction of word length and matching condition (average vs. summed confusability)—D.K.: $F(2, 221) = 4.2, p < .05$; D.M.: $F(2, 227) = 4.3, p < .05$; E.L.: $F(2, 217) = 16.1, p < .001$; H.J.A.: $F(2, 215) = 6.8, p < .005$; I.H.: $F(2, 258) = 4.6, p < .05$; L.H.: $F(2, 318) = 13.9, p < .001$; W.R.: $F(2, 262) = 7.7, p < .005$. An analysis of simple effects revealed a strong word-length effect in all patients when matching was based on average confusability—D.K.: $F(2, 221) = 31.1, p < .001$, slope = 369 ms/letter, $r^2 = .95$; D.M.: $F(2, 227) = 11.4, p < .001$, slope = 462 ms/letter, $r^2 = .90$; E.L.: $F(2, 217) = 25.7, p < .001$, slope = 846 ms/letter, $r^2 = .97$; H.J.A.: $F(3, 215) = 6.0, p < .005$, slope = 621 ms/letter, $r^2 = 1.0$; I.H.: $F(2, 258) = 10.6, p < .001$, slope = 620 ms/letter, $r^2 = 1.0$; L.H.: $F(2, 318) = 20.4, p < .001$, slope = 566 ms/letter, $r^2 = .97$; W.R.: $F(2, 262) = 14.0, p < .001$, slope = 1,035 ms/letter, $r^2 = 1.0$. However, 6 of the 7 patients showed no significant effect of word length when summed confusability was controlled—D.M.: $F(2,227) < 1$; E.L.: $F(2,217) < 1$; H.J.A.: $F(2, 215) = 1.6$, n.s.; I.H.: $F(2, 258) < 1$; L.H.: $F(2, 318) < 1.0$; W.R.: $F(2, 262) < 1.0$. Only D.K. showed a significant effect of word length in this condition, $F(2, 221) = 3.8, p < .05$, slope = 165 ms/letter, $r^2 = .99$, and this effect was substantially weaker than the effect when words were matched on average confusability.

Average response latencies across patients in Experiment 1 are shown in Fig. 1a. On average, the slope of the word-length effect was 645 ms/letter when words of different lengths were matched on average letter confusability and was reduced to a nonsignificant −4 ms/letter when words of different lengths were matched on summed letter confusability.

Discussion

The results of Experiment 1 show that the word-length effect diagnostic of LBL dyslexia was abolished in 6 out of 7 patients and greatly diminished in the remaining case when words of different lengths were matched on the summed confusability of their constituent letters. The abolition of the word-length effect in these patients indicates that they can process letters in parallel. However, the probability that parallel letter processing can support overt word recognition in LBL dyslexia is strongly determined by the summed letter confusability of a word. When summed confusability is not controlled, it increases with longer words, and this generates a word-length effect that is diagnostic of the disorder.

Alternatively, the results of Experiment 1 could be construed as being consistent with word recognition in LBL dyslexia

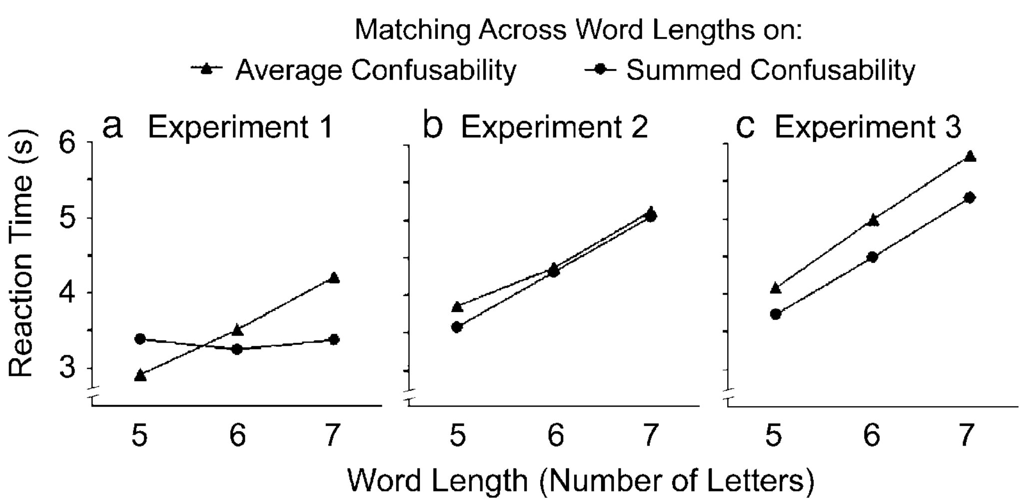

Fig. 1. Average reaction times for all patients in Experiment 1 (a), Experiment 2b (b), and Experiment 3 (c) as a function of word length.

always being performed in a strictly LBL manner. This would be possible if the rate of serial letter processing is a direct linear function of the confusability of the individual letters. Matching words of different lengths on average letter confusability would mean the sequential letter processing rate would remain the same across word lengths, and therefore RTs would increase linearly with word length. Conversely, matching words of different lengths on their summed letter confusability would make the average confusability of letters in the words decrease with increasing word length. This could speed individual letter recognition, counteracting effects due to the increased time needed to read more letters in longer words. The net outcome would be invariant reading latencies across word lengths. We tested this alternative account directly in three control experiments. In these control experiments, the effect of letter confusability was assessed in tasks involving the identification of single letters shown in isolation or within a word context and in a task requiring the identification of words shown in a distorted format that prevented parallel processing.

EXPERIMENT 2

Method

If the outcome of Experiment 1 resulted from an impact of letter confusability on the rate of serial letter identification, then single-letter identification should be sensitive to letter confusability. This possibility was tested in Experiment 2 using tasks requiring the identification of single letters shown either in isolation or in a word context. In Experiment 2a, the procedure was the same as in Experiment 1 except that the target was a single letter. The letters of the alphabet were presented 10 times each in a random order. In Experiment 2b, the fixation star (again presented for 500 ms) was followed by an arrow that appeared just above the location of the target letter to follow and remained visible until the subject responded. A word appeared 500 ms after the onset of the arrow, and the subject's task was to name the letter indicated by the arrow as rapidly as possible while avoiding errors. Each RT was measured from stimulus onset by a voice key triggered by the subject's oral response. Only one letter was probed on each trial, and the position of the probe varied randomly across trials. Words were repeated until all the letters in each word had been probed.

Results

Experiment 2a: Single-Letter Naming

The correlation between letter confusability and the time required for identification failed to reach significance in every patient—D.K.: $r = -.03$, n.s.; D.M.: $r = .07$, n.s.; E.L.: $r = .09$, n.s.; H.J.A.: $r = .04$, n.s.; I.H.: $r = .07$, n.s.; L.H.: $r = .06$, n.s.; W.R.: $r = .01$, n.s. Even in a comparison of the RTs for the five letters with the highest confusability and the RTs for the five letters with the lowest confusability (mean RTs of 826 and 810 ms, respectively), no patient showed a significant confusability effect—D.K.: $F(1, 96) < 1$; D.M.: $F(1, 92) < 1$; E.L.: $F(1, 93) < 1$; H.J.A.: $F(1, 95) < 1$; I.H.: $F(1, 93) < 1$; L.H.: $F(1, 87) = 1.8$, n.s.; W.R.: $F(1, 91) < 1$. These observations are incongruent with an account of the results of Experiment 1 based on a modulation of serial processing rate by letter confusability.

Experiment 2b: Letter Naming in a Word Context

Total RT for each word was calculated by adding the RT for each of its letters. The results of each patient were analyzed individually. No interaction of word length and matching condition (average vs. summed confusability) was found in any patient—D.K.: $F(2, 216) < 1$; D.M.: $F(2, 220) < 1$; E.L.: $F(2, 219) < 1$; H.J.A.: $F(2, 219) = 1.7$, n.s.; I.H.: $F(2, 258) < 1$; L.H.: $F(2, 319) < 1$; W.R.: $F(2, 257) < 1$. Indeed, a significant word-length effect was obtained on these summed RTs in all patients and for both word lists (Fig. 1b). The average slope of the word-length effect was 879 ms/letter when words were matched on average letter confusability and 774 ms/letter when words were matched on summed confusability. Most important, no patient showed a word-length effect that varied significantly across the two forms of matching.

Discussion

The results of Experiments 2a and 2b indicate that single-letter identification is impervious to letter confusability in LBL dyslexics. It could be argued that the conditions of Experiment 2a do not relate to how letters are identified within a word context because individually presented letters, unlike letters presented in strings, do not suffer from lateral masking caused by neighboring letters. This argument is fully countered, however, by Experiment 2b, which showed no letter-confusability effect in single-letter recognition even within a stimulus context favorable to lateral masking. The findings of Experiment 2 therefore fail to support an account of the results of Experiment 1 based on a modulation of the rate of sequential letter processing by letter confusability.

One possible shortcoming of Experiments 2a and 2b is that they involved static recognition, whereas, by definition, the sequential LBL strategy implies a dynamic process. It is thus possible that a letter-confusability effect occurs in the letter identification of LBL dyslexics only when the rapid sequential processing of letters is required. The following experiment assessed this possibility.

EXPERIMENT 3

Method

Experiment 3 assessed word recognition under conditions that minimized the likelihood of parallel processing in order to determine whether the results of Experiment 1 are attributable to serial processing. The procedure and the words used were the same as in Experiment 1, but this time the consecutive letters of words were displayed on alternating lines (e.g., for the word "baker," "b k r" would be on the top line and "a e" on the line below). This stimulus format breaks the normal visual letter sequence in a word, thereby disrupting parallel processing and encouraging sequential, LBL processing.

Results

The results of each patient were analyzed individually. No patient showed a significant interaction of word length and matching condition (average vs. summed confusability)—D.K.: $F(2, 216) = 1.9$, n.s.; D.M.: $F(2, 218) = 1.5$, n.s.; E.L.: $F(2, 216) < 1$; H.J.A.: $F(2, 224) < 1$; I.H.: $F(2, 258) < 1$; L.H.: $F(2, 263) = 1.8$, n.s.; W.R.: $F(2, 262) < 1$. The average slopes for the word-length effect were 628 ms/letter and 732 ms/letter for words matched on average versus summed letter confusability, respectively (Fig. 1c). These findings indicate that the rate of serial letter processing in the recognition of our visually altered words is resistant to the manipulation of letter confusability. As was the case for Experiment 2, the results fail to support an account of Experiment 1 that implies that the rate of sequential letter processing in LBL dyslexia is (even partially) determined by letter confusability.

GENERAL DISCUSSION

The present findings falsify the classical view that the word-length effect in LBL dyslexia is caused by the number of letters in a word, and thus exclusively reflects serial letter identification. In fact, Experiment 1 demonstrated that the word-length effect is an artifact of the summed confusability of the constituent letters of a word, which happens to increase regularly with word length if it is left uncontrolled. Thus, if words of different lengths are matched on summed confusability, the diagnostic criterion of LBL dyslexia is abolished. This influence of letter confusability on reading performance is not normal because this factor has absolutely no effect in neurologically intact readers (Arguin et al., 2002). Moreover, the impact of letter confusability in LBL dyslexia is restricted to conditions that may involve parallel letter processing. Thus, LBL dyslexics show no impact of letter confusability in tasks that require the processing of single letters, either individually (Experiments 2a and 2b) or in a sequence (Experiment 3).

Given these considerations, we propose a new theory of LBL dyslexia to account for the summed-letter-confusability effect that is responsible for the diagnostic sign of increasing RTs with word length. This theory assumes that patients initially attempt to recognize words through the parallel processing of letters, which is the normal default mechanism for word recognition. Past work by Howard (1991) has demonstrated that this process may occasionally be successful in LBL patients. However, the probability that parallel processing will allow overt word recognition is markedly diminished in LBL dyslexics relative to normal readers. Moreover, in LBL dyslexics, this probability decreases monotonically with increasing summed letter confusability (hence with increasing word length if summed confusability is left uncontrolled), whereas normal readers are entirely impervious to letter confusability (Arguin et al., 2002; Fiset et al., in press). In our theory, these two limitations in LBL dyslexics are assumed to result from an abnormally low signal-to-noise ratio for letter identification when visual attentional resources are spread over the entire surface of the target word, as is necessary with parallel processing. We propose that this is the core deficit responsible for LBL dyslexia, which might be more appropriately relabeled "letter confusability dyslexia."

At the letter identification level, a signal-to-noise ratio that is too low will effectively prevent word recognition because it becomes impossible to discriminate between the constituent letters of the target and other, visually similar letters (see Arguin & Bub, 1995, and Arguin et al., 2002, for relevant evidence and discussion). We propose that it is this signal-to-noise ratio that is controlled by summed letter confusability. If the summed confusability is low, the signal-to-noise ratio for letter identification will be high, and overt word recognition based on parallel processing will be possible. In contrast, if summed confusability is too high, parallel processing will fail to identify the target word because the signal-to-noise ratio at the letter level is too low. In the latter case, an alternative, compensatory processing mode may be required to permit word recognition. We propose that this compensatory mode involves serial focused attention on individual letters, which is known to be associated with an increased signal-to-noise ratio (Yeshurun & Carrasco, 1998). Thus, the letter-confusability effect is eliminated when the task involves the recognition of individual letters (Experiments 2a and 2b) or when parallel letter processing is prevented in a word recognition task (Experiment 3).

This theory accounts for the results of Experiment 1 as reflecting differential probabilities that parallel letter processing is sufficient for overt word recognition and proposes that these probabilities are directly determined by summed letter confusability. The elimination of the impact of summed confusability in Experiments 2a, 2b, and 3 resulted from the particular conditions of these experiments, which involved focused attention at the letter level (Experiments 2a and 2b) or made it impossible to effectively process letters in parallel because of their irregular relative positioning.

The proposed theory is also congruent with past observations showing that high-level effects, including effects of orthographic (Arguin & Bub, 1996; Arguin et al., 2002; Montant & Behrmann, 2001) and phonographic (Fiset et al., in press) neighborhood size, lexical frequency, and imageability, occur in LBL dyslexia, but only with words having low letter confusability (Arguin et al., 2002; Fiset et al., in press). In particular, we (Fiset et al., in press) have shown that these effects occur with words that have low, but not high, letter confusability when they are displayed normally. However, these effects are abolished, as is the letter-confusability effect, when words are presented incrementally, one letter at a time, to prevent parallel processing. These observations demonstrate that high-level effects, as well as the impact of letter confusability, are exclusive to parallel processing and that high letter confusability can effectively block access to the high-level representations mediating the neighborhood-size, lexical-frequency, and imageability effects. Finally, the initial attempt by LBL dyslexics to read words in a parallel processing mode may account for the implicit-reading phenomena reported in a number of patients (Coslett & Saffran, 1989; Coslett, Saffran, Greenbaum, & Schwartz, 1993; Shallice & Saffran, 1986; see Saffran & Coslett, 1998, for an overview). An appropriate test of the latter proposal, which has yet to be conducted, would be to examine whether implicit reading may be blocked or diminished by high summed letter confusability.

A point that still needs to be clarified is the criterion for patients' switch from a parallel to a sequential letter-processing mode. We propose that this criterion may be a joint function of the signal-to-noise ratio for letter identification via a parallel process and of the time elapsed since target onset. For instance, a severely impaired patient may have such difficulty obtaining a proper signal-to-noise ratio that he or she may rapidly decide to switch to a serial letter processing, except on some rare occasions when the target has an especially low summed letter confusability. In contrast, a less impaired patient may maintain a parallel processing mode for a longer duration and switch to serial processing only if the signal-to-noise ratio remains too low after some criterion duration or if its rate of increase becomes too low for the patient to expect a successful outcome. This switch to serial processing does not necessarily imply a slavish left-to-right processing of each letter in the word, as LBL is often described. Instead, it is possible that serial letter processing through focused attention concerns only a subset of the letters whose identity has been especially difficult to resolve using the initial parallel process. In other words, the serial mode may take the form of a guided search aimed to complete the partial letter-identity information that may have been obtained by the parallel mode. Future studies should be conducted to assess this possibility.

We conclude that the word-length effect that is diagnostic of LBL dyslexia is an artifact of summed letter confusability. This factor affects reading performance by modulating the signal-to-noise ratio at the level of letter identification, a ratio that is abnormally low in LBL dyslexics. This core letter-processing deficit is responsible for the low probability of overt word recognition based on parallel processing that characterizes the disorder, as well as for the fact that this probability is controlled by the sum of the confusability of the letters making up the target word.

Acknowledgments—We are grateful for the kind collaboration offered by the patients in this study, as well as to Marlene Behrmann for allowing access to E.L. and D.K. This research was supported by a grant from the Canadian Institute for Health Research to Martin Arguin and grants from the Medical Research Council and the Stroke Association (United Kingdom) to Glyn Humphreys and Jane Riddoch. Martin Arguin is chercheur-boursier of the Fonds de la Recherche en Santé du Québec, Quebec, Canada.

REFERENCES

Arguin, M., & Bub, D. (1995). Priming and response selection processes in letter classification and identification tasks. *Journal of Experimental Psychology: Human Perception and Performance*, *21*, 1199–1219.

Arguin, M., & Bub, D. (1996). A facilitatory effect of orthographic neighborhood size in letter-by-letter reading. *International Journal of Psychology*, *31*, 402.

Arguin, M., & Bub, D. (in press). Parallel processing blocked by letter similarity in letter-by-letter dyslexia. *Cognitive Neuropsychology*.

Arguin, M., Bub, D., & Bowers, J.S. (1998). Extent and limits of covert lexical activation in letter-by-letter reading. *Cognitive Neuropsychology*, *15*, 53–92.

Arguin, M., Fiset, S., & Bub, D. (2002). Sequential and parallel letter processing in letter-by-letter dyslexia. *Cognitive Neuropsychology*, *19*, 535–555.

Behrmann, M., Plaut, D.C., & Nelson, J. (1998). A literature review and new data supporting an interactive account of letter-by-letter reading. *Cognitive Neuropsychology*, *15*, 7–51.

Binder, J.R., & Mohr, J.P. (1992). The topography of callosal reading pathways: A case-control analysis. *Brain*, *115*, 1807–1826.

Bub, D.N., Arguin, M., & Lecours, A.R. (1993). Jules Dejerine and his interpretation of pure alexia. *Brain and Language*, *45*, 531–559.

Coslett, H.B., & Saffran, E.M. (1989). Evidence for preserved reading in 'pure alexia.' *Brain*, *112*, 327–359.

Coslett, H.B., Saffran, E.M., Greenbaum, S., & Schwartz, H. (1993). Reading in pure alexia: The effect of strategy. *Brain*, *116*, 21–37.

Damasio, A.R., & Damasio, H. (1983). The anatomic basis of pure alexia. *Neurology*, *33*, 1573–1583.

Dejerine, J.J. (1892). Contribution à l'étude anatomo-pathologique et clinique des différentes variétés de cécité verbale. *Comptes Rendus et Mémoires de la Société de Biologie*, *3*, 61–90.

Fiset, D., Arguin, M., & McCabe, E. (in press). The breakdown of parallel letter processing in letter-by-letter dyslexia. *Cognitive Neuropsychology*.

Geisler, W., & Murray, R. (2003). Practice doesn't make perfect. *Nature*, *423*, 696–697.

Gilmore, G.C., Hersh, H., Caramazza, A., & Griffin, J. (1979). Multidimensional letter similarity derived from recognition errors. *Perception & Psychophysics*, *25*, 425–431.

Gosselin, F., & Schyns, P.G. (2002). RAP: A new framework for visual categorization. *Trends in Cognitive Sciences*, *6*, 70–77.

Howard, D. (1991). Letter-by-letter readers: Evidence for parallel processing. In D. Besner & G.W. Humphreys (Eds.), *Basic processes in reading: Visual word recognition* (pp. 34–76). Hillsdale, NJ: Erlbaum.

Humphreys, G.W., & Riddoch, M.J. (1987). *To see but not to see: A case of visual agnosia*. Hove, England: Erlbaum.

Loomis, J.M. (1982). Analysis of tactile and visual confusion matrices. *Perception & Psychophysics*, *31*, 41–52.

McCandliss, B.D., Cohen, L., & Dehaene, S. (2003). The Visual Word Form Area: Expertise for reading in the fusiform gyrus. *Trends in Cognitive Sciences*, *7*, 293–299.

Montant, M., & Behrmann, M. (2001). Phonological activation in pure alexia. *Cognitive Neuropsychology*, *18*, 697–727.

Osswald, K., Humphreys, G.W., & Olson, A. (2002). Words are more than the sum of their parts: Evidence for detrimental effects of word-level information in alexia. *Cognitive Neuropsychology*, *19*, 675–695.

Saffran, E.M., & Coslett, H.B. (1998). Implicit vs. letter-by-letter reading in pure alexia: A tale of two systems. *Cognitive Neuropsychology*, *18*, 141–165.

Shallice, T., & Saffran, E.M. (1986). Lexical processing in the absence of explicit word identification: Evidence from a letter-by-letter reader. *Cognitive Neuropsychology*, *3*, 429–458.

Townsend, J.T. (1971). Theoretical analysis of an alphabetic confusion matrix. *Perception & Psychophysics*, *9*, 40–50.

Van Der Heijden, A.H.C., Malhas, M.S.M., & Van Den Roovaart, B.P. (1984). An empirical interletter confusion matrix for continuous-line capitals. *Perception & Psychophysics*, *35*, 85–88.

Warrington, E.K., & Shallice, T. (1980). Word-form dyslexia. *Brain*, *103*, 99–112.

Weekes, B.S. (1997). Differential effects of number of letters on word and nonword naming latency. *Quarterly Journal of Experimental Psychology*, *50A*, 439–456.

Yeshurun, Y., & Carrasco, M. (1998). Attention improves or impairs visual performance by enhancing spatial resolution. *Nature*, *396*, 72–75.

(Received 4/15/04; Revision accepted 1/11/05)