Journal of Experimental Psychology:
Human Perception and Performance
1995, Vol. 21, No. 5, 1199–1219

0096-1523/95/$3.00

Priming and Response Selection Processes in Letter Classification and Identification Tasks

Martin Arguin
Université de Montréal and
Centre Hospitalier Côte-des-Neiges

Daniel Bub
Centre Hospitalier Côte-des-Neiges and
University of Victoria

The processing of isolated visual letters was studied by means of a priming paradigm. In alphabetic (letter vs. nonletter) classification, any letter prime reduced response times to letter targets. Additional facilitation occurred only with primes physically identical to the target. In letter naming, facilitation was seen with primes nominally identical to the target even when they were physically different. This result is not due to phonological priming because phonologically similar primes had no effect on naming times. Primes nominally different from the target but physically similar to it increased naming times. The classification task seems to be performed through the global monitoring of stored visual knowledge of letters. In contrast, the absolute identification of letters appears to rest on a signal-to-noise statistic derived from an abstract encoding of letter identities. Connectionist simulations provide support for these proposals.

The encoding of letter identities is an important part, and quite possibly an essential precursor, of the normal word reading process (e.g., Pollatsek & Rayner, 1989, for a review). The understanding of the mental operations and codes involved in the identification of letters is therefore crucial for a detailed theory of reading. In addition, it is clear that performance in any reading task must be intimately tied to the kind of representation on which response is based and to the decision mechanisms that lead to response selection (e.g., Monsell, Doyle, & Haggard, 1989; Neely, 1991). The dual aim of this article is to provide evidence relevant to the organization of the letter recognition system and to distinguish between the response selection operations involved in absolute identification and classification tasks.

The mechanisms involved in letter recognition have previously been the subject of investigation with the matching paradigm. Possibly the most fundamental result from this work (Posner & Mitchell, 1967) is that, in a task in which participants have to decide whether two simultaneous letters have the same name, responses to physically identical (PI) pairs (e.g., A–A) are faster than those to nominally identical but physically different (NI) pairs (e.g., A–a). Several replications of this PI–NI discrepancy have been reported since then using similar methods or variants of the basic letter matching paradigm (Boles & Eveland, 1983; Carrasco, Kinchla, & Figueroa, 1988; Kellicutt, Parks, Kroll, & Salzberg, 1973; Kroll & Parks, 1978; Parks & Kroll, 1975; Posner, Boies, Eichelman, & Taylor, 1969; Proctor, 1981; Walker, 1978). From their initial observation, Posner and Mitchell (1967) determined that isolated letters may be registered under two separate codes: the visual and the name codes. The visual code represents letter shape and becomes available sooner than the name code, which abstracts away information about visual shape and therefore allows the decision that two visually different instances of a particular letter have the same name. Thus, when two letters are physically identical, they must be nominally identical as well and the same-name decision may be based on the faster visual code. With NI pairs however, the letters are physically different and the same-name decision must rest on the slower name code. It is of interest to note that, under this explanation, the kind of code (i.e., visual or name) on which the matching decision is taken can vary from trial to trial as a function of stimulus conditions (i.e., PI vs. NI pairs).

In spite of the empirical support for dual mechanisms in letter encoding, what has remained unclear and is still controversial today is the specific format under which the so-called name code is represented. A clarification of this concept seems quite critical for reading theory, however. Indeed, several experiments interested in the processing of letter strings have indicated that the representation format for lexical orthographic knowledge is abstract with respect to visual shape (e.g., Adams, 1979; Allport, 1979; Carr, Brown, & Charalambous, 1989; Evett & Humphreys, 1981; McClelland, 1976; Pollatsek, Well, & Schindler, 1975; Segui & Grainger, 1990). Most convincing among these is

---

Martin Arguin, Département de Psychologie and Groupe de Recherche en Neuropsychologie Expérimentale, Université de Montréal, Montréal, Québec, Canada, and Laboratoire Théophile-Alajouanine, Centre Hospitalier Côte-des-Neiges, Montréal, Québec, Canada; Daniel Bub, Laboratoire Théophile-Alajouanine, Centre Hospitalier Côte-des-Neiges and Department of Psychology, University of Victoria, Victoria, British Columbia, Canada.

This research was supported by grants from the Medical Research Council of Canada. We thank Marnie Filer and Eric Loken for their technical assistance in this project.

Correspondence concerning this article should be addressed to Martin Arguin, Département de Psychologie, Université de Montréal, C.P. 6128, Succursale Centre-Ville, Montréal, Québec, Canada H3C 3J7. Electronic mail may be sent via Internet to arguinm@ere.umontreal.ca.

the evidence that the superior recognition of words over pseudowords with brief and masked displays persists when stimuli are presented in an unusual visual format (e.g., alternation of uppercase and lowercase letters; Adams, 1979; McClelland, 1976). The implication of such observations is that, for the purpose of word recognition, the reading system appears to abstract away information pertaining to the visual properties of the stimulus and only retain information about orthographic identities. In addition, different sources of evidence have shown that the normal recognition of a visual word proceeds by the prior identification of its component letters (e.g., Adams, 1979; Besner, Davelaar, Alcott, & Parry, 1984; Coltheart, Curtis, Atkins, & Haller, 1993; Johnston & McClelland, 1980; McClelland, 1976; McClelland & Rumelhart, 1981; Paap, Newsome, McDonald, & Schvaneveldt, 1982; Paap, Newsome, & Noel, 1984). Given this, it appears that the filtering out of visual shape information for reading may take its source in letter recognition; more specifically in the derivation of what Posner and Mitchell (1967) have called the name code, or some variant thereof.

According to Posner (1978), the name code proposed by Posner and Mitchell (1967) should be equated with a phonological representation which, in the letter matching task, would obviously permit participants to decide that NI letter pairs (e.g., A–a) have the same name. This hypothesis has been challenged however, by the demonstration that the name equivalence of physically different letters can be established without phonological coding (Boles & Eveland, 1983; Rynard & Besner, 1987; for relevant evidence see also Besner, Coltheart, & Davelaar, 1984; Boles, 1986; Boles & Hellige, 1984; Carrasco et al., 1988; Parks & Kroll, 1975). Two apparently equally viable accounts have therefore been presented as alternatives to the phonological code for the process by which an abstract representation of letter identities may be derived. One is that of *letter types,* which are defined as abstract internal units that specifically encode orthographic identity, to the exclusion of shape or phonological information (Besner et al., 1984; Coltheart, 1981; Mozer, 1989; Rynard & Besner, 1987). These letter types are contrasted with *letter tokens,* which would stand as form-specific letter representations; that is, visual representations of knowledge about letter shapes (Mozer, 1989). A rival to the letter-type hypothesis is the view defended by Boles (1986, 1992; Boles & Eveland, 1983), who proposed a process by which a visual representation of the opposite-case version of a letter stimulus is rapidly and automatically generated (for a related proposal, see also Parks & Kroll, 1975). Under the generation hypothesis, no actual representations of abstract orthographic identities would exist. Rather, the abstraction of letter-shape information would be provided by the generation of the different shape descriptions (i.e., token level) under which a particular letter identity may be depicted visually.

One main goal of this article is to study the abstraction of visual shape information in letter recognition with the priming paradigm. Surprisingly, although this paradigm has been used before to study letter recognition, it has so far failed to provide convincing evidence for abstract encoding. Eichelman (1970) used a letter naming task and examined the effect of the relationship between targets on successive trials (intertrial intervals of 200 or 700 ms). His results showed that, with a target nominally identical but physically different from that of the previous trial, response times were shorter than with letters unrelated (i.e., different; DI) to the preceding target. In a letter naming experiment where primes were passively viewed for 500 ms, Walker (1978) observed a similar effect if primes and targets were separated by an interstimulus interval (ISI) of 1 s or 2 s and were shown in different locations. With no spatial separation between primes and targets or with an ISI of 0 ms or 500 ms, no difference was observed between the response times in the NI and DI conditions. Because no neutral condition was run in either study, it cannot be determined whether the differences reported by Eichelman (1970) and Walker (1978) between the NI and DI conditions are due to actual benefits from abstract priming or instead to DI primes having a name different from the target. The critical importance of a neutral condition for data interpretation is revealed by the work of Proctor (1981). In his Experiment 2, participants named a target letter preceded by a 500-ms prime and a 500-ms ISI. Even though response times were shorter with NI than DI primes, no difference was observed between the results with neutral (a percent sign) and NI primes.

More recently, Jacobs and Grainger (1991) studied the effect of very brief (up to 80-ms duration) masked primes on the time necessary to classify a target character as being a letter or a nonalphabetic character. These authors claimed to have found evidence for abstract letter priming in this task. However, we argue that their observations fail to clearly support this conclusion. Thus, in one experiment where NI primes were used (Experiment 1), no particular selection was made on the degree of visual similarity between these primes and their corresponding target (see Grainger & Jacobs, 1991, for a similar design in a letter-string to single-letter priming paradigm). Some NI primes were physically different from the target they preceded (e.g., prime = b; target = B), whereas others were quite similar (e.g., prime = c; target = C). It is possible then, that the facilitation observed in this condition, relative to primes both physically and nominally different from the target (e.g., prime = X, target = G), was caused by the physical similarity between some of the primes and their corresponding targets. This is all the more likely that the authors did find, in the same kind of experiment, that primes which were only visually similar to the target (SIM; e.g., prime = G; target = C) led to shorter response times than DI primes.

In another experiment (Experiment 3), Jacobs and Grainger (1991) considered separately the effects of NI primes that were visually similar or different from the target. These two conditions resulted in shorter response times, an effect that was notably greater with NI primes that were visually similar to the target. One important issue in interpreting this observation is the baseline against which the results from the NI conditions were compared. Indeed, no DI condition was run in this experiment and the baseline used was one where the prime (a nonletter) was associated with a response different from that associated with the target (a letter). As response priming effects were evident in their alphabetic decision experiments, it appears possible that the facilitation reported by Jacobs and Grainger (1991) with visually different NI primes may be an artifact of the baseline condition. In other words, response priming was not dissociated from the effect of visually different NI primes, and it may therefore not be concluded that abstract orthographic priming occurred.

In the present report, we studied abstract letter priming with a condition in which NI primes were visually different from their corresponding target. As well, appropriate baseline conditions were included in each experiment. Finally, the range of prime durations was extended (from 50 ms to 200 ms) compared with that used by Jacobs and Grainger (1991; from 20 ms to 80 ms) to ensure the occurrence of NI priming if a process that abstracts away the particular shapes of letters is actually involved.

Another interesting aspect from the results of Jacobs and Grainger (1991), which has been noted earlier, is the effect of SIM primes on the time required to classify letter targets. Specifically, this condition led to shorter response times than DI primes, suggesting that the prior activation of a shape code compatible with that of the target facilitates its recognition. Although this effect of SIM primes does not appear especially surprising, there is reason to suspect that it may in fact be contingent on the task participants have to perform on the target. Indeed, discussions as to the requirements of word classification and absolute word identification tasks have suggested fundamental differences in response selection mechanisms (Besner et al., 1984; Monsell et al., 1989; Neely, 1991; see Andrews, 1989; Balota & Chumbley, 1984, 1985; Carr, Brown, Vavrus, & Evans, 1990; Carr, Pollatsek, & Posner, 1981; Forster & Chambers, 1973; Frederiksen & Kroll, 1976; McCann, Besner, & Davelaar, 1988; Parkin, McMullen, & Graystone, 1986; and Seidenberg, Waters, Barnes, & Tanenhaus, 1984; for relevant evidence and discussion). A related distinction between response selection for classification and absolute identification has also been proposed for the processing of nonlinguistic materials (Ashby & Gott, 1988; Ashby & Lee, 1991; Nosofsky, 1986). The distinction may also be true in the letter processing domain, as suggested by the following task analysis.

Consider the alphabetic decision task used by Jacobs and Grainger (1991). In this case, the production of a correct response may not imply the absolute identification of the target. In other words, the production of a correct letter response does not seem to require a specification of which letter is presented. Rather, the presence of a sufficient level of activation within a representation system specific to letters may be sufficient for an accurate letter versus nonletter classification. Given this assumption, it follows that the prior activation, by a SIM prime, of a shape code compatible with the target will result in shorter letter-decision times. Formal support for this was provided by Jacobs and Grainger (1991) through simulations based on the interactive activation model of McClelland and Rumelhart (1981). Thus, they were able to fit simulation results for the SIM and DI priming conditions to their empirical observations by using, in those simulations, the level of activation of letter representations as a criterion for response.

In contrast to alphabetic decision, if participants have to perform the absolute identification of a target letter, the information on which an accurate response is based may differ. For instance, in a letter naming task, it appears not only necessary that the representation corresponding to the target identity be appropriately activated but also that there be a sufficient contrast between the activation of the target representation and that of other competing letter units (i.e., a large enough signal-to-noise ratio; e.g., Luce, 1959, 1977). As an example, consider a situation in which the target representation is highly activated. If, for some reason, another letter representation is also activated to a high degree, it may be difficult or even impossible to determine the exact identity of the target, that is, which letter is presented. Nevertheless, this state of the letter recognition system, where representations are highly activated, would seem appropriate for the correct decision that the target is a letter.

If response selection processes vary as a function of task in the way assumed here, it can be expected that the effect of SIM primes will differ between alphabetic decision and absolute letter identification. As indicated above, by virtue of its shape compatibility, a SIM prime may accelerate the activation of the target representation. At the same time, however, a prime whose identity is different from that of the target will increase the level of background noise against which target activation occurs. If absolute identification of the target is based on a signal-to-noise ratio, prior exposure to a prime with a different nominal identity should have a negative impact on performance. Therefore, in the context of an absolute identification task, the effect of the shape compatibility of a SIM prime would be opposed by its nominal incompatibility with the target. It can reasonably be expected that this situation would prevent any facilitation to occur with SIM primes, in contrast to what was observed by Jacobs and Grainger (1991) in alphabetic decision. In fact, it can be argued that these primes may actually produce inhibition in an absolute identification task. Thus, if a SIM prime activates a visual code that is partially compatible with that of the target, the reverse may also be true, that is, the activation resulting from exposure to the target may cause leakage which maintains the activity of the representation coding the SIM prime. In such a case, because of the higher level of background noise target identification should be delayed relative to a condition in which the prime is visually incompatible with the target (e.g., DI).

One purpose of the present report is to test the hypothesis that letter classification and absolute letter identification tasks differ on the processes by which response selection is performed. Following the task analysis presented above, it is expected that the effects of SIM primes in classification and absolute identification tasks will differ. To test this hypothesis, the experiments reported here used letter versus nonletter classification and letter naming tasks in the context of the priming paradigm developed by Jacobs and Grainger (1991).

Following the presentation of our empirical work on letter priming, a series of simulations that used a connectionist network are discussed. Their purpose is not so much to present a full-fledged theory of letter processing, but rather to assess, through their implementation in a mechanistic system, the specific hypotheses we present to account for the experimental results.

Experiment 1

Experiment 1 was mainly intended to replicate and extend the work reported by Jacobs and Grainger (1991). Thus, participants performed a letter versus nonletter classification where targets were preceded by briefly exposed primes. A condition in which NI primes (name identity) that were physically different from the target was included. A condition in which letter primes were both physically and nominally different from the subsequent target letter was also used and served as a baseline that controlled for response priming with letter targets. The other priming conditions were as follows: physically identical primes (PI), physically similar but nominally different primes (SIM), a nonletter prime (NL), and a neutral prime (NE, a blank character). Prime durations were of 50, 100, 150, or 200 ms.

Method

Participants. Five experienced participants who were part of the personnel of the Neurolinguistics Laboratory of the Montreal Neurological Institute, Montreal, Québec, Canada, took part in this experiment. Their ages ranged between 21 and 32 years. All but one were right-handed.

Stimuli and materials. The experiment was run on a Macintosh Plus microcomputer and was controlled by the software Psychlab (Bub and Gum, University of Victoria, Victoria, British Columbia, Canada).[1] Responses were registered through a key press. Participants used their dominant hand to indicate that the target was a letter and used their nondominant hand to indicate a nonalphabetic character. Participants were seated approximately 45 cm from the screen and the experiment was conducted in a normally lit room.

The target letters used were the following 20 uppercase letters: A, B, C, D, E, F, G, H, I, K, M, N, O, P, Q, R, S, T, U, and V. The nonletter targets were the following 10 keyboard characters: !, $, %, &, +, ?, #, <, >, and =. The prime letters used were the 20 uppercase letters just mentioned, as well as the 10 following lowercase letters: a, b, d, e, g, h, m, n, q, and r. Two nonalphabetic characters were also used as primes. Those were an asterisk and a blank character, the latter serving as a neutral prime. The width of these stimuli was between 3 and 6 mm and their height was between 4 and 6 mm. A masking stimulus, which took the form of a checkerboard with sides of 10 mm, was also used. This stimulus was presented before and after the prime (see below). All stimuli were presented in the middle of the display screen.

Procedure. Several conditions defined the nature of the relationship between the prime and the target presented on any given trial. There were six kinds of priming categories for letter-target trials:

1. Physically identical primes (PI), where the prime was identical to the target that followed (e.g., prime = A; target = A). Any of the 20 uppercase letters used in this experiment could serve in this condition.
2. Nominally identical primes (NI), where the prime had the same name as the target but both were physically different (Boles & Clifford, 1989). In this condition, the prime was one of the 10 lowercase letters used here and the target was its uppercase version (e.g., prime = a; target = A).
3. Similar primes (SIM), where the prime was physically similar to the target but was nominally different from it. In this condition, uppercase letters that were physically similar were paired and either item of a pair could serve as the prime while the other served as the target. The pairs of similar letters used were C–G, E–F, I–T, O–Q, and U–V.
4. Different primes (DI), where the prime and target were both nominally and physically different. The primes used in this condition were the letters A, B, D, H, K, M, N, P, R, and S, and the targets matched with each of these items were M, N, K, V, P, U, O, A, S, and F, respectively.
5. Nonletter prime (NL), where the prime was an asterisk.
6. Neutral prime (NE), where the prime was a blank character. In both the NL and NE priming conditions, any of the uppercase letters used in this experiment could serve as target.

For each of the trials that was constructed with a letter target, a corresponding trial with the same prime but a nonletter target was made. This was done by replacing the target letter by a nonletter randomly selected from the set presented above. Thus, the priming conditions with nonletter targets were (a) real letter primes (RL), (b) nonletter primes (NL), and (c) neutral primes (NE). With this way of preparing trials for nonletter targets, no prime could serve in predicting the response to the target that followed. Note that, with this design, four times more trials were run in the RL condition than in the NL and NE conditions. The specific items used as prime and target on any given trial were selected randomly within the constraints presented above.

The course of a trial was as follows: The masking stimulus was first presented in the center of the screen for a duration of 750 ms. It was then replaced by the prime, which remained on for a duration of either 50, 100, 150, or 200 ms.[2] 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 immediately replaced by the target, which remained visible until the participant responded.

The experimental design comprised 36 conditions. Of these, 24 used letter targets, with the effect of six prime categories (PI, NI, SIM, DI, NL, and NE) examined over four different prime durations (50, 100, 150, and 200 ms). The 12 other conditions used nonletter targets, with three different prime categories (RL, NL, and NE) and four prime durations. Each participant was tested over a period of 2 to 4 days on 20 blocks of 96 trials each. Each block comprised two trials for each of the experimental conditions, with the exception of RL primes preceding nonletter targets, for which eight trials were run at each prime duration in each block. The trials for each condition were distributed randomly within each block. Participants were instructed to respond as rapidly as possible while avoiding errors. The main dependent variable was response time.

---

[1] The accuracy of response time measurements with this program has been assessed. Its precision is of ±1 ms.

[2] Although this was not examined formally, informal inquiries suggest that participants could have been consciously aware of the identity of the primes, even with an exposure duration of 50 ms. This differs from the experiments of Jacobs and Grainger (1991), where participants were unable to report the primes.

Results

Figures 1 and 2 illustrate the average correct response times and average error rates for each condition where the target was a letter. The average correct response times and error rates to nonalphabetic targets are shown in Figures 3 and 4. No evidence for a speed–accuracy trade-off was seen, as the correlation between average response times and error rates across conditions was positive and significant (.63; $p < .01$). The observations with letter and nonletter targets were analyzed separately with two-factor (Prime Category × Prime Duration) analyses of variance (ANOVA).

The main finding of Experiment 1 is that the compatibility between the responses (letter vs. nonletter) associated with the prime and the target had marked effects on response times (i.e., response priming; Eriksen & Shultz, 1979; Taylor, 1977; Weisgerber & Johnson, 1989). Thus, relative to the NE condition, response times to letter targets were longer if the prime was a nonletter (NL) and were shorter if the prime was a letter (DI). Also, response times to nonletter targets were shorter when the prime was a nonalphabetic stimulus (NL) than if it was neutral (NE). The only other important effect on response times is that PI primes led to faster letter responses than primes physically and nominally different from the target (DI). No response time benefit from NI or SIM primes over DI primes was found. The error rate data largely parallel that on response times except that facilitation was observed with NI primes but not with PI primes. The details of the data analyses are reported below.

Letter targets. Analysis of the correct response times to letter targets indicated main effects of both prime category, $F(5, 20) = 32.2$, $p < .001$, and prime duration, $F(3, 12) = 7.4$, $p < .005$, along with a significant Prime Category × Duration interaction, $F(15, 60) = 4.6$, $p < .001$. The main effect of duration indicated a decrease in response times with an increase of prime duration. Analysis of the simple effects of the interaction indicated a significant effect of prime category at each duration: 50 ms, $F(5, 20) = 7.1$, $p < .001$; 100 ms, $F(5, 20) = 36.3$, $p < .001$; 150 ms, $F(5, 20) = 16.7$, $p < .001$; 200 ms, $F(5, 20) = 25.1$, $p < .001$.

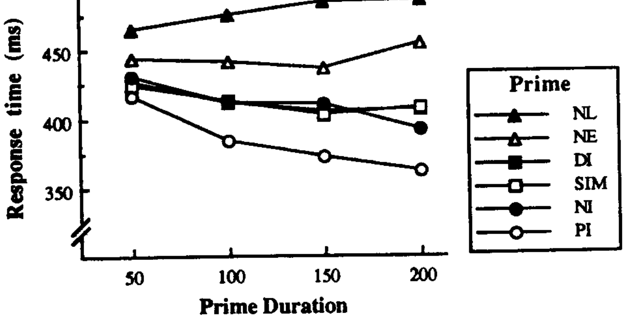

Figure 1. Average correct response times to letter targets in the alphabetic decision task in Experiment 1. NL = nonletter; NE = neutral; DI = different; SIM = similar; NI = nominally identical; PI = physically identical. Prime duration is expressed in milliseconds.

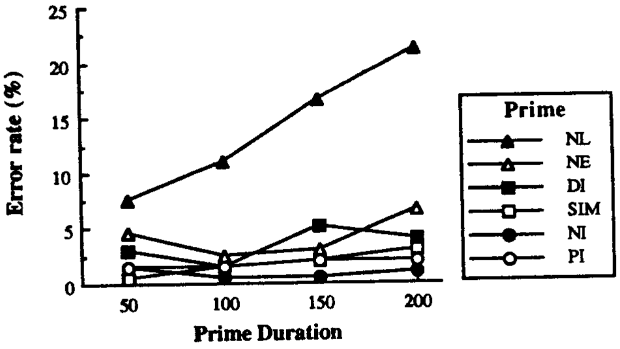

Figure 2. Average error rates with letter targets in the alphabetic decision task in Experiment 1. NL = nonletter; NE = neutral; DI = different; SIM = similar; NI = nominally identical; PI = physically identical. Prime duration is expressed in milliseconds.

Pairwise comparisons between priming conditions at each duration examined two classes of priming effects. One was response priming. By using the observations with an NE prime as a baseline, we assessed the effect of presenting a letter (DI prime) or a nonletter (NL prime) on response times to letter targets. Another class of priming can be labeled *letter-specific* priming. We assessed the impact of physical or nominal compatibility between the prime and target in a way that dissociated these effects from response priming. Thus, the baseline condition for this category of priming was that of DI primes and response times in this condition were compared with those in the PI, NI, and SIM conditions. Only the significant effects observed in these comparisons are reported.

Response priming is the most prominent effect to emerge from the pairwise comparisons at each prime duration for trials where the target was a letter. Thus, at all prime durations, response times to letter targets were longer with NL than with NE primes: 50 ms, $t(4) = 2.5$, $p < .05$; 100 ms, $t(4) = 3.7$, $p < .05$; 150 ms, $t(4) = 3.8$, $p < .01$; 200 ms, $t(4) = 2.9$, $p < .05$. Also, at all prime durations, response times to targets preceded by a DI prime were shorter than with an NE prime: 50 ms, $t(4) = 2.5$, $p < .05$; 100 ms, $t(4) = 3.6$, $p < .05$; 150 ms, $t(4) = 6.6$, $p < .01$; 200 ms, $t(4) = 3.5$, $p < .05$. The only effect that relates to letter-specific priming is that response times were shorter with PI than with DI primes. This effect was seen at all prime durations: 50 ms, $t(4) = 2.9$, $p < .05$; 100 ms, $t(4) = 5.0$, $p < .01$; 150 ms, $t(4) = 3.9$, $p < .01$; 200 ms, $t(4) = 2.4$, $p < .05$. The lack of any difference in response times between the DI and NI conditions and between the DI and SIM conditions does not appear to result from a lack of power in our statistical tests. Thus, as can be seen in Figure 1, there was, at all prime durations except 200 ms, a nearly perfect overlap of the response times observed with DI, NI, and SIM primes. At a prime duration of 200 ms, the overlap between the response times with DI and SIM primes was still excellent but response times with NI primes were slightly lower than those with DI primes. This latter difference failed to reach significance however, $t(4) = 1.9$, *ns.*

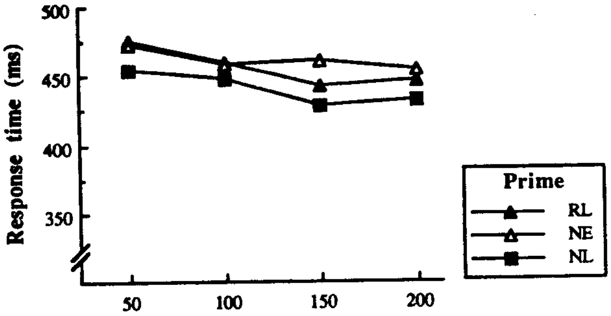

Figure 3. Average correct response times to nonletter targets in the alphabetic decision task in Experiment 1. RL = real letter; NE = neutral; NL = nonletter. Prime duration is expressed in milliseconds.

The ANOVA applied on the error rates with letter targets indicated no main effect of prime duration, $F(3, 12) = 2.7$, *ns*, but a main effect of prime category, $F(5, 20) = 6.9$, $p < .001$, and a significant interaction of Prime Category × Prime Duration, $F(15, 60) = 2.8$, $p < .005$. Simple effects of prime category were significant at durations of 100 ms or longer, but not with 50-ms primes: 50 ms, $F(5, 20) = 2.3$, *ns*; 100 ms, $F(5, 20) = 4.8$, $p < .005$; 150 ms, $F(5, 20) = 5.1$, $p < .005$; 200 ms, $F(5, 20) = 7.8$, $p < .001$. Pairwise comparisons showed significant response priming at durations of 100 ms or longer, with larger error rates with NL primes than with an NE prime: 100 ms, $t(4) = 2.2$, $p < .05$; 150 ms, $t(4) = 3.0$, $p < .05$; 200 ms, $t(4) = 6.0$, $p < .01$. No difference in error rates between the DI and NE conditions was observed, however. Other effects related to letter-specific priming were also observed, but their magnitude was small (see Figure 2). Thus, with SIM primes of a 50-ms duration, error rates were lower than with DI primes, $t(4) = 3.2$, $p < .05$. Also, error rates were lower with NI than with DI primes at durations of 150 and 200 ms: 150 ms, $t(4) = 2.5$, $p < .05$; 200 ms, $t(4) = 3.2$, $p < .05$. In contrast, however, error rates with PI and DI primes did not differ at any duration.

Nonletter targets. The ANOVA applied on the correct response times observed with nonletter targets showed significant main effects of prime category, $F(2, 8) = 6.3$, $p < .05$, and of prime duration, $F(3, 12) = 25.6$, $p < .001$, but no interaction between these factors, $F(6, 24) = 2.0$, *ns*. The main effect of duration indicated a decrease in response times with an increase of prime duration. With respect to pairwise comparisons that examined the effect of prime category, analyses showed evidence for response priming. Thus, response times were shorter with NL than with NE primes, $t(4) = 3.9$, $p < .01$. However, no difference was seen between RL and NE primes, $t(4) = 1.4$, *ns*. The ANOVA examining the error rates with nonletter targets indicated no main effect of prime category, $F(2, 8) = 1.9$, *ns*, or of duration, $F(3, 12) = 2.0$, *ns*, and no interaction between these two factors, $F(6, 24) = 1.7$, *ns*.

Discussion

Possibly the most conspicuous finding from Experiment 1 is the massive response priming effect, which was apparent in many of the pairwise comparisons we performed. Thus, primes associated with the same response as the target led to shorter response times than a neutral prime (for letter targets: DI < NE; for nonletter targets: NL < NE). Conversely, primes associated with a nonletter response yielded longer response times and higher error rates to letter targets than a neutral prime (NL > NE for both dependent measures). Jacobs and Grainger (1991) also observed such effects in their alphabetic decision experiments and it was the strongest kind of priming they reported (see Jacobs & Grainger, 1991, Experiment 2). We note however that, in the present experiment, letter primes did not result in an increase of response times to nonletter targets. Weisgerber and Johnson (1989) have also reported, in several experiments, that response times to nonalphabetic characters in a letter versus nonletter classification task are not increased by exposure to a letter prime.

According to Jacobs and Grainger (1991), response priming effects result from a bias in a response selection mechanism that would affect response times according to the compatibility between the responses associated with the prime and the target. Although this explanation appears well suited to account for the response priming effects observed in Experiment 1, we point out that any effect of the prime on a response selection mechanism must originate from a pertinent change in the state of the letter representation system, that is, a change which affects the signal that is being monitored for response selection in the classification task.

From this, the widespread occurrence of response priming effects in Experiment 1 may be taken as support for the hypothesis that the letter versus nonletter classification is performed through the global, or nonselective, monitoring of activation within a set of representations that is specific to letters (i.e., a response selection process that disregards the specific identity to which the activated representation corresponds). Thus, it may be assumed that the presentation of any letter as a prime increases the activation of some

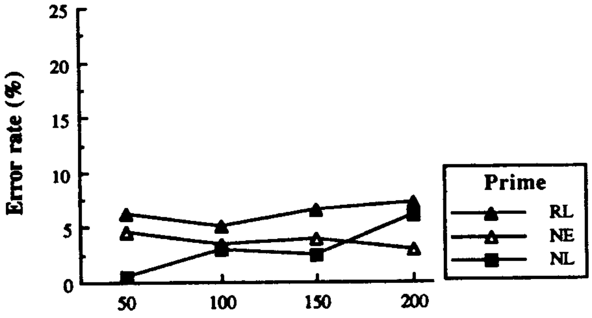

Figure 4. Average error rates with nonletter targets in the alphabetic decision task in Experiment 1. RL = real letter; NE = neutral; NL = nonletter. Prime duration is expressed in milliseconds.

internal letter unit. If participants attend to the activation of letter units in a nonselective manner to perform the alphabetic decision task, the activation produced by a letter prime will affect the status of the response selection mechanism and bias it toward a letter response, regardless of its physical or nominal relation with the subsequent target. The converse may also be true. Thus, a nonletter prime (here an asterisk) may result in an inhibition of letter units and therefore bias the response selection mechanism toward a nonletter response.

Besides response priming effects, we also observed that error rates were lower with NI than with NE primes at durations of 150 and 200 ms. This effect was weak however (see Figure 2). In addition, its meaning is unclear. Indeed, had the effect of NI primes on error rates been linked to the shared nominal identity of the prime and the target, PI primes should have also led to a reduction in error rates. No such effect of PI primes occurred, however. On that subject, it should also be noted that another alphabetic decision experiment, identical to Experiment 1 except for the fact that nonletters were visually similar to real letters (i.e., pseudoletters), replicated all the principal aspects of the results of Experiment 1. However, no effect of NI primes on error rates occurred in that experiment. The weakness, ambiguity, and unreliability of the effect of NI primes on error rates casts doubt on the interpretative value of this observation.

Another, more straightforward letter-specific priming effect observed in Experiment 1 is a facilitation of response times with PI relative to DI primes. If we attempt to consider this effect in terms of its components, one possible assumption is that PI primes activate both visual and nominal representations that are compatible with the target. These two separate kinds of prior activation would then facilitate the processing of the target when it is presented. Contrary to this assumption however, we find that even if the combined physical and nominal compatibility between prime and target in the PI condition leads to notable benefits, neither the physical (SIM primes) nor name (NI primes) compatibility between the prime and the target, in isolation, results in any response time improvement over DI primes.

The absence of clear and unequivocal NI priming in Experiment 1 suggests that abstract letter encoding did not contribute to performance in the alphabetic decision task. This is congruent with the reservations we presented in the introduction about the results of Jacobs and Grainger (1991) with NI primes. It was indicated at that point that the facilitatory effect of NI primes they observed on response times could be explained by the visual similarity of some prime–target pairs in their first experiment and by response priming in their third experiment. These alternative accounts are supported by the fact that, when factors related to prime–target similarity and response priming are controlled in assessing the effect of NI primes, as in the present experiment, these primes do not lead to a reduction of response times.

These observations suggest that, to classify targets, participants attended representations of knowledge about letter shapes (i.e., letter-token representations). As stated in the introduction, these representations are tied to specific letter shapes so that items that are nominally identical but physically different (e.g., a–A) are represented as separate units. A second and related implication of the lack of abstract letter encoding in Experiment 1 concerns theories of how the letter recognition system derives abstract letter identity codes. Indeed, following the generation hypothesis proposed by Boles (1986, 1992; Boles & Eveland, 1983), the only letter representations to which normal readers have access are those of letter tokens. Under this view, abstraction in letter recognition is achieved by the fast and automatic generation of the different visual forms that can be used to represent a particular letter identity. If this kind of generation process had occurred in Experiment 1 however, a clear NI priming effect should have been observed in the response time data. Thus, the presentation of an NI prime would have led to the internal generation of a visual code corresponding to the subsequent target and therefore to a reduction in the time required to classify it. This, apparently, did not happen in Experiment 1—the only evidence for generation in Experiment 1 is the effect of NI primes on error rates; this effect was weak and difficult to replicate however, and its interpretation was obscured by the lack of PI priming on error rates. It seems then that the results from the alphabetic decision task reported here do not support the particular version of the generation theory where this process is mandatory (i.e., automatic). In contrast, the theory according to which abstraction in letter recognition is achieved by contacting letter-type representations—abstract orthographic units (Besner et al., 1984; Coltheart, 1981; Mozer, 1989; Rynard & Besner, 1987)—is not contradicted by the results of Experiment 1. Under this theory, letter types are considered as a level of representation that is separate from that of letter tokens. The fact that participants seem to have opted to monitor the activation of letter tokens as a basis for response selection in Experiment 1 does not have any implication as to the possible existence of letter-type representations.

To summarize, the lack of clear evidence for NI priming in the letter and nonletter classification task suggests that the activation monitored by participants to make a decision on the target was that of letter tokens. In addition, it seems that generation of the opposite-case version of the prime letter did not occur. Taken in conjunction with the response priming evidence discussed earlier, it appears that, to perform the alphabetic decision task, participants attended to letter-token representations through a response selection process assessing the activation occurring within those representations while neglecting the particular identity of the units that were activated.

From the discussion presented above, we may conclude that the only source for the response time benefits observed with PI primes is the visual compatibility between the prime and target. If this is so, however, one remaining question concerns the absence of a facilitatory effect of SIM primes in Experiment 1. Indeed, this prime category is also physically compatible with the target, although to a lesser degree than PI primes. With respect to the effect of SIM primes, Jacobs and Grainger (1991) have shown that these do lead to shorter classification times of letter targets than DI primes (see their Experiment 2). Why did we fail to replicate this effect in the present experiment?

One explanation that may be readily rejected is that the lack of SIM priming results from an inherent insensitivity of the procedure used in Experiment 1 to priming effects. Indeed, massive response priming effects have been observed, as well as large benefits from PI primes over DI primes. Clearly then, the results of the present experiment were affected by priming.

Another explanation for the discrepancy between the results of Experiment 1 and those of Jacobs and Grainger (1991) on the effect of SIM primes is a difference between experiments in the duration of the mask that followed the primes. Thus, while this duration was of 20 ms in the Jacobs and Grainger (1991) experiment, the mask duration used here was of 33 ms. Because the benefit from SIM primes over DI primes found by Jacobs and Grainger was rather small, it may be that the longer mask duration used here was sufficient to eliminate it entirely. This explanation is discussed further below. In particular, the connectionist simulations show that the presence or absence of benefits from SIM priming in the alphabetic decision task is not a fundamental issue for the main concerns of the present article and that very weak variations in a parameter corresponding to mask strength can affect the occurrence of this effect.

Experiment 2

The evidence gathered in Experiment 1 suggests that response selection in the alphabetic classification task is performed through the monitoring of letter units in a way that is not affected by the particular identity to which the activated representation corresponds. In particular, under this assumption, the facilitation of a letter response following exposure to a letter prime, whatever its physical or nominal relationship with the target that followed, could be explained in a straightforward manner. As indicated in the introduction, one main purpose of the present report is to distinguish between the response selection mechanisms involved in classification and absolute identification paradigms. For this purpose, Experiment 2 used a letter naming task. In most respects, the general procedure and priming conditions were the same as in Experiment 1.

Method

Participants. The participants were the same as those who served in Experiment 1.

Stimuli and materials. Materials were the same as those used in Experiment 1. In addition, a microphone, linked to the computer, was used as a voice-key to register the naming response that was required from participants on each trial. After the participant's verbal response, the experimenter recorded it via the keyboard and then pressed a key to initiate the next trial.

All targets were uppercase letters. The set of stimuli used as targets was made of the same 20 uppercase letters that were used in Experiment 1. The same lowercase primes that served in Experiment 1 were used again in the present experiment. An asterisk was used as a neutral prime and the stimulus that served as a mask in Experiment 1 (checkerboard) served again here. All stimuli were presented at the center of the display screen.

Procedure. Almost the same priming conditions as those used with letter targets in the previous experiment were studied in Experiment 2. The exceptions were that an asterisk served as a neutral prime and that there was no condition where a blank character was used as a prime. Thus, the priming conditions in Experiment 2 were physically identical (PI), nominally identical but physically different (NI), physically similar but nominally different (SIM), physically and nominally different (DI), and neutral (NE). A set of filler trials was also used, where the prime was a lowercase letter and the target an uppercase letter with a different name. This was done because the only other condition in which lowercase primes were used was the NI condition, where the prime had the same name as the subsequent target. If no filler trials had been used, those lowercase primes could have led participants to predict the naming response that had to be given to the target and thus artifactually inflate the benefits of NI priming. The constraints as to the stimuli that could be used as prime or target in the different priming conditions of Experiment 2 were the same as those applied for letter targets in Experiment 1.

The course of a trial was identical to that of Experiment 1, except that the response required of participants was to name the target.

The experimental design comprised 20 conditions, with the effect of five prime categories (PI, NI, SIM, DI, and NE) examined at four different prime durations (50, 100, 150, and 200 ms). The complete experiment consisted of a series of eight blocks made of 120 trials each, and each participant was tested over a period of 2 to 4 days. In each block, five trials in each condition were distributed randomly, along with five filler trials for each prime duration. Participants were instructed to name the target as rapidly as possible while avoiding errors. The main dependent variable was response time. The voice-key used to register responses failed to trigger on 1.0% of the trials. Those trials were not included in the data analyses.

Results

The average correct response times and error rates observed in Experiment 2 are illustrated in Figures 5 and 6, respectively. The correlation between average response times and error rates across conditions was positive (0.49, $p < .05$), thus indicating the absence of a speed–accuracy trade-off.

The results of Experiment 2 were markedly different from those observed in the alphabetic decision task. With respect to response priming, no effect was observed on the response time data. Thus, primes associated with a response that was different from the target name (DI primes) led to response times that were either shorter or the same as an NE prime. However, error rates were higher with DI than NE primes. In addition, large facilitatory effects of PI and NI primes were found on response times relative to the NE condition. Finally, primes that were physically similar to the target but with a different identity (SIM primes) resulted in significantly longer response times and larger error rates than the neutral prime condition. Details of the data analyses are reported below.

A two-factor ANOVA was applied on the correct response times of Experiment 2. It showed main effects of

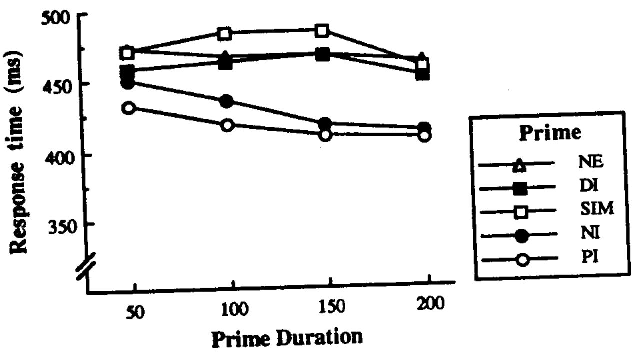

Figure 5. Average correct response times in letter naming in Experiment 2. NE = neutral; DI = different; SIM = similar; NI = nominally identical; PI = physically identical. Prime duration is expressed in milliseconds.

prime category, $F(4, 16) = 33.9$, $p < .001$, and prime duration, $F(3, 12) = 6.0$, $p < .01$, as well as a Prime Category × Prime Duration interaction, $F(12, 48) = 3.4$, $p < .005$. The main effect of duration indicated a reduction of response times with increases in the duration of the prime. Simple effects of the interaction indicated significant priming effects at each duration: 50 ms, $F(4, 16) = 12.3$, $p < .001$; 100 ms, $F(4, 16) = 17.5$, $p < .001$; 150 ms, $F(4, 16) = 27.9$, $p < .001$; 200 ms, $F(4, 16) = 16.5$, $p < .001$.

The fact that the response required from participants in Experiments 2 was naming, the degree to which the effects of response priming and of letter-specific priming (i.e., of physical and name compatibility between prime and target) may be isolated is not as complete as for a classification task such as Experiment 1. In the event that response priming was a factor in Experiment 2, we should expect response times to be longer with DI primes, where the prime had a name different from that of the target, than with an NE prime. This is therefore the comparison that was performed to assess the occurrence of a response priming effect. In contrast to Experiment 1 however, the DI condition cannot really be used as a baseline to examine the effects of shape and name compatibility between prime and target. Indeed, if response priming occurred in Experiment 2, the use of such a baseline would artificially inflate any facilitatory effect of letter-specific priming—the results of Proctor (1981), cited in the introduction, verify this possibility. For this reason, it appeared more appropriate to use the NE condition as a baseline against which to compare the results with PI, NI, and SIM primes.

Contrary to the results of the previous experiment, no evidence for a response priming effect on response times was seen in Experiment 2. As indicated above, if any response priming were to occur, response times to targets preceded by DI primes should be longer than to those preceded by an NE prime. In fact, the opposite result was seen at a prime duration of 50 ms, where response times with DI primes were shorter than with an NE prime, $t(4) = 5.1$, $p < .01$. No difference in response times between the DI and NE conditions were seen at longer prime durations: 100 ms, $t(4) = 0.6$, *ns;* 150 ms, $t(4) = 0.1$, *ns;* 200 ms, $t(4) = 0.8$, *ns*. Clear evidence for letter-specific priming was observed in Experiment 2 however. Most evident, PI primes resulted in shorter response times than NE primes at all durations: 50 ms, $t(4) = 6.7$, $p < .01$; 100 ms, $t(4) = 6.6$, $p < .01$; 150 ms, $t(4) = 5.5$, $p < .01$; 200 ms, $t(4) = 4.1$, $p < .01$. Facilitation was also obtained with NI primes, which resulted in significantly shorter response times than an NE prime at all durations: 50 ms, $t(4) = 3.3$, $p < .05$; 100 ms, $t(4) = 3.9$, $p < .01$; 150 ms, $t(4) = 4.9$, $p < .01$; 200 ms, $t(4) = 3.7$, $p < .05$. Finally, pairwise comparisons revealed a significant inhibitory effect of SIM primes relative to an NE prime at durations of 100 and 150 ms: 100 ms, $t(4) = 4.4$, $p < .01$; 150 ms, $t(4) = 3.0$, $p < .05$.

The ANOVA applied on error rates showed main effects of prime category, $F(4, 16) = 7.3$, $p < .005$, and of prime duration, $F(3, 12) = 5.2$, $p < .05$, along with an interaction between those factors, $F(12, 48) = 2.1$, $p < .05$. The main effect of duration indicated an increase in error rates with increasing prime duration. Simple effects of the interaction indicated significant priming effects at durations of 100 ms or longer: 100 ms, $F(4, 16) = 3.6$, $p < .05$; 150 ms, $F(4, 16) = 5.3$, $p < .01$; 200 ms, $F(4, 16) = 5.2$, $p < .01$.

The pairwise comparisons done in order to specify the nature of priming effects at duration of 100, 150, and 200 ms were performed following the procedure used for the analysis of response times. Response priming was evident in the outcome of those comparisons. Thus, error rates with DI primes were higher than with an NE prime at durations of 100 ms or longer: 100 ms, $t(4) = 2.1$, $p < .05$; 150 ms, $t(4) = 2.4$, $p < .05$; 200 ms, $t(4) = 2.3$, $p < .05$. Results also showed that error rates to targets preceded by SIM primes were larger than to targets preceded by an NE prime at durations of 150 and 200 ms: 150 ms, $t(4) = 2.6$, $p < .05$; 200 ms, $t(4) = 2.2$, $p < .05$.

Discussion

One striking feature of the response time results of Experiment 2 is the marked difference between the pattern of priming effects observed here, in a letter naming task (Figure 5), and those seen with letter targets in Experiment 1,

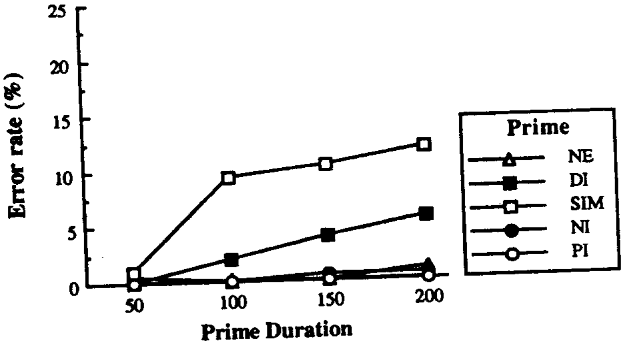

Figure 6. Average error rates in letter naming in Experiment 2. NE = neutral; DI = different; SIM = similar; NI = nominally identical; PI = physically identical. Prime duration is expressed in milliseconds.

where the task was one of letter versus nonletter classification (Figure 1). Because the general aspects of the procedure and the priming conditions used in Experiment 2 were practically identical to those of the previous experiment, those differences in priming patterns can only be attributed to the difference in the task that participants had to perform on the target.

Contrary to the alphabetic decision task (Experiment 1), no evidence for response priming was observed on response times in letter naming. Thus, with DI primes, which were associated to a response different from that associated to the target, response times were about the same as those with an NE prime. The only response time difference that occurred between those conditions (with a prime duration of 50 ms) was weak and it was in a direction opposite to that expected from priming of the response stage. By inference, because naming the target is a clear sign that it has been explicitly identified, what the results with DI primes mean is that the identification of the target is not delayed by the prior processing of a letter that is both physically and nominally different. Nevertheless, there is clear indication that DI primes had an effect on the state of the representation system on which performance was based. Indeed, more errors were observed in this condition than with an NE prime when duration was of 100 ms or more. Taken in conjunction, the response time and error data in the DI condition suggest that, at long prime durations, participants had a tendency to name the DI prime but when they resisted doing so, the time to identify the target was not affected. In support of this fast-trigger hypothesis, we find that with DI primes of 100 ms or longer (no error was made with 50-ms DI primes), error response times were 62 ms shorter than correct response times.

Again contrary to the results of the alphabetic decision task of Experiment 1, response times in the naming task appeared very susceptible to letter-specific priming effects. One interesting case involves NI primes. As can be seen in Figure 5, the benefits of NI priming were rather large and were comparable in magnitude to the facilitation obtained with PI primes at durations of 150 and 200 ms. The benefits observed with NI primes are explained by an abstraction process through which the information about the shape of the stimulus is, in some way, filtered out from the representation derived by the letter recognition system. With this abstraction process, an NI prime can activate the same representation as that on which the identification of the target is based, thus reducing response times.

Two rival accounts for the abstraction process responsible for NI priming can be proposed; the generation of a visual representation of the target or the access to letter-type representations. As indicated in the discussion of the alphabetic decision experiment, the evidence suggests that generation did not occur in that task. This is incongruent with the assumption that the process of opposite-case generation is automatic (i.e., mandatory) and thus calls for a modification of the generation theory. It seems this modification would be somewhat contrived, however, because it would need to explain not only why generation did not occur in alphabetic decision but also why it did occur in letter naming. An account of the discrepant effect of NI primes in alphabetic decision and letter naming appears to follow more naturally from the letter-type hypothesis. Under this view, two separate levels of letter representation are assumed, that of letter tokens, which are tied to a particular letter shape, and that of letter types, which do not code stimulus shape but only orthographic identity. Depending on the task, it may be proposed that participants can opt to base their response on the activation of letter tokens or on that of letter types. The choice of level of representation as a basis for response selection may be determined by the speed with which either can provide a solution to the task. In the case of the alphabetic decision task, the question participants have to answer is whether the target is known as being a letter. Access to letter-shape representations appears sufficient to answer this question and it seems reasonable to assume that this access occurs more rapidly than that to letter types (cf. PI–NI discrepancy in letter matching, Posner & Mitchell, 1967). In contrast, in letter naming, the production of a response eventually requires access to phonological representations of letter names. It is conceivable that letter types may have a privileged access to these phonological representations. If this were the case, a solution to the letter naming task would be provided more quickly by the letter-type level of representation.

One last important feature of the results of Experiment 2 is that if the prime was physically similar to the target but had a different name (SIM prime), an increase of response times was observed relative to an NE prime at durations of 100 and 150 ms. This inhibitory effect can hardly be accounted for by the hypothesis of response priming because, as mentioned earlier, response times with DI primes showed no evidence for such an effect. Clearly, the reason why SIM primes did not result in a reduction of response times is because their identity was different from that of the target. This lack of facilitation from SIM primes had been predicted (see introduction) from the hypothesis that response selection in absolute letter identification rests on the contrast between the activation of the target representation and that of other, competing representations. As well, the possibility of longer response times with SIM primes than with DI or NE primes had been considered. It appears that the reason for this inhibitory effect of SIM primes is the structural overlap between the prime and the target because DI primes, which differ from the target both in shape and in name, did not result in such an effect. One account for this result is based on the hypotheses that participants actually derive a signal-to-noise ratio of the activations of letter units to perform the absolute identification (i.e., naming) task and that the activation function of letter identities is somewhat noisy. That is, a letter stimulus will tend to activate not only its own representation but also, to a lesser degree, those of letters that are physically similar to it.

Consider for instance what may occur during a trial in which a SIM prime is used. In this case, the letter unit activated by the prime differs from that corresponding to the target. Presumably, a notable degree of activation of the prime's unit is gathered while this stimulus is presented. Given the hypothesis that the activation of letter representations is more or less noisy, what may happen at target onset is that some proportion of the activation that results from exposure to the target leaks to the representation that corresponds to the SIM prime, and thus maintains a higher activation level than if the prime had been visually different from the target. If this were the case, the level of background noise against which the activation of the target representation is assessed would be greater with a SIM prime than with a DI prime. Provided that reaching a sufficient signal-to-noise ratio is the basis for absolute identification of the target and therefore for its naming, this increased background noise should result in an increase in the time required to respond to the target. Congruent with this interpretation as to the increase of background noise with SIM primes, the error rate data has shown a substantial number of erroneous responses in this condition. Of course, these errors may partially be attributed to a response priming effect similar to that observed on error rates in the DI condition. However, there is no reason to believe that a response priming effect on error rates should be larger with SIM than with DI primes. Still, errors were much more frequent in the former condition (see Figure 6). A difference in the amount of background noise activity produced by these two kinds of primes appears as a likely explanation for the increased error rates with SIM primes.

Experiment 3

The two previous experiments have provided evidence for distinct response selection mechanisms in letter classification and absolute identification tasks. Thus, as anticipated from the task analysis presented in the introduction, the effect of SIM primes differed markedly between the two tasks. However, the observations presented thus far have left the issue of the origin of abstract letter identity (NI) priming in the letter naming task—and of its absence in the alphabetic decision task—partially unresolved.

On the one hand, although the hypothesis of a distinction between letter-token and letter-type representations appeared better suited to account for the available data, the difficulties pointed out for the generation hypothesis may not be unsurmountable because they only seem to concern the mandatory aspect of the assumed generation process. It is not clear what sort of priming condition could be used in the context of a letter naming task in which each theory would provide unambiguously distinct predictions (see also Boles, 1992, on this question). However, there exists one condition for which the generation hypothesis clearly predicts an inhibitory priming effect, whereas this prediction is not as straightforward for the letter-type hypothesis. This condition is one in which the opposite-case version of the prime displayed is visually similar to the subsequent target (e.g., prime = e; target = F). This condition is called *generation–similar* (*GEN–SIM*), that is, the opposite-case letter-shape representation, which may be generated from the prime is physically similar to the target. Under the generation hypothesis, the effect of GEN–SIM primes in a letter naming task should be the same as that of SIM primes (i.e., inhibitory). In fact, possibly the strongest support for the hypothesis of opposite-case generation originates precisely from the use of such a GEN–SIM condition in a task in which opposite-case letter pairs were matched on their name identity. Thus, it has been shown (Boles & Eveland, 1983) that responding that the letters *e* and *F* were nominally different took longer than the same response to the letters *a* and *F*. Boles and Eveland (1983) proposed that this kind of interference from GEN–SIM pairs would result from the generation, in the case of the e–F pair, of the uppercase E, which is visually similar to F. In comparison, the generated uppercase A with the a–F pair is visually different from F. Although Boles (1992) indicated that the letter-type hypothesis can also explain the interference effect of GEN–SIM letter pairs in name matching, the account appears more convoluted. In Experiment 3, where we again used the letter naming task, GEN–SIM primes were studied. The lack of inhibition from these primes would constitute a strong argument against the generation hypothesis. Conversely, it seems that the occurrence of an inhibitory effect in this condition is somewhat challenging for a letter-type theory because it does not involve any specific mechanism that can be directly responsible for such a result.

On the other hand, one important point that should be noted is that our explanation of NI priming in Experiment 2 has implicitly assumed that phonological representations of letter names were not involved in the abstract priming effect observed, although we recognized that such a representation system is ultimately required to produce the letter naming response. The assumption that phonological representations of letter names do not contribute to NI priming in the letter naming task needs to be verified, however. A new condition in Experiment 3 is one in which the name of a letter prime is phonologically similar (PHON–SIM) to that of the target. If phonological priming is responsible for the facilitatory effect of NI primes, PHON–SIM primes should have a significant effect on performance. Conversely, if no effect of PHON–SIM primes is observed, it would imply that the derivation of a phonological code does not contribute to priming.

Method

Participants. Five participants with prior experience in reading experiments were tested. Their ages ranged between 20 and 29 years, and all were right-handed.

Stimuli and materials. Materials were the same as those used in Experiment 2. The set of stimuli from which primes and targets were selected was also the same as in the previous experiment, except that, in addition, the lowercase letters *f, c, t, o, p,* and *i* could serve as primes. The masking stimulus used in the previous experiments served again in Experiment 3. All stimuli were presented at the center of the display screen.

Procedure. The NI, DI, and NE priming conditions used in Experiment 2 served again in Experiment 3. The prime–target pairs in these conditions were the same as in the previous experiment, with the exception of two pairs in the DI condition. In the previous experiments, the DI condition included the N–O and S–F prime–target pairs. We realized however that the letter names S and F were phonologically similar (see below). Therefore, in

Experiment 3, the N–O and S–F pairs were replaced by S–O and N–F in the DI condition. The GEN/SIM condition was made up of the following prime–target pairs: g–C, f–E, e–F, c–G, t–I, q–O, r–P, o–Q, p–R, and i–T. According to the letter similarity matrix published by Boles and Clifford (1989), the veridical similarity of the prime-target pairs in the GEN–SIM condition was somewhat lower than in the DI condition (average similarity values of 215 and 230, respectively). However, relative to the target, the similarity of the opposite-case letter that could be generated from the prime in the GEN–SIM condition was notably higher than the veridical similarity of the prime–target pairs in the DI condition (average similarity values of 348 and 230, respectively; Boles & Clifford, 1989). The other new priming condition used in Experiment 3 was one in which the names of the prime and target letters differed on only one phonological feature (Chomsky & Halle, 1968; PHON–SIM condition). Four such pairs were found; they were P–B, T–D, S–F, and N–M. In the PHON–SIM condition, any of these letters could serve as the prime while the letter phonologically similar to it served as the target. The course of a trial was identical to that of Experiment 2.

The experimental design included 20 conditions, with the effect of five prime categories (NI, DI, GEN–SIM, PHON–SIM, and NE) tested at four different prime durations (50, 100, 150, and 200 ms). The experiment was run in four separate blocks of 200 trials each. In each block, 10 trials were run for each Prime × Duration combination. Participants were instructed to name the target as rapidly as possible while avoiding errors. The main dependent variable was response time. The voice-key used to register responses failed to trigger on 1.0% of the trials. These trials were not included in the data analyses.

Results

The average correct response times and error rates observed in Experiment 3 are shown in Figures 7 and 8, respectively. The correlation between average response times and error rates across conditions was nonsignificant and positive, which indicated the absence of a speed–accuracy trade-off.

In summary, the main results of Experiment 3 indicated that DI primes led to response times that either did not differ from those with an NE prime or were shorter. Facilitation of response times was observed with NI primes, but PHON–SIM primes showed no effect on performance. Finally, relative to an NE prime, GEN–SIM primes did not result in any significant inhibitory effect. However, response times tended to be longer with GEN–SIM than with DI primes. Details of the data analyses are reported below.

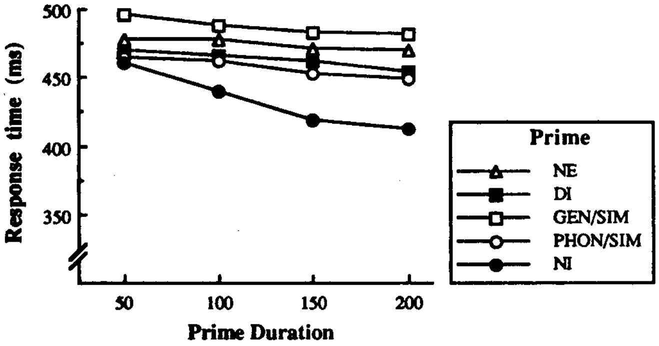

Figure 7. Average correct response times in letter naming in Experiment 3. NE = neutral; DI = different; GEN/SIM = generation–similar; PHON/SIM = phonologically similar; NI = nominally identical. Prime duration is expressed in milliseconds.

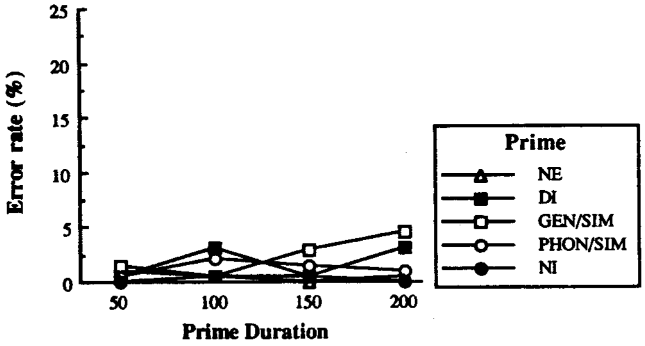

Figure 8. Average error rates in letter naming in Experiment 3. NE = neutral; DI = different; GEN/SIM = generation–similar; PHON/SIM = phonologically similar; NI = nominally identical. Prime duration is expressed in milliseconds.

The two-factor ANOVA applied on the correct response times of Experiment 3 showed main effects of prime category, $F(4, 16) = 10.4$, $p < .001$, and prime duration, $F(3, 12) = 11.8$, $p < .001$, and an interaction of those factors, $F(12, 48) = 4.3$, $p < .001$. The main effect of duration indicated a reduction of response times with increases in the duration of the prime. Simple effects of the interaction indicated significant priming effects at each duration: 50 ms, $F(4, 16) = 5.8$, $p < .005$; 100 ms, $F(4, 16) = 8.5$, $p < .001$; 150 ms, $F(4, 16) = 10.6$, $p < .001$; 200 ms, $F(4, 16) = 10.2$, $p < .001$. Decomposition of these simple effects into pairwise comparisons proceeded in the same way as for the data analyses of Experiment 2.

No evidence for response priming was seen on response times in Experiment 3. Relative to an NE prime, response times with DI primes had no effect at prime durations of 50 ms, $t(4) = 1.6$, *ns,* and 150 ms, $t(4) = 1.9$, *ns,* and resulted in facilitation at prime durations of 100 ms, $t(4) = 2.3$, $p < .05$, and 200 ms, $t(4) = 5.7$, $p < .005$. As indicated previously, response priming in letter naming would have required longer response times with DI than with NE primes. Again, as in the previous experiment, NI primes led to shorter response times than an NE prime at all durations: 50 ms, $t(4) = 2.6$, $p < .05$; 100 ms, $t(4) = 4.2$, $p < .01$; 150 ms, $t(4) = 6.2$, $p < .005$; 200 ms, $t(4) = 6.6$, $p < .005$. In contrast, the phonological similarity of the prime with the target had no effect on performance. Thus, at all prime durations, no significant difference was observed between the response times with PHON–SIM and NE primes: 50 ms, $t(4) = 1.4$, *ns;* 100 ms, $t(4) = 1.8$, *ns;* 150 ms, $t(4) = 1.6$, *ns;* 200 ms, $t(4) = 1.7$, *ns.* Relative to an NE prime, no significant inhibition was observed with GEN–SIM primes: 50 ms, $t(4) = 2.1$, *ns;* 100 ms, $t(4) = 1.6$, *ns;* 150 ms, $t(4) = 1.4$, *ns;* 200 ms, $t(4) = 1.1$, *ns.* It should be pointed out, however, that response times were longer with GEN–SIM than with DI primes at durations of 50, 150, and 200 ms: 50

ms, $t(4) = 3.1, p < .05$; 150 ms, $t(4) = 2.3, p < .05$; 200 ms, $t(4) = 2.8, p < .05$. The difference did not reach significance at a prime duration of 100 ms, $t(4) = 2.0$.

An ANOVA applied on the error rates only indicated a main effect of prime, $F(4, 16) = 3.8, p < .05$, with no effect of duration, $F(3, 12) = 1.9$, *ns*, and no interaction, $F(12, 48) = 1.9$, *ns*. Pairwise comparisons following the same scheme as with the response times data only revealed a smaller error rate with NI than with DI primes, $t(4) = 2.9, p < .05$. All other differences, including that between the DI and NE conditions that refers to response priming, failed to reach significance.

Discussion

The results of Experiment 3 replicated the facilitatory effect of NI primes observed in the previous experiment. The priming of a phonological representation that corresponds to the target cannot be a basis to account for this effect of NI primes. Indeed, the failure of PHON/SIM primes to significantly affect performance in Experiment 3 indicates that phonological representations are not involved in the priming effects observed in the letter naming task. In additional support for this conclusion, the lack of impact of phonological priming was replicated in a separate experiment, not reported here, where phonological similarity was operationally defined by the acoustic confusability of prime-target pairs as measured by Conrad's (1964) empirical confusion matrix. It can therefore be concluded that the facilitatory effect of NI primes truly results from an abstraction process designed to recover the identity of letter stimuli in a way that disregards information about letter shape.

GEN–SIM primes failed to produce a significant increase of response times relative to an NE prime. The hypothesis according to which abstraction in letter recognition is achieved by the generation of the different visual forms under which a given letter identity can be depicted clearly predicted inhibition from GEN–SIM primes. It may therefore appear that the lack of GEN–SIM inhibition in Experiment 3 is severely damaging to the generation hypothesis. We point out, however, that although no significant difference is present, response times with GEN–SIM primes are slightly longer than with an NE prime at all prime durations (see Figure 7). In addition, to be able to firmly conclude that GEN–SIM primes have no effect on performance, the response times in this condition should not differ from those observed with unrelated prime–target pairs (i.e., DI primes). This last point is not verified because, as noted in the preceding section, response times are significantly longer with GEN–SIM than with DI primes at durations of 50, 150, and 200 ms. The tentative conclusion that can be proposed then is that GEN–SIM primes may actually result in the same kind of inhibitory effect as the SIM primes used in Experiment 2, but that this inhibition is markedly weaker and therefore less evident. Our test of GEN–SIM primes therefore failed to distinguish between the generation and letter-type hypotheses. Although the former requires an inhibitory effect of the GEN–SIM condition in a naming task, the latter can also account for the weak effect observed here, as shown below (see also Boles, 1992).

Simulation of the Empirical Data

To provide formal support for our account for the priming effects in the alphabetic decision and naming tasks, we conducted simulations that used a connectionist network. One main purpose was to examine our proposals about the different response selection mechanisms involved in classification and absolute identification tasks. The other was to determine whether the presence or absence of a letter-shape abstraction procedure can account for the difference between the two tasks on the occurrence of name identity (NI) priming. The aim of the connectionist simulations, therefore, was to show that the hypotheses proposed to account for our results can actually reproduce the qualitative features of the priming effects observed in alphabetic decision and letter naming when implemented in a mechanistic system.

The hypotheses presented above about response selection and abstraction in letter processing are general and should not be especially tied to a specific architecture for the letter recognition system. The essential requirements for the present tests about the architecture of a letter recognition network are as follows:

1. Abstraction in letter recognition occurs—either via letter types or generation. It is not mandatory however, in the sense that access to letter representations is possible without the explicit encoding of the orthographic equivalence of letters with the same name but different shapes. These assumptions seem required by the presence of NI priming in letter naming and its absence in alphabetic decision.
2. Separate response selection mechanisms are available for classification and absolute identification tasks. As stated previously, it is assumed that a positive (i.e., letter) response in alphabetic decision is triggered by the presence of a sufficient level of activation within a set of representations specific to the positive stimulus set (i.e., letters). By contrast, it was proposed that an absolute identification response (i.e., naming) is triggered by a sufficient signal from a particular letter representation over the background noise created by the activation of competing units.
3. The activation that results from exposure to a particular letter within the letter recognition network can leak to letter representations that are physically similar to the stimulus actually presented. This assumption is not directly related to questions about how abstraction occurs in letter recognition or about how response selection is performed. It nevertheless appears necessary in light of the facilitatory effect of SIM primes reported by Jacobs and Grainger (1991) in alphabetic decision and the inhibition produced by these primes in letter naming (Experiment 2).

It appears that the empirical observations reported here have no additional implications about the organization of the letter recognition system beyond these three points. In other words, provided the three hypotheses that appear critical to explain our letter priming data are implemented, other aspects of the particular connectionist network used should be secondary. The present text focuses on the critical aspects of the network used. Further details and technical aspects of the simulations are reported in the Appendix.

The particular architecture chosen for the present simulations was based on the letter-type hypothesis. The network[3] was made of three separate levels of representation, which are presented here in the same order as the processing sequence in the network:

1. The feature level (30 units), through which inputs were presented to the model.
2. The letter-token level (52 units), which represented specific instances of letter shapes and where the lowercase and uppercase versions of a particular letter were encoded separately.
3. The letter-type level (26 units), which served for the abstract representation of orthographic identities in a way that was independent of letter-shape.

Separate simulations were conducted where the activation of letter tokens or that of letter types served as a basis for responses. Note that no phonological representations of letter names are implemented in this network and therefore that it cannot serve as a model of speech production. Connections existed only between consecutive levels and were feedforward only. An attempt was made to implement a network based on the generation hypothesis as the source of abstraction in letter recognition. In spite of the apparent simplicity of the generation hypothesis, difficulties (described in the Appendix) were encountered in designing its implementation. Potential solutions to these difficulties were either impractical, difficult to justify theoretically, or made the network indistinguishable from one implementing a letter-type model. No data is therefore presented from simulations using a generation network.

To the connectionist network used, a response-selection module was added. For the alphabetic decision task, the function of the response module was to establish whether a letter response should be emitted. Essentially, over time cycles, the module accumulated strength for a letter response from the activation of the most active unit among the set of letter representations constituting a given level of representation (letter tokens or letter types), without regard to the particular identity to which the unit corresponded. This integration procedure takes into account the activation history of letter representations and is global, or holistic, because the response module makes no explicit encoding of the specific unit from which the strength of a letter response is gathered. A letter response was emitted once its accumulated strength exceeded a fixed criterion. For the absolute identification task, the function of the response module was to establish which of the letter units should serve as a basis for the response. Over time cycles, it integrated separately the activation of each of the individual letter units it monitored (letter tokens or letter types). On each time cycle, it established the ratio of the integrated activation of the most active unit over the summed activation of all the units constituting the particular level of representation monitored. The version of the signal-to-noise statistic used is largely inspired from the choice model of Luce (1959, 1977) and has been previously used by McClelland and Rumelhart (1981). Once the signal-to-noise ratio exceeded a fixed criterion, an identification response was produced, which corresponded to the most active letter unit.

The priming conditions tested for both the alphabetic decision and letter naming simulations included the following prime–target relationships: physically identical (PI), nominally identical but physically different (NI), physically similar but nominally different (SIM), both nominally and physically different (DI), and neutral (NE; a blank stimulus). In addition to those conditions, primes that were nominally and physically different from the target, but where the opposite-case version of the prime was visually similar to the target (GEN–SIM; e.g., d–B) were tested in the letter naming simulations. A fixed set of six uppercase letters served as targets in each condition.

Inasmuch as the parameters used to define the operation of the network rendered it capable to complete the task, NI primes consistently resulted in a marked facilitatory effect if the level of representation monitored by the response selection module was that of letter types. This result was true whether the response module was set to perform an alphabetic decision or an absolute identification on the target. This follows from the fact that two letters with the same orthographic identity but different shapes are encoded, at the level of letter types, by the same unit. Thus, even though it is physically different from the subsequent target, an NI prime will activate the same letter-type unit as the target and therefore facilitate its processing. In contrast, the response times produced by the network with NI primes did not differ from those obtained with DI primes if the level of representation being monitored for response production was that of letter tokens. This is because whatever their nominal relationship with the target, primes that are not physically identical to the target will activate a token unit different from that of the target. These observations support our account for the lack of NI priming in the alphabetic decision experiment (Experiment 1) and for its occurrence in letter naming (Experiments 2 and 3). That is, abstraction of letter-shape information occurs in letter recognition and if the level of representation monitored for response selection is one where abstraction has taken place (here, the letter-type units), NI priming will be observed, as was the case in the letter naming experiments (Experiments 2 and 3). Conversely, letter representations can be accessed without the explicit encoding of the orthographic equivalence of letters that share the same name but are physically different. This latter set of representations is embodied here by the letter tokens. If the activation of these representations is monitored for response production, no NI priming will occur, as in the alphabetic decision task (Experiment 1).

Table 1 presents the letter priming results obtained with the alphabetic decision mechanism monitoring letter tokens and with the absolute identification mechanism monitoring letter types. Both experiments were conducted using exactly the same set of network parameters and the same set of stimuli. The prime duration in those experiments was of 12

---

[3] The program used is available on request from Martin Arguin.

Table 1
Average Response Times (in Number of Cycles) in Simulations of the Alphabetic Decision and Letter-Naming Tasks

Prime	Task	
	Alphabetic decision	Letter naming
Neutral	36.0	38.0
Different	33.0	38.0
Similar	33.0	40.7
Nominally identical	33.0	29.7
Physically identical	31.0	28.0
Generation–similar	—	39.0

Note. Both simulations were run with exactly the same network parameters. Dash indicates data not available.

processing cycles. The only effect of prime duration in the simulations was on the magnitude of priming effects, which grew with an increase of prime duration. As can be noted by comparing the results in Table 1 to those in Figures 1, 5, and 7, the main qualitative features of the empirical priming effects in alphabetic decision (Experiment 1) and letter naming (Experiments 2 and 3) were replicated by the simulations. This statement is true for a rather wide range of parameters for the weights of connections between units. The particular conditions in which network parameters have a qualitative effect on priming are noted in the following discussion.

The main feature of the alphabetic decision data (Experiment 1), which suggested that the classification of an item as being a letter was based on the nonselective (i.e., global) monitoring of the activation of a set of representations specific to letters, was that any letter prime, whatever its physical or nominal relationship with the target, resulted in facilitation relative to an NE prime. This result was replicated by the alphabetic decision response mechanism described above. Thus, facilitation relative to an NE prime was observed with any prime that is a letter. This result is because the strength of a letter response starts accumulating from the onset of a letter prime (i.e., before the onset of the target). This leads to a decrease in the time required to reach the criterion for a letter response in comparison to an NE prime, which has no effect on the state of the response selection module. In addition, by virtue of the fact that a PI prime activates the same unit as the target, additional facilitation was observed in this condition relative to DI primes. In contrast, because the alphabetic decision simulation was conducted by monitoring the activation of letter tokens for response production, no difference was found between the results in the NI and DI conditions.

The alphabetic decision results presented in Table 1 indicate no difference between the effects of SIM and of DI primes. However, facilitation from SIM primes over DI primes may occur with a slight reduction of the parameters corresponding to mask strength or to the inhibitory effect of the activation of features incompatible with a particular letter token.[4] In both cases, the effect of the parameter change was an increase in the duration with which the strength of a letter response was gathered from an SIM prime (i.e., before the activation of the target unit became higher) in comparison with that gathered from a DI prime. This variation in the effect of SIM primes following small parameter changes is congruent with the account presented in the discussion of Experiment 1 for the discrepancy between the alphabetic decision results reported by Jacobs and Grainger (1991) and those of Experiment 1. Recall that whereas Jacobs and Grainger reported shorter response times with SIM than DI primes, no such difference was observed in Experiment 1. This discrepancy was attributed to a higher duration of the mask interposed between the prime and the target in Experiment 1 (33 ms) in comparison with the mask duration used by these authors (20 ms). In the present simulations, a reduction of mask strength as small as 16% could change the effect of SIM primes from null to facilitatory. As well, we emphasize that the presence or absence of facilitation from SIM primes should not become a fundamental issue relative to our interpretation of the alphabetic decision results. Indeed, by keeping the same response selection mechanism that monitors the same level of letter representation, a facilitatory effect of SIM primes may or may not occur.

The principal feature of the letter naming results, which suggested that the absolute identification of the target is based on a signal-to-noise ratio measure, is the inhibitory effect of SIM primes. The response selection mechanism described above for the simulation of the absolute letter identification task can reproduce this effect (see Table 1). This result may be attributed to the larger degree of background noise activity against which the activation of the target unit needs to be assessed when the prime is physically similar (SIM) to the target than when it is physically different (DI). In turn, the higher degree of background noise activity with SIM primes is due to a leak of the activation produced by exposure to the target onto the unit that corresponds to the prime. The inhibitory effect of SIM primes in the letter naming simulations is less sensitive to variations in the parameters that were shown to determine the occurrence of the facilitatory effect of these primes in the simulations of the alphabetic decision task. The reason for this is that, with the alphabetic decision response module, the persistent activation of the unit that corresponds to a SIM prime following target onset stops to affect the accumulation of the strength of a letter response once the activation of another unit (i.e., target) becomes higher. In contrast, with the absolute identification module, the persistent activation of the unit activated by an SIM prime increases the level of background noise even when the activation of the target unit is higher, hence the longer response times. As can be seen in Table 1, these different properties of the response selection mechanisms used here may result, with

---

[4] This latter manipulation affects the degree to which exposure to a given letter results in an activation that leaks to representations of letters physically similar to the stimulus. The exact nature of the manipulation is to change the ratio of strengths of activatory and inhibitory connections from features to tokens. This was achieved here by a modification of the strength of the inhibitory connections.

the same network parameters, in a null effect of SIM primes in alphabetic decision and in inhibition from these primes in letter naming. As a general rule however, any manipulation of the network parameters that results in an increased effect of SIM primes in one task will also increase their effect, but in the opposite direction, in the other task.

It can be noted as well that GEN–SIM primes also resulted in an increase of response times (relative to NE primes; see Table 1), although this increase was weaker than that seen with SIM primes. These observations replicate the empirical letter naming data reported above in which the inhibition from SIM primes was significant (Experiment 2), whereas the inhibitory effect of GEN–SIM primes was less evident (Experiment 3). As with SIM primes, the increased response times with GEN–SIM primes result from an increase, relative to DI primes, in the level of background noise activity against which the activation of the target unit is assessed. Any manipulation of network parameters that leads to an increased inhibitory effect of SIM primes in the letter naming simulations will also result in increased inhibition from GEN–SIM primes. It is interesting to note that the simulation of the inhibitory effect of GEN–SIM primes was obtained here by using a network based on a letter-type model, which does not implement any operation directly aimed at producing this result.

Because the results from the letter naming simulation reported in Table 1 were obtained with the response selection module monitoring the letter-type level, facilitation was observed with NI primes. As indicated previously, this follows from the fact that the letter-type unit activated by an NI prime is the same as that on which response to the subsequent target is based. Additional facilitation was observed with PI primes. This originates from differences in the effects of PI and NI primes on the activation of token units. Thus, whereas an NI prime activates a token unit different from that activated by the target, a PI prime activates the same token unit as the target and therefore accelerates its encoding.

General Discussion

One main goal of the work reported here was to test the hypothesis that response selection processes differ between letter versus nonletter classification and absolute letter identification tasks. Following a task analysis, it was proposed that a decision as to whether a given stimulus is an alphabetic character may be based on the global monitoring of activation within a set of representations that is specific to letters. In contrast, it was supposed that absolute letter identification requires not only a high enough level of activation of letter representations but also a sufficient contrast between the strength of the target signal and the level of background noise of competing representations.

To assess these possibilities, we compared the patterns of priming effects in alphabetic decision and letter naming tasks. The results have shown several differences in priming effects as a function of task. These differences indicate a distinction between the decision mechanisms contributing to those tasks and a distinction on the occurrence of a process by which shape information is abstracted from the letter representation derived.

Shape Abstraction in Letter Recognition

The letter naming results reported in Experiments 2 and 3 have demonstrated that the letter recognition system is capable of deriving a representation of orthographic identity that disregards information about the visual shape of the stimulus. Thus, in both experiments, primes that were physically different from the target but had the same name (NI) resulted in substantial facilitation. This is, to our knowledge, the first clear demonstration of abstract letter encoding in a priming paradigm (see introduction). In addition, Experiment 3 has shown that the abstraction of shape information does not occur merely by the access to phonological representations of letter names. Indeed, names of primes that were phonologically similar to those of the targets (PHON–SIM) had no significant impact on letter naming time, thus indicating that phonological processes are not involved in the facilitatory effect of NI primes. This is congruent with previous observations from the matching paradigm, which have shown that the orthographic equivalence of letters with different shapes but the same name can be established without recourse to phonology (e.g., Boles & Eveland, 1983; Rynard & Besner, 1987).

Interestingly however, the observations from Experiment 1 suggest that access to representations about letter knowledge can occur without the abstraction of shape information (i.e., without either generation or access to letter types). Indeed, and contrary to the letter naming data, the results from the alphabetic decision experiment failed to show a clear difference between the effect of NI primes and that of primes that were both physically and nominally different from the target (DI). The discrepant effect of NI primes in alphabetic decision and letter naming can be explained in either of two ways.

According to the hypothesis that abstraction in letter recognition occurs by the internal generation of a visual image of the opposite-case version of the stimulus, the lack of NI priming in Experiment 1 needs to be explained by the assumption that opposite-case generation does not occur in alphabetic decision. The difficulty however, is that the reason why generation would occur in the context of one task and not in another remains unclear. If opposite-case generation is to be maintained as an explanation of abstraction in letter recognition, it seems that an account of why this process would be optional will need to be provided.

The challenge posed to the letter-type hypothesis by the divergent effects of NI primes in alphabetic decision and letter naming is of a different nature. According to this view, abstraction of shape information is achieved by access to letter-type representations, which encode orthographic identity without regard to letter shape. This assumption is compatible with the existence of a level of letter-token representations, which would be shape specific, and whose access would precede that to letter types. The simulations presented here were based on such a model, which embodied separate levels of representation for letter tokens and letter types. Following the letter-type account, the absence of NI priming in alphabetic decision may be explained by the assumption that the level of representation to which participants attended to perform the classification was that of letter tokens, where the lowercase and uppercase versions of a letter are encoded separately. In contrast, the occurrence of NI priming in letter naming may be explained by assuming that specification of the target identity was based on the monitoring of letter types. It may be noted that the assumption of a change in the level of representation serving as a basis for response as a function of task is congruent with the observation initially made by Posner and Mitchell (1967) that different representations—what they called the "visual code" and the "name code"—seem to underly performance with PI and NI letter pairs in name matching. What remains to be explained however, is the reason why the particular level of letter representation monitored varied as a function of task in the present experiments.

One speculation that may be considered in future research is that, for either task, what is occurring is a race between the information gathered from the token and type levels of representation and that whichever provides the solution first serves as the basis for response. If the nature of the discriminations that had to be performed in the alphabetic decision task is considered, it seems sensible that a quick distinction between letters and nonletters could be performed at the level of token representations. In addition, it can be expected that access to letter tokens would be faster than that to letter types if, as assumed in the simulations presented here, the letter recognition system is organized hierarchically, with the encoding of letter tokens serving as the access pathway to letter types. As for the letter naming task, it is clear that it involved the use of phonological codes corresponding to the letter names, even though it was shown that such codes were not directly involved in the priming effects. It is possible that letter types have privileged access to these phonological codes, by opposition to token representations. If this were so, letter naming responses would normally be based on the activation of letter types and would be sensitive to NI priming, as seen in Experiments 2 and 3.

One last important issue raised by the observation of abstraction of shape properties in the visual recognition of isolated letters concerns theories of reading. As indicated in the introduction, visual word recognition seems to operate on an abstract representation of the input, that is, a representation that is not tied to the actual shape of the stimulus (e.g., Adams, 1979; Allport, 1979; Carr et al., 1989; Evett & Humphreys, 1981; McClelland, 1976; Pollatsek et al., 1975; Segui & Grainger, 1990). A complete theory of reading needs to explain how it is that orthographic content becomes represented as separate from visual form. Initially, it was proposed that this abstraction might possibly be achieved at the stage responsible for the identification of the letters constituting words, which is widely agreed on as a precursor to orthographic lexical access (e.g., Adams, 1979; Besner et al., 1984; Coltheart et al., 1993; Johnston & McClelland, 1980; McClelland, 1976; McClelland & Rumelhart, 1981; Paap et al., 1982; Paap et al., 1984), with multiple letters being analyzed in parallel. This conjecture that the stage of letter recognition is the source of abstraction of shape information in reading finds support in observations such as that of NI priming in Experiments 2 and 3. On this view, the apparent indifference of the word recognition process to stimulus shape would be explained by an access to lexical orthographic knowledge based on the abstract orthographic identities derived by the letter recognition stage. The more general implication of this is that, beyond the stage of letter recognition, the reading system would be unconcerned by the visual properties of the stimulus. In other words, the stage of letter recognition would mark the transition between a purely visual process operating on the surface properties of the stimulus—here, shape—and a more symbolic process that operates on abstract and linguistically significant orthographic representations.

Response Selection Mechanisms

The experiments reported here have also shown that the mechanisms responsible for response selection vary as a function of the task that has to be performed.

In the alphabetic decision experiment, the results indicated that any prime that is a letter leads to faster letter responses than a neutral prime. It was proposed that this kind of response priming occurs because the response selection mechanism involved monitors the activation of letter units without regard to the particular identities that these units represent. Thus, the presentation of any letter as a prime, whatever its physical or nominal relationship with the subsequent target, biases the response selection mechanism through the activation of a letter representation. Simulations of the alphabetic decision task that used a response module whose properties were dictated by the account just presented systematically resulted in response priming effects comparable to those observed in Experiment 1.

In contrast to the alphabetic decision task, only letter primes that had the same name as the target produced substantial response time benefits relative to a neutral prime in letter naming. It was proposed that this specificity of priming in letter identification results from a response selection mechanism that is sensitive to the exact identity of the representations that are monitored. This follows from the fact that the naming task, contrary to alphabetic decision, not only requires knowledge that the target is a letter but also knowledge of what letter is presented (i.e., only one letter representation can serve as a basis for response). The results of Experiment 2 have also given indications that the response selection mechanism involved in the absolute identification of letters is sensitive to the level of background noise within the representations competing with the target for a response. Thus, when the identity of the prime was distinct from that of the target, response times and error rates were higher with primes physically similar to the target than with primes that were different. This inhibitory effect of SIM primes has been attributed to leakage of the activation produced by the target to representations of letters that are physically similar to it. This leakage was assumed to result in an increased level of background noise against which the activation of the target unit is assessed in the case of SIM primes relative to DI primes. A simulation of the letter naming task where the operation of the response module followed from the account just presented replicated the main features of the empirical data of Experiments 2 and 3. Included in this replication is the weak inhibitory effect of GEN–SIM primes (e.g., prime = d; target = B). As noted above, this effect is explained in the same manner as the inhibition resulting from SIM primes. That is, the level of background noise against which the activation of the target is assessed for response production is higher with GEN–SIM primes than with DI primes.

As pointed out above, there is reason to believe that the differences in the way the activation of letter representations is monitored for response selection in the alphabetic decision and letter naming tasks follow directly from differences in the nature of the information required for a correct response. This distinction between classification and absolute identification tasks as to the kind of information required to support an accurate performance may also extend to the word processing domain.

Indeed, it may be speculated that a decision as to the lexical status of a stimulus (i.e., word vs. nonword classification) may rest on the presence of a sufficient degree of activation within a system that represents orthographic word forms. In contrast, the absolute identification of words may not only require sufficient activation of the target representation but also a sufficiently high signal-to-noise ratio. Although we know of no direct test of this hypothesis, there certainly is, in the literature on word processing, ample evidence for a difference in the processes through which lexical decision and absolute word identification tasks are executed (Andrews, 1989; Balota & Chumbley, 1984; Besner et al., 1984; Forster & Chambers, 1973; Frederiksen & Kroll, 1976; McCann et al., 1988; Monsell et al., 1989; Neely, 1991; Parkin et al., 1986; Seidenberg et al., 1984). Part of the differences reported in the literature may relate to the response selection procedures applied.

One set of data for which this distinction seems to apply originates from the study of patients with brain damage and pure alexia (see for instance Bub, Black, & Howell, 1989; Coslett & Saffran, 1989; Shallice & Saffran, 1986). These patients show a reading disorder in the absence of any other linguistic impairment. When asked to name a word, their response latencies increase in a more or less linear fashion with the number of letters in the stimulus. This suggests that reading in these patients proceeds through the sequential identification of the individual letters constituting the string. This is in sharp contrast with the word reading process in neurologically intact participants where response times are virtually independent of word length (e.g., Bub & Lewine, 1988; Schiepers, 1980).

Observations in some patients with pure alexia have shown that they are able to determine the lexical status of a letter string without being able to tell what the identity of the item was (Coslett & Saffran, 1989; Shallice & Saffran, 1986). Experiments with one such patient (D.M.) in our laboratory have replicated this dissociation, but the observations also have provided clear evidence for a difference in the processes by which lexical decision and word naming tasks are performed (Bub & Arguin, 1995). Thus, although a massive effect of the number of letters on response times was found in word naming, this effect with the same set of words was about null in lexical decisions, which were also performed much more rapidly. What this suggests is that whereas lexical decision can be performed by direct access to word representations in these patients, naming is executed through an assembly process on the basis of the serial identification of the individual letters. This dissociation seems congruent with the hypotheses presented previously as to the requirements of classification and explicit identification tasks. Thus, we suggest that the activation resulting from lexical access is sufficient for patients with pure alexia to determine whether the letter string presented is a word or not. However, for reasons having to do with the effects of brain damage, the contrast between signal and noise in lexical activation may not be sufficient to determine the identity of the item (see Arguin & Bub, 1993, for relevant evidence). This would then force these patients to revert to a letter-by-letter strategy when the absolute identification of the target is required.

This support for our speculations concerning how representation systems are monitored for response selection in classification and identification tasks in domains other than letter processing is only preliminary. Further work will be necessary to determine whether the dissociation seen in patients with pure alexia extends to the processes involved in lexical decision and absolute word identification in neurologically intact individuals.

Conclusions

To summarize, the observations reported here have shown marked differences in the patterns of priming effects as a function of the task participants had to perform on a subsequent letter target. One important difference indicates that the way the activation of letter representations is monitored for response selection varies with task. Thus, letter and nonletter classification can be performed by the global, or nonselective monitoring of activation levels within a set of representations that is specific to the positive stimulus set (i.e., letters). In contrast, the absolute identification of letters appears to require a sufficient signal-to-noise ratio in the activation of letter representations. The other notable difference between alphabetic decision and letter naming tasks is in the occurrence of facilitation from NI primes. This discrepancy was interpreted as an indication that the letter recognition system is capable of deriving an abstract orthographic code but that access to letter representations can be achieved without this abstraction process. Support for these interpretations has been provided through connectionist simulations that formalized our account of the classification and identification results.

References

Adams, M. J. (1979). Models of word recognition. *Cognitive Psychology, 11,* 133–176.

Allport, A. (1979). Word recognition in reading: A tutorial review. In P. A. Kolers, H. Bouma, & M. Wrolstad (Eds.), *Processing of visible language* (vol. 1, pp. 227–257). New York: Plenum Press.

Andrews, S. (1989). Frequency and neighborhood effects on lexical access: Activation or search? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15,* 802–814.

Arguin, M., & Bub, D. (1993). Single-character processing in a case of pure alexia. *Neuropsychologia, 31,* 435–458.

Ashby, F. G., & Gott, R. E. (1988). Decision rules in the perception and categorization of multidimensional stimuli. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 14,* 33–53.

Ashby, F. G., & Lee, W. W. (1991). Predicting similarity and categorization from identification. *Journal of Experimental Psychology: General, 120,* 150–172.

Balota, D. A., & Chumbley, J. I. (1984). Are lexical decisions a good measure of lexical access? The role of word frequency in the neglected decision stage. *Journal of Experimental Psychology: Human Perception and Performance, 10,* 340–357.

Balota, D. A., & Chumbley, J. I. (1985). The locus of word-frequency effects in the pronunciation task: Lexical access and/or production? *Journal of Memory and Language, 24,* 89–106.

Besner, D., Coltheart, M., & Davelaar, E. (1984). Basic processes in reading: Computation of abstract letter identities. *Canadian Journal of Psychology, 38,* 126–134.

Besner, D., Davelaar, E., Alcott, D., & Parry, P. (1984). Wholistic reading of alphabetic print: Evidence from the FDM and the FBI. In L. Henderson (Ed.), *Orthographies and reading* (pp. 121–135). Hillsdale, NJ: Erlbaum.

Boles, D. B. (1986). Confusion and visual field effects in rhyme and name letter matching. *Perception and Psychophysics, 39,* 123–128.

Boles, D. B. (1992). Fast visual generation: Its nature and chronometrics. *Perception and Psychophysics, 51,* 239–246.

Boles, D. B., & Clifford, J. E. (1989). An upper- and lowercase alphabetic similarity matrix, with derived generation similarity values. *Behavior Research Methods, Instruments, and Computers, 21,* 579–586.

Boles, D. B., & Eveland, D. C. (1983). Visual and phonetic codes and the process of generation in letter matching. *Journal of Experimental Psychology: Human Perception and Performance, 9,* 657–674.

Boles, D. B., & Hellige, J. B. (1984). Case effects in letter-name matching: A partial replication. *Bulletin of the Psychonomic Society, 22,* 23–25.

Bub, D. N., & Arguin, M. (1995). Visual word activation in pure alexia. *Brain and Language, 49,* 77–103.

Bub, D. N., Black, S., & Howell, J. (1989). Word recognition and orthographic context effects in a letter-by-letter reader. *Brain and Language, 36,* 357–376.

Bub, D. N., & Lewine, J. (1988). The nature of half-field processing for words as a function of hemispheric specialization. *Brain and Language, 14,* 16–53.

Carr, T. H., Brown, J. S., & Charalambous, A. (1989). Repetition and reading: Perceptual encoding mechanisms are very abstract but not very interactive. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15,* 763–778.

Carr, T. H., Brown, T. L., Vavrus, L. G., & Evans, M. A. (1990). Cognitive skill maps and cognitive skill profiles: Componential analysis of individual differences in children's reading efficiency. In T. H. Carr & B. A. Levy (Eds.), *Reading and its development: Component skills approaches* (pp. 1–55). New York: Academic.

Carr, T. H., Pollatsek, A., & Posner, M. I. (1981). What does the visual system know about words? *Perception and Psychophysics, 29,* 182–190.

Carrasco, M., Kinchla, R. A., & Figueroa, J. G. (1988). Visual letter-matching and the time course of visual and acoustic codes. *Acta Psychologica, 69,* 1–17.

Chomsky, N., & Halle, M. (1968). *The sound patterns of english.* New York: Harper & Row.

Coltheart, M. (1981). Disorders of reading and their implications for models of normal reading. *Visible Language, 15,* 245–286.

Coltheart, M., Curtis, B., Atkins, P., & Haller, M. (1993). Models of reading aloud: Dual-route and parallel-distributed processing approaches. *Psychological Review, 100,* 589–608.

Conrad, R. (1964). Acoustic confusions in immediate memory. *British Journal of Psychology, 55,* 75–84.

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

Eichelman, W. H. (1970). Stimulus and response repetition effects for naming letters at two response-stimulus intervals. *Perception and Psychophysics, 7,* 94–96.

Eriksen, C. W., & Schultz, D. W. (1979). Information processing in visual search: A continuous flow conception and experimental results. *Perception and Psychophysics, 25,* 249–263.

Evett, L. J., & Humphreys, G. W. (1981). The use of abstract graphemic information in lexical access. *Quarterly Journal of Experimental Psychology, 33,* 325–350.

Forster, K. I., & Chambers, S. M. (1973). Lexical access and naming time. *Journal of Verbal Learning and Verbal Behavior, 12,* 627–635.

Frederiksen, J. R., & Kroll, J. F. (1976). Spelling and sound: Approaches to the internal lexicon. *Journal of Experimental Psychology: Human Perception and Performance, 2,* 361–379.

Grainger, J., & Jacobs, A. M. (1991). Masked constituent letter priming in an alphabetic decision task. *European Journal of Cognitive Psychology, 3,* 413–434.

Jacobs, A., & Grainger, J. (1991). Automatic letter priming in an alphabetic decision task. *Perception and Psychophysics, 49,* 43–52.

Johnston, J. C., & McClelland, J. L. (1980). Experimental tests of a hierarchical model of word identification. *Journal of Verbal Learning and Verbal Behavior, 19,* 503–524.

Kellicutt, M. H., Parks, T. E., Kroll, N. E. A., & Salzberg, P. M. (1973). Visual memory as indicated by latency of recognition for normal and reversed letters. *Journal of Experimental Psychology, 97,* 387–390.

Kroll, N. E. A., & Parks, T. E. (1978). Interference with short-term visual memory produced by concurrent central processing. *Journal of Experimental Psychology: Human Learning and Memory, 4,* 111–120.

Luce, R. D. (1959). *Individual choice behavior.* New York: Wiley.

Luce, R. D. (1977). The choice axiom after twenty years. *Journal of Mathematical Psychology, 15,* 215–233.

McCann, R. S., Besner, D., & Davelaar, E. (1988). Word recognition and identification: Do word-frequency effects reflect lexical access? *Journal of Experimental Psychology: Human Perception and Performance, 14,* 693–706.

McClelland, J. L. (1976). Preliminary letter identification in the perception of words and nonwords. *Journal of Experimental Psychology: Human Perception and Performance, 2,* 80–91.

McClelland, J. L., & Rumelhart, D. E. (1981). An interactive activation model of context effects in letter perception. Part 1: An account of basic findings. *Psychological Review, 88,* 375–407.

Monsell, S., Doyle, M. C., & Haggard, P. N. (1989). Effects of frequency on visual word recognition tasks: Where are they? *Journal of Experimental Psychology: General, 118,* 43–71.

Mozer, M. C. (1989). Types and tokens in visual letter perception. *Journal of Experimental Psychology: Human Perception and Performance, 15,* 287–303.

Neely, J. H. (1991). On the influence of response uncertainty and task structure on retrieval from lexical memory. In G. R. Lockhead & J. R. Pomerantz (Eds.), *The perception of structure* (pp. 279–293). Washington, DC: American Psychological Association.

Nosofsky, R. M. (1986). Attention, similarity, and the identification-categorization relationship. *Journal of Experimental Psychology: General, 115,* 39–57.

Paap, K. R., Newsome, S. L., & Noel, R. W. (1984). Word shape's in poor shape for the race to the lexicon. *Journal of Experimental Psychology: Human Perception and Performance, 10,* 413–428.

Paap, K. R., Newsome, S. L., McDonald, J. E., & Schvaneveldt, R. (1982). An activation-verification model for letter and word recognition: The word-superiority effect. *Psychological Review, 89,* 573–594.

Parkin, A. J., McMullen, M., & Graystone, D. (1986). Spelling-to-sound regularity affects pronunciation latency but not lexical decision. *Psychological Research, 48,* 87–92.

Parks, T. E., & Kroll, N. E. A. (1975). Enduring visual memory despite forced verbal rehearsal. *Journal of Experimental Psychology: Human Learning and Memory, 1,* 648–654.

Pollatsek, A., & Rayner, K. (1989). Reading. In M. I. Posner (Ed.), *Foundations of cognitive science* (pp. 401–436). Cambridge, MA: MIT Press.

Pollatsek, A., Well, A. D., & Schindler, R. M. (1975). Familiarity affects visual processing of words. *Journal of Experimental Psychology: Human Perception and Performance, 1,* 328–338.

Posner, M. I. (1978). *Chronometric explorations of mind.* Hillsdale, NJ: Erlbaum.

Posner, M. I., Boies, S. J., Eichelman, W. H., & Taylor, R. L. (1969). Retention of visual and name codes of single letters. *Journal of Experimental Psychology, 79,* 1–16.

Posner, M. I., & Mitchell, R. F. (1967). Chronometric analysis of classification. *Psychological Review, 74,* 391–409.

Proctor, R. W. (1981). A unified theory for matching-task phenomena. *Psychological Review, 88,* 291–326.

Rynard, D., & Besner, D. (1987). Basic processes in reading: On the development of cross-case letter matching without reference to phonology. *Bulletin of the Psychonomic Society, 25,* 361–363.

Schiepers, C. (1980). Response latency and accuracy in visual word recognition. *Perception and Psychophysics, 27,* 71–81.

Segui, J., & Grainger, J. (1990). Priming word recognition with orthographic neighbors: Effects of relative prime-target frequency. *Journal of Experimental Psychology: Human Perception and Performance, 16,* 65–76.

Seidenberg, M. S., Waters, G. S., Barnes, M. A., & Tanenhaus, M. K. (1984). When does irregular spelling or pronunciation influence word recognition? *Journal of Verbal Learning and Verbal Behavior, 23,* 383–404.

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

Taylor, D. A. (1977). Time course of context effects. *Journal of Experimental Psychology: General, 106,* 404–426.

Walker, P. (1978). Short-term visual memory: The importance of the spatial and temporal separation of successive stimuli. *Quarterly Journal of Experimental Psychology, 30,* 665–679.

Weisgerber, S. A., & Johnson, P. J. (1989). Effect of familiarity and category contrast on stimulus and response priming. *Perception and Psychophysics, 46,* 592–602.

Appendix

Simulation Methods

The connectionist network used to conduct the simulations was made of three separate levels of processing. The first, to which inputs were presented, was the feature level (30 units). It included the same set of oriented line detectors as the interactive activation model (IAM) of McClelland and Rumelhart (1981). Also included were two feature units that served as size markers and allowed a discrimination of lowercase and uppercase letters with different sizes but similar shapes (e.g., c and C). All lowercase letters had size features indicating a small stimulus and uppercase letters had size features indicating a large item. The feature units projected onto representations of specific visual instances of letters (i.e., letter tokens). There were 52 letter-token units (i.e., one for each lowercase and uppercase letter of the alphabet). Letter tokens projected to letter types (26 units), which served to represent abstract letter identities. Every unit in one level projected to every unit in the subsequent level. Connections were feedforward only, as no feedback or within-level connections existed in the network. Connections between compatible units (e.g., token a to type A) were excitatory (i.e., positive weights) and connections between incompatible units (e.g., token b to type A) were inhibitory (i.e., negative weights). All excitatory connections between a pair of levels had the same value, as was also the case for inhibitory connections. The exact values of these weight parameters were set by the experimenter so that (a) the asymptotic level of activation of units corresponding to the input was sufficiently high to plausibly cause a response (0.8 or higher), and (b) the response time for the production of a response with a neutral prime was slightly shorter for an alphabetic decision based on letter tokens than for the absolute identification of the target based on the activation of letter types. This was motivated by the fact that the response times with neutral primes in alphabetic decision (Experiment 1) were somewhat shorter than those in letter naming (Experiments 2 and 3). The equations used to compute the net input received by units and the activation level of units were the same as those used in the IAM (see Equations 1–4 in McClelland & Rumelhart, 1981).

In the simulations of the alphabetic decision task, the integration of activation across time cycles for response selection was not tied to any particular unit. Rather, it was based on the activation level of the most active unit among those monitored (tokens or types) on a particular time cycle. Thus,

$$\bar{a}_{\text{letter}}(t) = (\text{i\_rate})\, a_{\text{highest}}(t) + (1 - \text{i\_\_rate})\, \bar{a}_{\text{letter}}(t-1), \tag{A1}$$

where $\bar{a}_{\text{letter}}(t)$ is the integrated activation value for a letter response at time cycle t, i_rate is the integration rate of activation, $a_{\text{highest}}(t)$ is the activation level of the most active letter unit on cycle t, and $\bar{a}_{\text{letter}}(t-1)$ is the integrated activation value for a letter response on cycle $t-1$. The strength of a letter response was given by

$$s_{\text{letter}}(t) = e^{k\bar{a}_{\text{letter}}(t)}, \qquad \text{(A2)}$$

where $s_{\text{letter}}(t)$ is the strength of a letter response, and k is the rate of growth of response strength with increases in activation. Assessment of whether a letter response should be emitted was done by

$$\frac{s_{\text{letter}}(t)}{n \cdot \mathrm{b}}, \qquad \text{(A3)}$$

where n is the number of units in the level of representation monitored, and b is a constant (value of 10 in all simulations). Once the value obtained from Equation A3 was of 0.9 or higher, a letter response was given.

In the simulations of the absolute identification (naming) task, the integration of activation across time cycles for response selection was performed on each individual unit in the level of representation monitored. Thus, integration of activations was obtained by

$$\bar{a}_i(t) = (\text{i\_\_rate})\, a_i(t) + (1\text{-i\_\_rate})\, \bar{a}_i(t-1), \qquad \text{(A4)}$$

where a_i corresponds to the activation of letter unit i. The response strength associated with a particular unit was given by

$$s_i(t) = e^{k\bar{a}_i(t)}. \qquad \text{(A5)}$$

Assessment of whether the absolute identification response could be emitted was done with

$$\frac{s_i(t)}{\sum s_j(t)}, \qquad \text{(A6)}$$

where $\Sigma s_j(t)$ is the sum of the response strengths of all the units monitored. An absolute identification response corresponding to unit i was emitted once the value obtained from Equation A6 was of 0.9 or higher. The set of operations from which absolute identification responses were obtained is the same as that used in the IAM of McClelland and Rumelhart (1981), which itself was largely inspired by Luce's (1959, 1977) choice model.

The following is a list of parameters under which the letter priming simulation results presented in Table 1 were conducted: minimum activation of any unit = 0.0; maximum activation of any unit = 1.0; rate of decay of activation = 0.01; resting activation of any unit = 0.0; integration rate of activations (i.e., i__ rate) = 0.05; rate of growth of response strength with increases in activation (i.e., k) = 10. The weight parameters under which the results presented in Table 1 were obtained are the following: activation from features to tokens = 0.005; inhibition from features to tokens = 0.1; activation from tokens to types = 0.1; inhibition from tokens to types = 0.06. Between the offset of the prime and the onset of the target, a masking stimulus was presented for a duration of two time cycles. The presentation of the mask was done by clamping a value of 0.3 (mask strength) to each of the feature (input) units.

A fixed set of six uppercase letters (A, B, D, G, Q, and R) served as targets in each priming condition (PI, NI, DI, SIM, GEN–SIM, and NE). In the PI condition, the prime was identical to the target. In the NI condition, the prime was the lowercase letter with the same name as the target (e.g., prime = a; target = A). In the DI condition, the prime shared no feature with the target. In this condition, the letter *X* was used as prime when A, B, D, or G served as the target and the letter *Y* served as the prime with the letters Q or R were the target. SIM primes were uppercase letters that shared a maximum number of features with their corresponding target (prime–target pairs = H–A, D–B, B–D, C–G, O–Q, and P–R). Primes in the GEN–SIM condition were the lowercase versions of those used in the SIM condition. The NE prime was a blank stimulus.

As indicated in the Simulation of the Empirical Data section, an attempt was made to design a connectionist network based on the cross-case generation model for abstraction in letter recognition. This model assumes only one level of representation for letter knowledge, that of letter tokens, and abstraction is achieved by the internal generation of a visual representation of the opposite-case version of a stimulus letter. The most direct way to implement these principles in a connectionist network requires a feature level of representation to present inputs to the system, and letter tokens with excitatory connections between units that correspond to the same letter identity. These excitatory connections serve as the process by which opposite-case generation is achieved. Simulations based on this architecture failed to result in abstract, name identity (NI) priming. The reason for this failure is that when a particular stimulus letter is visually different from its opposite-case version, the activation of the opposite-case token is effectively prevented by the inhibition coming from the incompatible feature units activated by the stimulus. Solution to this problem would require either feature-to-token inhibition to be null, or a second, separate set of shape-specific letter representations where the token units corresponding to the target and to its opposite-case version could be concurrently activated. Neither of these solutions appears acceptable. Indeed, setting the feature-to-token inhibition parameter to zero would result in a large degree of activation of units corresponding to letters similar to the stimulus presented. This would prevent the network from solving an absolute identification task because of the lack of differentiation between the activations of the target and competing units. In turn, some principle would need to be found to justify the implementation of a duplicate level of letter-token units. The simple fact that such a duplication would allow opposite-case generation seems a weak argument. An additional difficulty with a generation network is in simulating an absolute identification performance. Absolute identification seems to require that the activation of one of the units monitored be significantly higher than that of any other (i.e., sufficient signal-to-noise ratio; see Simulation of Empirical Data section). However, within a set of letter-shape representations in which opposite-case generation has occurred, at least two units are highly active; that corresponding to the target and that corresponding to its opposite case. Although they are both associated with the same response, that is, same phonological representation of their name, these units will compete with one another unless a special operation is implemented to indicate they are both associated with the same letter identity. It seems such a special operation would involve either letter-type units or some functional equivalent.

Received October 16, 1992
Revision received December 2, 1993
Accepted October 18, 1994 ■