

Bodies, Antibodies, and Neighborhood-Density Effects in Masked Form Priming

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Facilitatory priming effects due to similarity of orthographic form are obtained for high- N target words provided that they have low-frequency bodies and the body is shared between the prime and target (e.g., *perd*–*HERD*). Conversely, it is shown that low- N target words show priming regardless of the frequency of the body, provided that the prime and target do not share the same body (e.g., *drice*–*DRIVE*). If the body is shared, then priming occurs only for targets with low-frequency bodies. These results suggest that neighborhood density should be defined in terms of both individual letter units and subsyllabic units and that both types of density jointly determine priming.

The concept of orthographic neighborhood has come to play an increasingly important role in the study of visual word recognition (Andrews, 1989; Coltheart, Davelaar, Jonasson, & Besner, 1977; Forster and Davis, 1991; Forster, Davis, Schoknecht, & Carter, 1987; Grainger, 1990; Grainger, O'Regan, Jacobs, & Segui, 1989; P. A. Luce, 1986; McClelland & Rumelhart, 1981; Taraban & McClelland, 1987). As originally defined by Coltheart et al. (1977), a word's neighborhood consists of all the other words that can be formed from this word by changing only one letter. Thus, *trick*, *crack*, and *trace* are all neighbors of the word *track*. The number of neighbors is represented as N , so *track* is said to have an N of 3.

There are many reasons for thinking that the number of neighbors might play a crucial role in the recognition process. For example, if some kind of competitive process is involved in word recognition, then one might expect that the competition would be keenest among clusters of words that all have a high degree of resemblance to each other. Similarly, it seems clear that the difficulty of discrimination between words must increase as the number of neighbors increases. Partial support for this expectation comes from the findings of Coltheart et al. (1977), who found that nonwords that have many words as neighbors (e.g., *nace*) take longer to classify in a word-nonword classification task than nonwords that have no, or

few, neighbors (e.g., *fient*). Yet strangely, Coltheart et al. found no corresponding N effect for word targets. High- N words such as *sound* took no longer to classify than low- N words such as *month*. Grainger et al. (1989) argued that the reason for this was the failure to take relative frequency into account. Their suggestion was that neighbors only interfered when they were higher in frequency than the target word. A similar proposal has also been put forward by P. A. Luce (1986). Whatever the merits of this proposal, it is very difficult to reconcile this argument with the findings of Andrews (1989), who found a reverse effect for low-frequency words. That is, high- N words were responded to faster than were low- N words, both in a lexical decision task and in a naming task. For high-frequency words, there was no effect of N at all. The interpretation is that the presence of neighbors amplifies the total amount of activation, leading to faster responses for words and slower responses for nonwords. What these conflicting results suggest is that there may be both facilitatory and inhibitory effects arising from the existence of close neighbors. Network models such as the interactive activation model of McClelland and Rumelhart (1981) allow for such opposed effects because feedback from a large number of neighboring words at the word level to the letter level will tend to reinforce the bottom-up activation, producing facilitation, whereas competition between neighbors within the word level may lead to inhibitory effects. It is tempting to think that the discrepancies between different experiments could be explained in terms of variations in the relative strengths of these opposed effects, but until it is possible to identify the task variables that are responsible for these variations, this is essentially an empty proposal.

The concept of neighborhood size also emerges in the context of orthographic priming, that is, priming due to similarity of orthographic form. The work of Evett and Humphreys (1981) and Forster and Davis (1984) has established that when two words are presented in rapid succession, the processing of the second (the target) is facilitated by the first (the prime) if they are closely related orthographically, that is, if they are neighbors. When the task is lexical decision on the target word, this priming effect appears to be lexical in nature; if the target is a nonword, no form priming is obtained (Forster et al., 1987). However, priming can be obtained by

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using either words or nonwords as primes (Forster, 1987). The effect of the prime is extremely short-lived (less than 2 s) and appears to be the result of a merging of the processing of the two stimuli. This merging must take place at an abstract orthographic level because primes are always presented in lowercase letters, whereas targets are presented in uppercase letters. Generally, subjects are unaware of the nature of the prime, and if the duration of the prime is increased so that subjects become aware of the prime as a separate stimulus, then no form priming is obtained (Humphreys, Besner, & Quinlan, 1988). More relevant to our discussion is the fact that this masked form-priming effect is observed only when the target word has few neighbors (Forster et al., 1987). Thus, lexical decision responses to the low-*N* target word *MONTH* are faster when preceded by the prime *mouth*, but the high-*N* word *SOUND* is not facilitated by a prior masked presentation of *mound*. Indeed, there is some suggestion that it might be inhibited (Forster et al., 1987; Segui & Grainger, 1990).

If we pursue the neighborhood analogy further, we can think of words as points in a lexical space, the dimensions of which are specified in terms of orthographic features. Words that are neighbors are represented by points that are close together, and words that have no overlap at all are represented by points that are far apart. Evidently, words are not distributed evenly across this lexical space but instead tend to clump together so that some words are located in high-density regions of lexical space (i.e., they have many neighbors, and each of the neighbors has many neighbors), whereas other words are located in sparsely populated regions (i.e., they have very few or no close neighbors). Forster and Davis (1991) summarized the priming results in terms of a *neighborhood density constraint*, which proposes that facilitatory priming effects are restricted to target words that are located in low-density regions of lexical space.

We are interested in this question because we believe that the way in which neighboring words interact in a masked form-priming experiment provides information about the earliest stages of word recognition, uncontaminated by the influence of strategic factors. We assume that if one word primes its neighbor, then some process involved in the recognition of the prime must have altered some aspect of the representation of the neighbor, and this is presumably mediated by similarity of form. Clearly, the fact that neighboring words do not have mutually facilitating interactions in high-density regions provides a potential clue to the nature of the underlying processes.

Perhaps the most natural approach to this phenomenon is to suggest that in a high-density region, the prime will tend to overlap with so many words that it will activate any one of them only weakly. The assumption is that there is a limit placed on the total amount of cross-activation that a stimulus word can produce and that its neighbors must share that activation between them, producing what could be called a *diffusion effect*. In a low-density region, however, the prime has few neighbors, and these are strongly activated by the prime. However, there are several results that raise doubts about whether this is the right approach. The initial doubt was generated by the work of Veres (1986), who found that when the number of neighbors of the prime and the target were varied factorially, the neighborhood of the target, not the

prime, was proved to control priming. Indirect support for this conclusion is provided by two additional findings (Forster, 1987). First, Forster found that it was not possible to obtain priming for a high-*N* target word by ensuring that the prime has only one neighbor, namely the target (e.g., *ekin-SKIN*). This produces much the same effect as a prime that has many neighbors (e.g., *skun-SKIN*). Second, Forster found that a prime that has only one neighbor does not exert any more powerful effect on that neighbor than a prime that has two competing neighbors. This can be shown by comparing the efficacy of stimuli such as *deadline* and *seadline* as primes for the target word *HEADLINE*. The word *deadline* has only one neighbor, but the nonword *seadline* has two, yet these primes have an equally strong effect on *HEADLINE*. Other unpublished findings obtained by the first author support this conclusion. For example, priming for pairs such as *probecT-PROTECT*, in which the activation produced by the prime would be divided between the words *protect* and *project*, is just as strong as for pairs such as *protact-PROTECT*, in which the target receives the undivided activation of the prime. Thus it appears to be irrelevant whether the prime resembles just one word or several. What does matter is how many words the target resembles.

There is another reason for rejecting the diffusion explanation of density effects. This explanation requires that cross-activation is weaker in high-density environments, that is, that the stimulus *face* only weakly activates the detectors for the nonidentical words *RACE*, *LACE*, *FACT*, *FADE*, and so forth. However, it follows that the detector for *FACE* itself will also be only weakly activated by this stimulus (although more strongly than for the neighbors) because there is no way to distinguish inappropriate activation (cross-activation) from appropriate activation. This leads to the prediction that repetition priming should also be much weaker in a high-density neighborhood, but this is definitely not the case (Forster et al., 1987). It also predicts that high-*N* words should be recognized more slowly than low-*N* words, which as we have seen, is also definitely not the case.

These results eventually led to the view that the detector systems for words in high-density neighborhoods are more narrowly tuned than for words in low-density neighborhoods (Forster, 1987). A narrowly tuned detector is less likely to tolerate a mismatching letter than is a broadly tuned detector, and hence word targets with narrow tuning are less likely to be primed by a nonidentical prime. This assumption explains why it is the neighborhood of the target that apparently controls priming, not the neighborhood of the prime. However, until we can explain why and how these tolerances change, this is little more than a restatement of the facts.

An implicit assumption throughout this research has been that the input to the word recognition system is coded in terms of individual letter-position units, such as A2 (meaning A in second position), B4, and so forth. There were several reasons for making such an assumption. For example, post hoc analyses of the strength of form priming as a function of the position of the changed letter consistently failed to reveal any interesting effects, which could be taken to imply that each letter plays an equally important role in priming. More important, the very definition of neighborhood size adopted by Coltheart et al.

(1977) presupposes such a code. However, this assumption is difficult to defend, given the evidence that language units are usually hierarchically structured and given the difficulty of coding long words with this scheme. The approach adopted in the present paper is to consider other more realistic forms of coding and the implications of these coding schemes for neighborhood structure and for masked form priming.

There is considerable linguistic and psycholinguistic evidence in support of the notion that printed words are coded in terms of subsyllabic units, in particular, word bodies and onsets (Bowey, 1990; Kay & Bishop, 1987; Patterson & Morton, 1985; Rapp, 1992; Taft, 1992; Treiman & Chafetz, 1987; Treiman & Zukowski, 1988). A *word body* is the orthographic equivalent of the subsyllabic unit, rime, in the phonological representation of a word. Syllables are divided into two parts, the onset and the rime. The *onset* consists of the initial consonant or consonant cluster, whereas the *rime* consists of the vowel and the final consonants. Orthographically, the onset consists of the letters that correspond to the phonetic onset, whereas the body consists of the letters that correspond to the remainder of the syllable. Thus, the high-*N* word *face* would be coded simply as two units: the onset *f* and the body *ace*.¹

What effect might such a coding scheme have on priming? A prime such as *fage* will share only the onset *f* with the target word *face*. Because this is not a particularly distinctive feature of the target (i.e., many other words also have this feature), we might not expect to obtain any priming. On the other hand, a prime such as *nace* shares a body with the target. Whether this will produce priming may depend also on how distinctive this feature is. If many words have this property in common with the target (e.g., *race*, *lace*, *pace*, and *mace*), then again, there may be no priming. However, if the body is less common (i.e., more distinctive), then priming may be obtained.

This account offers the possibility of redescribing neighborhood effects in terms of subsyllabic units, rather than individual letter-position units. Thus, we could extend the definition of neighbor in the following way. Two words are neighbors if one can be formed from the other by changing any letter (letter neighbors) or by changing just the onset (body neighbors). Thus, words could be classified as high or low in terms of the number of letter neighbors or in terms of the number of body neighbors. These two measures will not be independent of each other. Words that have many letter neighbors, that is, high-*N* words, will tend to also have many body neighbors. This is because the majority of letter neighbors of a word beginning with a *cv* structure are typically derived from a change in the initial letter (as in *sound*, *bound*, *hound*, *mound*, *found*, *round*, *wound*, and *pound*). As a result, the body of a word is likely to be a more commonly occurring one for high-*N* words than for low-*N* words (e.g., the *ound* of *sound* is a more common body than the *onth* of *month*).

It is possible to propose a different method of classifying words, namely according to whether they contain commonly occurring bodies or rarely occurring bodies. We refer to this variable as *body frequency*, noting that it is defined in terms of type frequency rather than token frequency, that is, the number of words that contain the body, regardless of their

individual frequencies of occurrence.² Therefore, words that share a high-frequency body all belong to a neighborhood defined by the body, which will be by definition a high-density neighborhood because many words are members of the neighborhood. Words that share a low-frequency body, however, will belong to a low-density neighborhood because few words share this body. By analogy with neighborhoods defined in terms of individual letters, we might expect to find corresponding effects of body frequency on form priming. Thus, words containing a high-frequency body might not show form priming, whereas words with a low-frequency body might.

To determine whether body frequency (henceforth *BF*) is also relevant to priming, we need to find cases in which *N* and *BF* are not confounded. For example, consider the word *drive*. The body *ive* occurs in many words (e.g., *hive*, *live*, *strive*, *thrive*, *five*, *dive*, and *give*) and therefore *drive* is a high-*BF* word. Yet it has only one letter neighbor, namely *drove*, and is therefore low *N*. Conversely, the word *soap* has a unique body, and is therefore low *BF*, but has many letter neighbors (e.g., *soup*, *snap*, *swap*, *soak*, and *soar*) and is therefore high *N*. The experiments that follow make use of such words.

In each experiment, we examine form-priming effects in neighborhoods in which the density has been manipulated either in terms of letter units or in terms of subsyllabic units. In all experiments, the target word is always a monosyllable, and the prime is a monosyllabic nonword that differs from the target word by one letter. The reason for using nonwords as primes is simply that there were such narrow constraints on the types of targets that could be used that it was nearly always impossible to find a word prime with the desired properties.

Experiments 1a and 1b

The first question is whether neighborhood density effects that are independent of the effects occurring at the letter level can be demonstrated at the subsyllabic level. If body frequency determines form priming in a manner analogous to *N*, then it should be possible to observe masked form priming with high-*N* target words if those words have an unusual word body, that is, if they are low-*BF* words. For example, despite the fact that *HERD* has many letter neighbors (e.g., *held*, *head*, *heed*, *head*, *here*, and *nerd*), it may nevertheless show facilitatory priming effects when it is preceded by a masked presentation of *perd* as a result of the fact that there is only one other word that has the body *erd*, namely *nerd* (i.e., *HERD* has only one body neighbor). However, priming would not be expected for pairs such as *hord-HERD* because they share only an onset.

Experiment 1 was designed to test this hypothesis. The specific aim was to determine whether the amount of form priming in a masked priming paradigm involving the lexical decision task could be manipulated by varying *BF* while holding *N* constant at a high level. If *BF* is relevant, then we expect to observe form priming when *BF* is low rather than

¹ We adopt the term *body* rather than the term *rime* to emphasize that we are dealing with the orthographic transcription of the rime. Thus, the words *yacht* and *dot* share a rime but do not share a body.

² Thus, a body that is found in only one word is highly distinctive, no matter how often that word occurs.

high, despite the fact that *N* is high. In Experiment 1a the prime and target shared the same body, but in Experiment 1b they did not.

Method

Subjects. A total of 48 undergraduate psychology students at the University of Arizona served as subjects in Experiment 1a, and 38 different students served in Experiment 1b. All subjects received course credit for their participation.

Materials. All target words selected for Experiments 1a and 1b came from a high-density letter neighborhood (high *N*). This was defined as more than 5 words, judged by the experimenters to be in general use, that were one letter different from the target word. There were 30 such words that had a commonly occurring body (high *BF*, e.g., *jump*) and 30 that had an uncommon body (low *BF*, e.g., *herd*). High *BF* was defined as 8 or more other monosyllabic words (of general usage) that shared that body (with a mean *BF* of 14.6); low *BF* was defined as 4 or fewer such words (with a mean *BF* of 2.6). The mean *N* value for both groups was 7.0, whereas the mean word frequency (antilog of mean log frequency as gauged from an average of values provided by Carroll, Davies, & Richman, 1971; Kucera & Francis, 1967; and Thorndike & Lorge, 1944) was 11.57 for the high-*BF* words and 9.39 for the low-*BF* words.

For each of these target words, a nonword prime was constructed that differed from the target by one letter. In Experiment 1a, this letter change kept the body of the target intact by altering the onset (e.g., *sump-JUMP* and *perd-HERD*), although in Experiment 1b, the letter change disrupted the body (e.g., *julp-JUMP* and *hord-HERD*). Another set of primes was also constructed to serve as a baseline against which to measure facilitation. These primes were nonwords that shared no letters with the target word (e.g., *dete-JUMP* and *tane-HERD*). The word targets and their associated primes are listed in the Appendix.

Sixty nonword targets were also constructed to act as distractors in the lexical decision task. For one half of these nonwords, the prime was another nonword that was one letter different from the target, keeping the body intact in Experiment 1a (e.g., *teip-WEIP* and *kile-SILE*), while disrupting the body in Experiment 1b (e.g., *weim-WEIP* and *sipe-SILE*). For the other half of the nonword distractors, the prime was nonword with no letters in common with the target (e.g., *hime-SLET* and *tope-HELK*). The nonwords were variable in their *N* and *BF* values.

Two sets of materials were constructed for each experiment so that items were counterbalanced across conditions. Each target word was

Table 1
Mean Lexical-Decision Times (ms) and Error Rates for High-N Target Words and Nonwords Varying in Body Frequency (BF) as a Function of Type of Masked Prime: The Related Primes Preserved the Body of the Target (Experiment 1a)

Condition	Example	RT	Error rate (%)	Priming
High BF				
Primed	<i>feep-WEEP</i>	583	9.0	4
Control	<i>bool-WEEP</i>	587	8.3	
Low BF				
Primed	<i>perd-HERD</i>	577	12.5	37
Control	<i>lisk-HERD</i>	614	14.9	
Nonwords				
Primed	<i>feap-TEAP</i>	649	11.1	10
Control	<i>wike-TEAP</i>	659	9.7	

Note. *N* = the number of letter neighbors; RT = reaction times.

Table 2
Mean Lexical-Decision Times and Error Rates for High-N Target Words and Nonwords Varying in Body Frequency (BF) as a Function of Type of Masked Prime: The Related Primes Did Not Preserve the Body of the Target (Experiment 1b)

Condition	Example	RT (ms)	Error rate (%)	Priming
High BF				
Primed	<i>weer-WEEP</i>	609	7.6	1
Control	<i>bool-WEEP</i>	610	7.2	
Low BF				
Primed	<i>hord-HERD</i>	618	12.6	-4
Control	<i>lisk-HERD</i>	614	11.1	
Nonwords				
Primed	<i>teep-TEAP</i>	684	8.7	4
Control	<i>wike-TEAP</i>	688	8.8	

Note. *N* = the number of letter neighbors; RT = reaction times.

observed under both priming conditions in each experiment across the two sets, but no subject saw the same target word more than once.

Procedure. Each item consisted of a sequence of three stimuli. The first was a forward mask consisting of a row of six hash marks (#####). This mask was presented for 500 ms. This was immediately followed by the prime in lowercase letters exposed for a duration of 50 ms, which was in turn immediately followed by the target in uppercase letters presented for a duration of 500 ms. Each stimulus was centered in the viewing screen and was superimposed on the preceding stimulus. Items were presented on a Princeton Ultrasync color monitor controlled by an IBM-compatible 286 PC, using the DMASTR display software developed at Monash University and at the University of Arizona, which synchronizes the timing of the display with the video raster. The normal IBM bit-mapped text font was used. In this font, the descenders of the lowercase primes are not fully masked by either the hash marks or by the uppercase letters of the target. However, ascenders are fully masked.

Subjects were asked to classify the letter sequence presented in uppercase letters as a word or a nonword. No mention was made of the number of stimuli that would be presented on each trial. Subjects indicated their decisions by pressing one of two response buttons. The onset of each new trial was controlled by the subject who pressed a foot switch. After presentation of each item, subjects were given feedback about both the accuracy of their response and their reaction time (RT). Subjects were run individually in a sound-attenuated booth. Practice trials were included. Each subject received a different pseudorandom ordering of items, arranged so that practice and fatigue effects would be evenly distributed across all conditions for each subject.

Results

In this, as in all subsequent experiments, error responses were discarded from the analysis and RTs more than two standard deviation units above or below the mean for that subject in all conditions were trimmed to the appropriate cutoff value. Any subject who made more than 20% errors was replaced. As a result of a typing error, the data for one of the nonwords had to be discarded entirely. The mean lexical-decision latencies and error rates for both word and nonword targets in Experiment 1a are shown in Table 1, and the corresponding values for Experiment 1b are shown in Table 2.

The data for the word targets were analyzed in a 2 × 2 × 2 design (Group [subject or item] × *BF* [high vs. low] × Prime

Type [related vs. control]). The group variable reflects the counterbalancing procedure and was included solely to extract the variance due to counterbalancing (it is of no interest, however). Two analyses were carried out, one using the subject means as the sampling unit and the other using item means. In the subject analysis, the group variable was the only nonrepeated measures variable, whereas in the item analysis, both the group and the *BF* variables were nonrepeated measures.

Looking first at the case in which the body is intact (Table 1), we found a substantial main effect of prime type on lexical decision time: for the subject analysis, $F(1, 46) = 15.82, p < .001, MS_e = 1,242.5$, and for the item analysis, $F(1, 56) = 14.88, p < .001, MS_e = 787.95$. However, there was a significant interaction between prime type and *BF* such that the difference between the related prime condition and the control condition for low-*BF* targets was 37 ms, but for high-*BF* targets, the effect was only 4 ms: for the subject analysis, $F(1, 46) = 8.60, p < .01, MS_e = 1,475.81$, and for the item analysis, $F(1, 56) = 7.50, p < .01, MS_e = 787.95$. Separate subanalyses examining these priming effects showed that the effect for low-*BF* word targets alone was significant in both the subject analysis, $F(1, 46) = 19.15, p < .001, MS_e = 1,669.53$, and in the item analysis, $F(1, 56) = 22.20, p < .001, MS_e = 852.58$, whereas the corresponding effect for high-*BF* targets was not (both $F_s < 1$).

However, a different pattern was obtained when the prime and the target did not share the same body (Table 2), in which the largest priming effect was only 4 ms and neither effect was significant (all $F_s < 1$ in each case). None of the analyses of the error rates in either experiment showed any significant effects.

The results for the nonword targets showed a weak trend toward priming (10 ms) when the body was intact (Experiment 1a). This effect approached significance in the subject analysis, $F(1, 46) = 3.63, p = .06, MS_e = 568.13$, but not in the item analysis, $F(1, 56) = 2.33, p > .10, MS_e = 1,146.81$. When the body was changed, this effect reduced to only 4 ms, which was not significant (all $F_s < 1$).

Discussion

These results indicate clearly that facilitatory form-priming effects can be obtained with high-*N* target words, contrary to expectations based on the results reported by Forster and Davis (1991) and Forster et al. (1987). However, the conditions under which this priming occurs are fairly restricted. Significant priming was observed only in Experiment 1a for the low-*BF* condition, in which both the prime and the target word shared a relatively unusual body (e.g., *oap*, *erd*, and *onk*). When the prime did not share the body of the target (Experiment 1b), no priming was obtained. Nor was any priming obtained when the target word contained a relatively common body (e.g., *eep*, *ain*, and *atch*), regardless of whether the prime shared the body of the target. These results suggest that neighborhood density places limits on form priming not only when neighbors are defined in terms of similarity at the letter level but also when neighbors are defined at a level higher than the letter but lower than the syllable, a level that we refer to here as the *subsyllabic level*.

The fact that there was a weak trend toward priming for the nonword targets when the body was intact is interesting. Masson (1991) has reported similar weak effects for nonword targets, but only when *N* was low. This result could be interpreted as indicating that the masked form-priming effect is entirely prelexical. However, it seems that lexical factors must be involved in some way because *N* and *BF* can be defined only with reference to the distribution of actual word forms. A strictly prelexical explanation of priming (e.g., persisting activation in letter nodes or body nodes) should predict equally strong priming for both words and nonwords regardless of the lexical neighborhood. A further point is that whatever effect there is for nonword targets, it is much weaker than the effect for word targets.

The general conclusion from this experiment is that *BF* appears to work the same way as *N*. In each case, form overlap between the prime and target produces priming only when the density of neighbors is low, whether density is defined by letter neighbors or body neighbors. At the letter level, the relevant measure of form overlap is the number of shared letters, and at the subsyllabic level, it is the number of shared subsyllabic units.

The next question to consider is whether *N* and *BF* each exert an independent effect on priming or whether *BF* in fact controls priming alone. The next two experiments address this question by determining the pattern of results when low-*N* target words are used instead of high-*N* target words. If form priming is controlled solely by *BF*, then we should not expect to find any form priming for low-*N* targets when *BF* is high.

Experiments 2a and 2b

These experiments included the same conditions as Experiments 1a and 1b, except that all the word targets were low-*N* words, that is, they had few letter neighbors. If it is *BF* alone that controls priming (i.e., *N* is irrelevant), then the results of Experiment 2 should match those of Experiment 1. In particular, the masked form priming that has been typically observed with low-*N* targets (Forster, 1987; Forster et al., 1987) should be eliminated when the low-*N* target word has many body neighbors. Thus, response times to the low-*N* target word *DRIVE* should not be facilitated by the prime *frive* because *ive* is a relatively common body (i.e., *drive* is high *BF*).³ However, the low-*N* target word *FRESH* should be facilitated by the prime *presh* because the body *esh* is contained in very few words (i.e., *fresh* is low *BF*). As in Experiment 1, this hypothesis was tested for the case in which the prime and the target have the same body (Experiment 2a) and for the case in which the prime and the target do not share a body (Experiment 2b). No priming at all would be expected for items in the latter conditions (e.g., *fresh-FRESH* and *drice-DRIVE*).

However, if *N* exerts its own independent effect on priming, then priming should be observed in all conditions because all

³ The target words in this condition necessarily have either a consonant cluster or a digraph as onset. If the onset consisted of a single letter, then the word would automatically become high *N* because all body neighbors would also be letter neighbors.

targets are low *N* and the related primes never differ from the targets by more than one letter.

Method

Subjects. A total of 60 undergraduate students enrolled at the University of New South Wales served as subjects, one half in Experiment 2a and one half in Experiment 2b.

Materials. All target words came from a low-density letter neighborhood (low *N*) defined in terms of there being no more than 2 words (of general usage) that were one letter different from the target word. There were 42 such words that had a commonly occurring body (high *BF*, e.g., *DRIVE*) and 42 that had an uncommon body (low *BF*, e.g., *FRESH*). High *BF* was defined in terms of there being 8 or more other words (of general usage) that shared that body, as was the case in Experiments 1a and 1b, whereas low *BF* was defined in terms of there being 3 or fewer other words. The mean *BF* values were 12.2 for the high-*BF* words and 1.8 for the low-*BF* words. The mean *N* value was 1.2 for both groups, whereas the mean word frequency (antilog of mean log frequency as gauged by Carroll, Davies, & Richman, 1971; Kucera & Francis, 1967; and Thorndike & Lorge, 1944) was 17.81 for the high-*BF* words and 17.52 for the low-*BF* words.

In Experiment 2a, the prime and the target shared the same body (e.g., *frive-DRIVE* and *presh-FRESH*), whereas in Experiment 2b, the letter change disrupted the body (e.g., *drice-DRIVE* and *frest-FRESH*). The baseline condition was provided by nonword primes that shared no letters at all with the target word (e.g., *flack-DRIVE* and *plont-FRESH*).

A set of 60 nonword targets was also designed to act as distractors. These were all low *N*. One half of these targets were preceded by a nonword prime that had no letters in common with the target (e.g., *slint-GROCK* and *soll-RYVE*). The other half were preceded by a nonword that was one letter different from the target, keeping the body intact in Experiment 2a (e.g., *prend-PLEND* and *laib-JAIB*), while disrupting the body in Experiment 2b (e.g., *plent-PLEND* and *jaid-JAIB*). The *BF* values for the nonword distractor targets were variable, with one half of them being zero. The word targets and their associated primes are listed in the Appendix.

As in the previous experiment, two sets of counterbalanced materials were constructed so that each target word occurred in both a primed and an unprimed condition, but only once within each set. One half the subjects were assigned to one set and one half to the other.

Procedure. The procedure was the same as in Experiments 1a and 1b, except for minor variations. Because of equipment differences and associated differences in refresh rates, the duration of the prime was 60 ms rather than 50 ms. No feedback was provided.

Results

The mean lexical-decision latencies are shown in Table 3. In Experiment 2a, in which the body was intact, a 2 × 2 × 2 analysis of variance (ANOVA) showed a significant main effect of prime type: for the subjects, $F(1, 28) = 6.40, p < .02, MS_e = 721.0$, and for items, $F(1, 80) = 6.22, p < .02, MS_e = 1,339.81$, with a strong trend toward an interaction with *BF* that was significant in the subject analysis, $F(1, 28) = 10.33, p < .01, MS_e = 368.67$, but was not significant in the item analysis, $F(1, 80) = 3.85, p < .10, MS_e = 1,339.81$. Subanalyses showed that the priming effect for the low-*BF* word targets (25 ms) was significant both in the subject analysis, $F(1, 28) = 19.48, p < .01, MS_e = 431.4$, and in the item analysis, $F(1, 40) = 13.92, p < .001, MS_e = 955.36$, but the small effect

Table 3
Mean Lexical-Decision Times and Error Rates for Low-*N* Target Words When the Body of the Target Is Intact (Experiment 2a) and When it Is Changed (Experiment 2b)

Condition	Example	RT (ms)	Error rate (%)	Priming
Body intact				
High <i>BF</i>				
Primed	<i>frive-DRIVE</i>	620	4.8	3
Control	<i>flack-DRIVE</i>	623	5.5	
Low <i>BF</i>				
Primed	<i>presh-FRESH</i>	618	7.0	25
Control	<i>plont-FRESH</i>	643	5.5	
Body changed				
High <i>BF</i>				
Primed	<i>drice-DRIVE</i>	631	2.7	20
Control	<i>flack-DRIVE</i>	651	5.2	
Low <i>BF</i>				
Primed	<i>frest-FRESH</i>	635	4.9	20
Control	<i>plont-FRESH</i>	655	5.4	

Note. *N* = the number of letter neighbors; RT = reaction times; *BF* = body frequency.

observed for the high-*BF* words (3 ms) was not reliable (all *F*s < 1).

In marked contrast, where the body was changed (Experiment 2b), priming effects of 20 ms were obtained for both high-*BF* and low-*BF* conditions. There was a strong main effect of prime type: for subjects $F(1, 60) = 14.47, p < .001, MS_e = 798.57$, and for items, $F(1, 40) = 10.26, p < .01, MS_e = 1,606.95$; prime type did not interact with body frequency (identical effects for both levels of the *BF* variable). Separate subanalyses showed that the effect for the low-*BF* targets was significant for subjects, $F(1, 28) = 8.86, p < .05, MS_e = 884.42$, and for items, $F(1, 40) = 7.78, p < .05, MS_e = 1,092.94$; and for the high-*BF* targets, both the subject and the item analyses were significant: for subjects, $F(1, 28) = 5.66, p < .05, MS_e = 712.72$, and for items, $F(1, 40) = 4.72, p < .05, MS_e = 1,690.7$.

There were no significant effects in the analysis of the error rates in either experiment, nor were there any significant effects in the analysis of the data for the nonword targets. In Experiment 2a, nonword items with the body intact (*marve-DARVE*) produced decision times of 710 ms, as compared with 718 ms for the control item (*mourt-DARVE*). The priming effect of 8 ms was not significant (all *F*s < 1). Similar results were obtained in Experiment 2b in which the body was changed. Primed items (*dauve-DARVE*) took 768 ms, whereas the control items (*mourt-DARVE*) took 769 ms.

Discussion

The results confirm neither the hypothesis that *BF* alone controls priming nor the hypothesis that *BF* and *N* each have independent effects. In Experiment 2a, the results favor the first hypothesis: When prime and target share the body, *BF* appears to be the sole determinant because priming is obtained when *BF* is low but not when it is high (as in Experiment 1a), despite the fact that the targets were low *N*. However, in Experiment 2b, in which the body is disrupted, *BF* appears to lose its controlling influence because priming should not be found in either condition (as in Experiment 1b) but is found in

both high-*BF* and low-*BF* conditions. This is the result that would be expected if *N* exerted an independent effect, but this hypothesis is also ruled out by the failure to obtain priming in the high-*BF* condition in Experiment 2a.

It should be noted that the interaction of prime type with *BF* in Experiment 2a fell short of significance in the item analysis, and hence we cannot say with complete confidence that the priming effect in the low-*BF* condition was significantly greater than in the high-*BF* condition, which it should have been if there was a priming effect in one condition but not in the other. Nevertheless, we feel that this is the most plausible interpretation of the statistical results, given that the alternative is to assume that the nonsignificant priming effect of 3 ms for high-*BF* words is equal to the highly significant priming effect of 25 ms for low-*BF* words.

The picture that appears to be emerging is as follows. When the body of the prime and target match, then form priming is controlled by *BF* because priming occurs only when *BF* is low, regardless of *N*. However, when the prime and target have different bodies, then *N* controls priming, regardless of *BF*. What this suggests is that both subsyllabic and letter-level effects play a critical role, but not independently. We return to the implications of this conclusion in the General Discussion section.

Experiment 3

Experiments 1–2 suggest that the body plays an important role in form priming, but we have no evidence of whether this is the only higher order constituent that might be involved or whether it is just one of many. The case for the body would be much stronger if it could be shown that other plausible constituents have no influence on form priming. For example, we might consider a syllabic analysis such as [BLA] [ST], in which the onset and the nucleus are taken to be the major constituent, rather than the body. We call such a unit the *antibody*⁴ of the word. Previous research suggests that such units might play some kind of role. Although a study by Treiman and Zukowski (1988) suggested that bodies, but not antibodies, were important units in lexical processing, Taraban and McClelland (1987) did find some evidence for the involvement of antibodies. They found that pronunciations of a nonword could be biased by the pronunciation of a previously presented word when that word and the nonword had matching antibodies. For example, the pronunciation /hem/ was more likely to be given to the nonword *heam* when it was preceded by *head* than when it was preceded by *dead* (though the effect was greater when the nonword and word shared a body rather than an antibody, for example, *vead* being pronounced /ved/ when it followed *head*).

In Experiment 3, the similarity of the prime and the target was manipulated in terms of antibodies, rather than bodies. Primes and targets shared an antibody that was either relatively common (e.g., *blash*–*BLAST*, in which *bla* is a relatively common word beginning, as in *black*, *blade*, *blame*, and *bland*, etc.) or relatively uncommon (e.g., *blesh*–*BLESS*, in which *ble* is a relatively rare word beginning). These conditions are referred to as high-*ABF* and low-*ABF*, respectively. The high-

ABF and low-*ABF* conditions were matched in terms of *N* (which was low) and *BF* (which was high).

By the logic used for body representations, if there are also antibody representations, then we should observe form priming arising from shared antibodies, but only for low-*ABF* targets. For example, the masked prime *blesh* should facilitate lexical decision responses to *BLESS* (low *ABF*), whereas the prime *blash* should not facilitate *BLAST* (high *ABF*). If such a result were obtained, it would suggest that the body is just one of several alternative methods of representing orthographic units.

In case antibodies were found not to have any influence on response times, a third condition was included in order to demonstrate that the experiment had the required sensitivity to detect form-priming effects. This condition consisted of items in which the prime and the target shared a body that was relatively uncommon (low *BF*, low *N*, and body intact). This condition constitutes a replication of the condition in Experiment 2a in which priming was observed.

Method

Subjects. A total of 26 undergraduates enrolled in an introductory psychology course at the University of Arizona served as subjects.

Materials. The antibody manipulation was set up by pairing words that had the same initial consonant cluster but which differed markedly on the frequency of the combination of this cluster with the following vowel (forming the antibody). For example, *pri* is more common than *pru*, and *bla* is more common than *ble*. Accordingly, *PRIZE* and *BLAST* were used as high-*ABF* targets, whereas *PRUNE* and *BLESS* were used as low-*ABF* items. The number of antibody neighbors was determined from a count of dictionary entries, including words of general usage only (e.g., no technical terms) and excluding suffixed and compound forms. A final silent *e* was ignored when determining the vowel of the antibody to maintain a single orthographic unit (e.g., the antibody of *prize* was taken to be *pri* rather than *pri e*), and diphthongs were not included in the frequency calculations for a single vowel (e.g., *bleed* was ignored when counting the frequency of *ble* because *blee* is an antibody in its own right). Antibody frequency was calculated on the basis of only monosyllabic words to make the antibody count comparable with the body count (which also was based solely on monosyllabic words). The mean antibody frequency for the 30 high-*ABF* words was 9.4 and for the 30 low-*ABF* words was 2.9. The two sets of words were approximately matched for high-*ABF* and low-*ABF* targets, respectively on *N* (2.1 vs. 1.8), word frequency (5.3 vs. 4.5), and body frequency (10.2 vs. 9.7).

For each of the high- and low-*ABF* target words, a nonword prime was constructed by changing one letter outside of the antibody (e.g., *prite* from *prize* and *blesh* from *bless*). Control conditions were also set up by pairing the target words with a nonword that shared no letters with the target (e.g., *twalk*–*PRIZE* and *whift*–*BLESS*).

In addition to the high- and low-*ABF* conditions, a low-*BF* condition was included. The 30 items in this condition were matched with the *ABF* items on *N* (1.9) and word frequency (4.8) but had a lower number of body neighbors (3.0). In addition, the nonwords generated as primes for these low-*BF* target words kept the body of the target intact (e.g., *treme*–*THEME* and *rault*–*VAULT*). As for the other conditions, a baseline condition was included in which the nonword prime and target had no letters in common (e.g., *blisk*–*THEME* and *poard*–*VAULT*).

⁴ We are indebted to Emmanuel Dupoux for suggesting this term.

A set of 90 nonword targets of similar orthographic structure to the word targets were also constructed to act as distractors in the lexical decision task. These nonwords were preceded by a masked presentation of another nonword, 45 of which shared no letters (e.g., *smuch-FRAKE* and *jaist-GERVE*), 30 of which had one letter different, but kept the antibody intact (e.g., *blint-BLING* and *smeld-SMERD*), and 15 of which had one letter different, but kept the body intact (e.g., *shirp-WHIRP* and *naist-DAIST*).

As in Experiments 1–2, two sets of materials were constructed with materials counterbalanced across the priming condition.

Procedure. The procedure was the same as in Experiment 1.

Results

The mean lexical-decision latencies and error rates are shown in Table 4. The results for the antibody items were analyzed in a 2 × 2 × 2 (Group [subject or item] × *ABF* [high vs. low] × Prime Type [related vs. control]) design. The only nonrepeated variables were the group variable in both the subject and the item analyses and the antibody frequency in the item analysis. For the decision times, this analysis revealed a significant main effect of prime type in the subject analysis, $F(1, 24) = 15.18, p < .001, MS_e = 1,035.87$, and in the item analysis, $F(1, 56) = 4.34, p < .05, MS_e = 3,183.52$, and a significant interaction between priming and antibody frequency by subjects, $F(1, 24) = 4.28, p < .05, MS_e = 2,675.23$, and by items, $F(1, 56) = 4.42, p < .05, MS_e = 3,183.52$. As can be seen in Table 4, this interaction resulted from the fact that there was a very small difference (4 ms) between the high-*ABF* condition and its baseline control condition, which was not significant ($F_s < 1$ for both subject and item analyses). However, the priming effect for the low-*ABF* items was substantial (46 ms) and was significant for subjects, $F(1, 24) = 12.16, p < .01, MS_e = 2,221.26$, and for items, $F(1, 28) = 6.96, p < .05, MS_e = 4,054.17$. Finally, the low-*BF* condition also produced a significant priming effect of 29 ms for subjects, $F(1, 24) = 15.18, p < .001, MS_e = 1,035.87$, and for items, $F(1, 56) = 4.34, p < .05, MS_e = 3,183.52$. The only significant effect in the error analysis was due to the main effect of *ABF*, with high-*ABF* items producing lower error rates than low-*ABF* items; however, this was significant only in the subject analysis, $F(1, 24) = 11.24, p < .01, MS_e = 54.74$, and not in the item analysis, $F(1, 56) = 1.32, p > .05, MS_e = 541.25$.

Discussion

From the results of Experiment 3, it seems that the antibody of a word does indeed play a role in lexical processing and that the effects of antibody frequency parallel those of *N* and *BF*; that is, when the prime shares the antibody of the target, then priming is found only when the antibody is low frequency. No priming is found for high-*ABF* words, despite the fact that the words used in this experiment were low *N*. In addition, the results confirm the results of Experiment 1a in showing the presence of priming for low-*BF* words.

Thus, the evidence for an interaction of priming with antibody density is at least as strong as the evidence for an interaction with body density. It cannot therefore be argued that the body is the primary unit. Instead, we must give equal weight to both the body and the antibody as subsyllabic

Table 4
Mean Lexical-Decision Times and Error Rates for Target Words Varying in Antibody Frequency (ABF) as a Function of Type of Masked Prime (Experiment 3)

Condition	Example	RT (ms)	Error rate (%)	Priming
High <i>ABF</i>				
Primed	<i>prite-PRIZE</i>	611	12.8	4
Control	<i>twalk-PRIZE</i>	615	11.3	
Low <i>ABF</i>				
Primed	<i>prute-PRUNE</i>	595	15.9	46
Control	<i>twest-PRUNE</i>	641	17.9	
Low <i>BF</i>				
Primed	<i>treme-THEME</i>	625	22.1	29
Control	<i>blisk-THEME</i>	654	25.4	

Note. RT = reaction times; *BF* = body frequency.

constituents, which involves postulating the existence of overlapping subsyllabic constituents because the vowel simultaneously belongs to the antibody and the body. An alternative interpretation is to simply abandon the notion of syllable structure altogether and to suggest that any substring of letters within the target that is reasonably distinctive will produce priming. Such a proposal has been made by Sanchez-Casas (1988), who used the first four letters of polysyllabic words as a masked prime and found priming when relatively few words contained these same four letters (e.g., *qual-QUALITY*). When these letters were found in many words, priming was sharply reduced (e.g., *comp-COMPANY*). Similar results were found for the last four letters (e.g., *dred-HUNDRED* as compared with *ture-PICTURE*). This is a statistical view of priming rather than a structural view and is similar in spirit to the proposals of Seidenberg (1987), who argued that many structural effects in word recognition are actually effects arising from frequently occurring letter combinations.

Of course, it is possible that the results obtained by Sanchez-Casas (1988) are a further demonstration of the effects of antibody frequency. Words with frequently occurring beginnings are more likely to be high-*ABF* words, and words with uncommon beginnings are more likely to be low-*ABF* words. To test whether purely statistical properties are at all relevant, we need to manipulate the frequency of a substring that corresponds neither to the antibody nor to the body. Experiment 4 was designed to test whether results comparable to those of the antibody experiment would be obtained when the prime and the target shared an arbitrary substring that did not correspond to any conceivable subsyllabic unit.

Experiment 4

In Experiment 4, the prime and the target shared a pseudo-unit that was neither the body nor the antibody. This unit included the word’s vowel (as does the body and antibody) but also included one or both of the consonants immediately before or after that vowel without including the first or last letter (e.g., the *kir* of *skirt*, the *ree* of *creep*, and the *laz* of *blaze*). We call this pseudounit the *torso* of the word. As in the antibody experiment (Experiment 3), target words containing either high-frequency or low-frequency torsos were selected. If torsos function like antibodies, then we should observe prim-

Table 5
Mean Lexical-Decision Times and Error Rates for Target Words Varying in Torso Frequency (TF) and in Antibody Frequency (ABF; Experiment 4)

Condition	Example	RT (ms)	Error rate (%)	Priming
High TF				
Primed	<i>slint-FLINT</i>	583	16.0	17
Control	<i>shoop-FLINT</i>	600	13.9	
Low TF				
Primed	<i>skirm-SKIRT</i>	581	14.6	12
Control	<i>blosp-SKIRT</i>	593	14.9	
Low ABF				
Primed	<i>prute-PRUNE</i>	581	17.3	43
Control	<i>twest-PRUNE</i>	624	18.4	

ing for items in which the target has an unusual torso (low TF), but there should be no priming when the torso is relatively common (high TF).

The primes in Experiment 4, as in Experiments 1–3, differed from the target by only one letter. Because the torso had to be preserved, this meant that either the body or the antibody had to be preserved in the prime as well (otherwise the prime would differ by more than one letter). For example, the prime for *SKIRT* was *skirm*, which preserves both the torso (*kir*) and the antibody (*ski*), but not the body (*irt*), whereas the torso-preserving prime for *FLINT* was *slint*, which preserves the body, but not the antibody. To minimize the possibility of priming from either the body or the antibody, both body frequency and antibody frequency were kept as high as possible.

In the event that torso frequency turned out not to influence priming, a further comparison was included as a check on the sensitivity of the experiment. These items were taken from the low-ABF condition of Experiment 3.

Method

Subjects. A total of 24 undergraduates who were enrolled in an introductory psychology course at the University of Arizona served as subjects. They received course credit for their participation.

Materials. Two sets of 24 target words were designed so that one set had a high-frequency torso (e.g., *FLINT*, in which *lin* occurs in many words, such as *cling*, *fling*, *blind*, and *blink*), whereas the other set had a low-frequency torso (e.g., *SKIRT*, in which *kir* is uncommon). The torso was defined as a unit in the middle of the monosyllabic word that included the vowel and at least one adjacent consonant, but not the initial or the final letter. Frequency was determined from a computerized dictionary, using only words in common usage, and was calculated on the basis of all monosyllabic words that included the letter combination in the torso position. The mean torso frequency was 10.0 for the high-frequency set (high TF) and 1.4 for the low-frequency set (low TF). The high-TF and low-TF sets were approximately matched on *N* (2.4 vs. 2.5), number of body neighbors (8.8 vs. 9.3), number of antibody neighbors (8.4 vs. 8.1), and word frequency (3.7 vs. 3.9).

The primes were nonwords that differed from the target by one letter but kept the torso of the target intact. By having to keep the vowel of the target intact, it was impossible to disrupt both the body and the antibody at the same time. So for one half of the items, the body of the target was disrupted (e.g., *skirm-SKIRT*), whereas for the other half, the antibody of the target was disrupted (e.g., *slint-FLINT*). Control conditions were set up by pairing the target words with a

nonword that shared no letters with the target (e.g., *blosp-SKIRT* and *shoop-FLINT*).

Also included were 24 low-ABF word targets taken from Experiment 3. These items act as a check on the sensitivity of the experiment and as a replication of that finding. These were primed with nonword primes that preserved the antibody (e.g., *thrash-THRASH*) or were completely unrelated to the target.

There were also 72 nonword targets that served as distractors, one half of which were preceded by a nonword prime with one letter different either in the body (e.g., *prash-PRASK*) or in the antibody (e.g., *plime-FLIME*) and one half of which were preceded by a nonword with no letters in common (e.g., *chisp-WRALK*).

As in Experiments 1–3, two sets of materials were constructed, with materials counterbalanced across the priming conditions.

Procedure. The procedure was the same as in Experiment 1.

Results

The mean lexical-decision latencies and error rates are shown in Table 5. The torso items showed a small priming effect of 17 ms for the high-TF items and an even smaller effect of 12 ms for the low-TF items. A $2 \times 2 \times 2$ (Group [subject or item] \times TF [high vs. low] \times Prime Type [related vs. control]) analysis of these means showed that the main effect of prime type was significant in the subject analysis, $F(1, 22) = 5.42, p < .05, MS_e = 961.48$, but not in the item analysis, $F(1, 44) = 2.71, p > .10, MS_e = 1,581.63$. There was no significant main effect of TF, nor any interaction between TF and prime type (all $F_s < 1$). A subanalysis showed that the priming effect for the low-TF items did not approach significance either in the subject analysis, $F(1, 22) = 1.79, p > .10, MS_e = 1,000.91$, or in the item analysis, $F(1, 22) = 1.11, p > .10, MS_e = 1,336.80$.

In contrast, a separate 2×2 analysis of the means for the low-ABF items showed a strong priming effect of 43 ms, which was significant in both the subject analysis, $F(1, 22) = 21.71, p < .001, MS_e = 1,055.99$, and in the item analysis, $F(1, 44) = 10.22, p < .01, MS_e = 2,321.77$. Comparison of the low-TF and low-ABF priming effects showed that the ABF effect was significantly greater in the subject analysis, $F(1, 22) = 5.28, p < .05, MS_e = 1,127.79$, but not significantly different in the item analysis, $F(1, 44) = 3.64, p = .06, MS_e = 1,829.29$. There were no significant differences in error rates in any of these comparisons.

Discussion

The first question to consider is whether there is any evidence that torso frequency influences priming in the same way as body or antibody frequency. The answer is that it does not. There was no evidence of reliable priming for the low-TF condition (the 12-ms effect for low-TF items did not approach significance in either the subject or the item analysis), and there was no trend toward stronger priming in the low-TF condition as compared with the high-TF condition (the reverse was the case). The only evidence that torsos play any role in priming is the trend toward a main effect of prime type (significant in the subject analysis but not in the item analysis). On the other hand, the sensitivity of the experiment to priming

is demonstrated by the robust effect for the low-*ABF* condition.

Hence, it cannot be argued that just any low-frequency substring repeated in the prime and target will lead to facilitation. There seems to be something special about the body and the antibody of the word. Of course, the results do not establish that the body and the antibody are the only substring types that produce priming (i.e., there may be other sublexical units), but they do rule out the possibility that statistical rarity is the only necessary feature of such units.

However, if we conclude that an arbitrary substring such as the torso is irrelevant for priming, then no priming should have been observed in any torso condition. On a strict criterion, this was indeed the case because the main effect of prime type was not significant in the item analysis. However, it was significant in the subject analysis, which means that priming was present but only for a small subset of the items. A possible explanation is that a weak priming effect occurred for some items as a result of effects at the letter level or at the subsyllabic level. To prevent such effects, it would have been necessary to choose items that were simultaneously high *N*, high *BF*, and high *ABF*, yet could still be either low or high in torso frequency. Although on average, both *BF* and *ABF* were maintained as high as possible, it was difficult to guarantee that both frequencies were kept equally high for every single item. An extreme example is the target word *BROIL*, which has a large number of body neighbors but has no neighbors with the same antibody. If we had chosen a torso prime that preserved the body (e.g., *croil*), then no priming would have been expected from the body, but if we had instead chosen a torso prime that preserved the antibody (e.g., *broin*), then priming would have been expected for that item. Inspection of the items showed that there were in fact five items in which the prime and target shared a low-frequency antibody (*ABF* < 3), and three in which they shared a low-frequency body. These items may have contributed to the weak priming effect observed. In addition, it should be noted that the average *N* values for the targets in these conditions (2.4 and 2.5) were not particularly high when compared with the upper limit of two that was used to define a low-*N* target in Experiment 2; hence, it may well have been the case that a weak priming effect at the letter level also contributed to the overall effect. Whatever the explanation, the important point is that there was no sign of a special priming effect being generated only for words with low-frequency torsos.

A brief comment concerning frequency of occurrence may be useful. It might be argued that it is pointless to test for priming with low-frequency torsos because a substring would not be expected to form a unit unless it had a high frequency of occurrence, as argued by Seidenberg (1987). There are two points to be made. First, this argument could be applied equally well to the body and antibody frequency experiments, and in these cases, it is obviously incorrect. Second, it must be kept in mind that the notion of frequency that is relevant is the number of different words in which this substring occurs, regardless of the frequency with which those individual words occur. However, we would have to concede that if some of these words were very low frequency, they may not contribute to the same degree as higher frequency words. Therefore, it

might be sensible to argue that an uncommon unit (in the sense that it is contained in very few words) might not mediate priming if the words in which it occurs have very low occurrence frequencies. Applied to this particular experiment, the argument might be that the torsos involved in the low-*TF* condition might not have occurred often enough to have formed sublexical recognition units. However, the target word frequencies used in this condition were comparable to the target word frequencies used in the low-*BF* and low-*ABF* conditions, so there is no suggestion that the target words in this experiment were markedly different with respect to frequency of occurrence.

Experiment 5

The analysis of priming we have offered suggests that density effects occur at both a letter level and a subsyllabic level. However, it is possible that it is unnecessary to take letter-level effects into account at all. In Experiment 2, it was shown that priming still occurred for low-*N* targets despite their being high-*BF*, but this only occurred if the body of the target was disrupted. However, one of the methods used to disrupt the body in this experiment was to change a letter in the final consonant cluster, which meant that the antibody was very often preserved (e.g., *drice-DRIVE*). Given the subsequent finding that the antibody is also relevant to priming, it would have to be acknowledged that some of the priming in this experiment could have been mediated by the antibody. To show that letter effects are relevant, we need to show that priming can be obtained for low-*N* targets when both the body and the antibody have been disrupted. The only way to do this is to alter the vowel (e.g., *ploin-PLAIN*).

Method

Subjects. A total of 60 undergraduate students enrolled at the University of New South Wales served as subjects.

Materials. A set of 36 high-*BF* word targets were selected, one half of which were low *N* and one half of which were high *N*. Two nonword primes were constructed for each target word. The first differed from the target by only one letter, which corresponded to the vowel, so that both the body and the antibody were disrupted (e.g., *troin-TRAIN* [high *N*] and *ploin-PLAIN* [low *N*]). The second prime was a control prime, which differed from the target at all positions (e.g., *snaff-TRAIN*). The items were designed in high-*N*/low-*N* pairs that shared the same body; therefore, four counterbalanced sets of materials were constructed. This ensured that no subject ever received both members of a pair with the same body (e.g., *TRAIN* and *PLAIN*) or the same target word twice: once with a form prime (e.g., *train-TRAIN*) and once with a control prime (e.g., *snaff-TRAIN*).

Procedure. The procedure was the same as in Experiment 1.

Results

The mean lexical-decision times and error rates are shown in Table 6. These means were analyzed in a $4 \times 2 \times 2$ (Group [group or item] \times Number of Neighbors [high vs. low] \times Prime Type [related vs. control]) design. The only significant effect in this analysis was the main effect of prime type: for subjects, $F(1, 56) = 8.93, p < .01, MS_e = 2,274.81$; and for items, $F(1, 64) = 6.99, p < .05, MS_e = 1,730.24$. The interaction of prime

Table 6
Mean Lexical-Decision Times and Error Rates for High-N and Low-N Targets Words When Both the Body and the Antibody are Disrupted (Experiment 5)

Condition	Example	RT (ms)	Error rate (%)	Priming
High N				
Primed	<i>troin-TRAIN</i>	696	7.0	6
Control	<i>snaff-TRAIN</i>	702	7.4	
Low N				
Primed	<i>ploin-PLAIN</i>	671	5.4	31
Control	<i>snaff-PLAIN</i>	702	6.7	

Note. N = the number of letter neighbors; RT = reaction time.

type with number of neighbors was not significant in the subject analysis, $F(1, 56) = 2.89, p > .05, MS_e = 3,190.05$, or in the item analysis, $F(1, 32) = 2.94, p > .05, MS_e = 1,730.24$. However, planned comparisons showed that for high-N word targets, the priming effect of only 6 ms was not significant ($F_s < 1$ in both subject and item analyses), whereas for low-N targets, the priming effect was 31 ms, which was significant in both the subject analysis, $F(1, 56) = 14.03, p < .001, MS_e = 2,027.77$, and in the item analysis, $F(1, 32) = 10.06, p < .01, MS_e = 1,622.27$. The absence of a significant interaction between number of neighbors and prime type means that we cannot conclude that the priming effect for the low-N targets was significantly greater than the effect for high-N targets (presumably as a result of high variance in the latter condition). Nevertheless, a reliable effect of priming was obtained only for the low-N targets. There were no significant effects in the error analysis.

These results demonstrate that reliable priming effects can be obtained with a one-letter-different prime even when the letter that is changed disrupts both the body and the antibody of the target. As before, significant priming is obtained only in a low-density environment. This result establishes the existence of a priming effect that cannot be accounted for in terms of orthographic overlap at the subsyllabic level and confirms that the overlap between prime and target needs to be assessed at the individual letter level, as well as at the subsyllabic level.

General Discussion

The purpose of these experiments was to establish whether neighborhood density effects can be satisfactorily described purely in terms of the number of letter neighbors. It seems clear that this is not the case, at least as far as masked form-priming effects are concerned. Previous work (Forster et al., 1987) suggested that form priming could not be obtained with high-N targets using a one-letter-different prime. However, Experiment 1 in our article showed that form priming could be obtained for high-N target words, provided that the target word contained a low-frequency body that was shared with the prime. This result could be taken to imply that it is the number of body neighbors rather than the number of letter neighbors that controls form priming, but Experiment 2 demonstrated that the converse was also true. That is, targets with few letter neighbors showed form priming regardless of

the number of body neighbors, provided that the prime and target did not share the same body.

Experiment 3 extended these findings, showing that parallel results were found for a subsyllabic unit that was not initially expected to affect priming, namely the antibody, which consists of the onset and the vowel. This raised the possibility that any arbitrary substrings might serve to mediate priming if it was relatively distinctive. The results of Experiment 4 suggest that this is not the case because a completely arbitrary substring such as the torso had no effect on priming. Finally, Experiment 5 confirmed that priming could occur even when both the body and the anti-body had been disrupted, indicating that priming can be mediated at the individual letter level, provided that the number of letter neighbors is low.

The preliminary conclusion then is that a one-letter-different prime will prime a target word only under the following conditions: (a) if the target and the prime share a low-frequency body or antibody or (b) if the target is low-N, and the target and prime do not share a high-frequency body or antibody. The findings are summarized in Figure 1.

If the conditions for form priming are so specialized, then it might be asked how earlier investigations that ignored subsyllabic structure managed to find any form priming at all (e.g., Forster et al., 1987). The answer is that in these earlier studies, priming was found only for low-N words, and for these targets the chances are high that any randomly chosen one-letter-different prime will produce priming. This is because low-N words are likely to be low in body frequency, antibody frequency, or both; hence whenever the prime shares either unit, priming is expected to occur. Even if the prime disrupts both the body and the antibody of the target, priming will still be produced at the letter level for low-N targets, as shown in Experiment 5. The only occasion on which we would not expect priming for low-N targets is when the prime preserves either a high-frequency body (e.g., *frive-DRIVE*) or a high-frequency antibody (e.g., *shrimb-SHRIMP*).

At a purely descriptive level, one can treat priming as a reflection of orthographic similarity, where similarity is defined in terms of a metric that scales the degree of overlap between the prime and the target in terms of the average degree of overlap between the target word and all other words, as formulated in the Luce choice model (R. D. Luce, 1963). Thus, on this account, the reason that the high-N target word *FACE* is not primed by a one-letter-different prime such as *nace* is simply that these two items do not have an unusually high degree of overlap because there are many words that resemble *FACE* to the same degree. However, for low-N target words this is not the case because (by definition) few words will resemble the target word to the same degree as a one-letter-different prime. Obviously, there is no single unit of measure to express the degree of overlap. Primes and targets can overlap in terms of individual letters, bodies, or antibodies; hence, we must consider several different types of similarity—body similarity, antibody similarity, and letter similarity. The problem for this type of approach is to explain how (and why) these different types of similarity interact. For example, similarity at one level appears to compensate for lack of similarity at another, as must be the case when we observe priming for low-BF targets even though they are high N (i.e., high body similarity

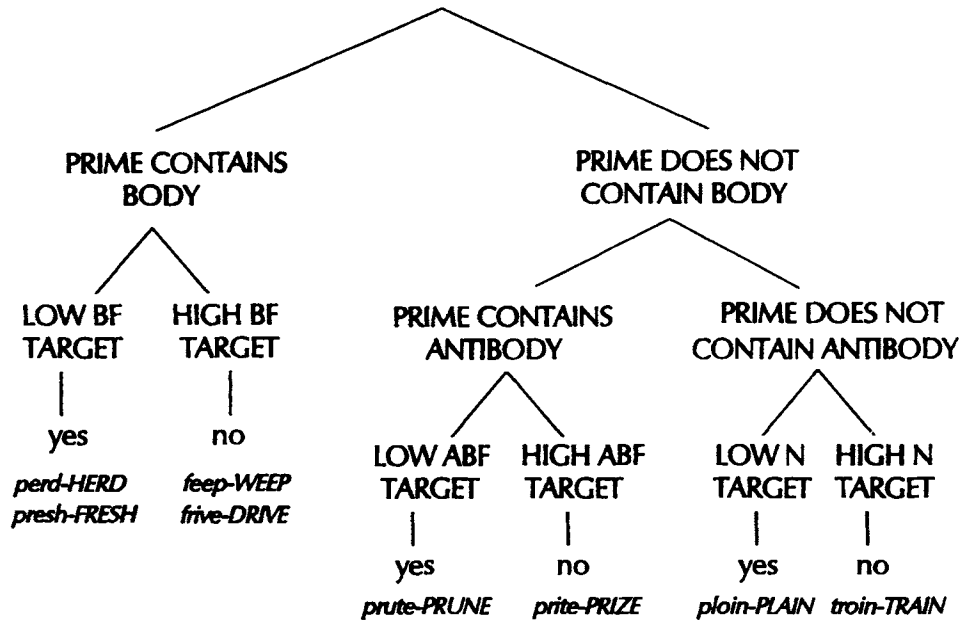


Figure 1. Prerequisites for form priming. The initial subdivision is in terms of the type of prime (whether it contains the body or the antibody of the target) and then by the type of target (low vs. high with respect to BF, ABF, or N). The final outcome (yes or no) indicates whether form priming occurs. The hierarchical structure implies a precedence of bodies over antibodies and of subsyllabic units over individual letters. However, evidence is reported here only for the latter relation, not the former. BF = body frequency; ABF = antibody frequency; N = the number of letter neighbors.

compensates for low letter similarity). This cannot be explained by a simple additive model because we would then expect to obtain priming for low-N targets in all conditions. Instead, similarity at one level appears to dominate over another, as shown in Experiment 2a. If the prime and the target share a body, then the degree of resemblance at that level (indexed according to the frequency of that body) controls priming. That is, there is no priming for high-BF targets, despite the fact that at the letter level, the prime closely resembles the target.

The deeper question to consider is the nature of the mechanism that might be responsible for this pattern of results. Why is it that similarity is dependent on neighborhood density? The following model, which is based loosely on a computational network approach, may explain why this is the case. In this model, it is assumed that a high density level triggers a change in the way the orthographic form of a word is coded. In sparse regions, words may be coded purely in terms of individual letters (i.e., word units are activated primarily by letter-to-word connections), but in more dense regions, words may also be coded in terms of higher order units, such as bodies or antibodies. The effect of this additional form of coding is to facilitate discrimination, that is, to make the words less similar. In computational network terms, the effect is to reduce the degree of overlap between correlated input vectors, a process that Marr (1969) termed *codon* formation (see also Baum, Moody, & Wilczek, 1988; McNaughton & Nadel, 1991).

This process is illustrated in Figure 2, which represents a hypothetical orthographic space in which the circles can be thought of as representing the set of activated elements for

each word in the lexicon (as in the sparse distributed model developed by Kanerva, 1988) or as receptive fields or as attractor basins. In the lefthand box of Figure 2, there are two high-density clusters and several low-density clusters. One method of spreading the words out more evenly is to recode the representations of words in high-density regions by a conjunctive coding scheme in which new dimensions are formed that represent conjunctions of input features. One example of this is the digraph coding scheme adopted by Rumelhart and McClelland (1986) in which the word *face* is coded as containing the digraphs #f, fa, ac, ce, and e#. Each digraph is a conjunctive feature, and the effect of this coding is to reduce overlap slightly (words that differ by only one letter unit will differ by two digraph units). Similarly, bodies and antibodies can also be thought of as higher order conjunctions of letter features. The righthand box of Figure 2 illustrates a possible consequence of recoding. The effect of recoding is to stretch the representational space so that dense areas become sparse once again. This stretching is achieved by the addition of new dimensions to the representational space. Note that this stretching can be purely local; words in sparse regions that have overlapping representations are totally unaffected.

The consequence of recoding is that priming between words in previously high-density regions is no longer expected because in the recoded space, their representations no longer overlap. However, priming will still occur for overlapping words in sparse regions because these regions have not been remapped. Figure 3 shows a concrete example of a high-density neighborhood: the *herd* neighborhood. When mapped in terms of individual letters, the receptive fields for these

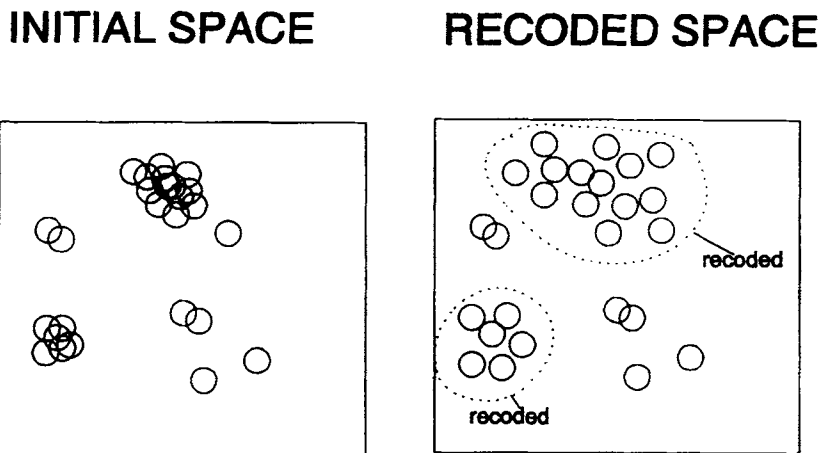


Figure 2. A hypothetical representational space for lexical items before and after recoding has taken place. Each circle represents the receptive field for a word. The effect of recoding is to stretch the representational space locally, so that very dense clusters are broken up.

words form the grouping as shown in Figure 3a. However, when the words are coded in terms of onsets and bodies, the words form different groupings, as shown in Figure 3b. In this remapped space, *head* and *herd* no longer have overlapping receptive fields, and hence no priming between them would be expected. This reasoning also applies to priming with nonword primes. Although nonwords do not have receptive fields, they nevertheless activate elements within the representational space. So, for example, the set of elements that might be activated by the nonword *hend* is indicated by the cross-hatched circle in each panel. In Figure 3a *hend* activates the fields for both *herd* and *head*, but in Figure 3b, it does not. (However, it would activate the fields for *tend* and *bend*, which are not shown.) A further point is that the recoding is not completely effective in breaking up the neighborhood because

read, *head*, and *dead* (plus others not included in the *herd* neighborhood, for example, *bead* and *lead*) still form a dense cluster. To break this cluster up, further recoding in terms of some other unit, such as the antibody, would be necessary.

This process of breaking up clusters can be seen in developmental terms. Early in the development of reading skill, there may be no high-density clusters, but as the child acquires visual representations for more and more words, dense clumps will begin to develop and interference between neighbors is produced. When the density becomes too high, a remapping process is triggered, which spreads the words out more evenly. This recoding proposal provides the following account of the neighborhood density effect: High-*N* neighbors do not prime each other because they are really represented in a remapped body space, so that unless they share a body, they do not in fact

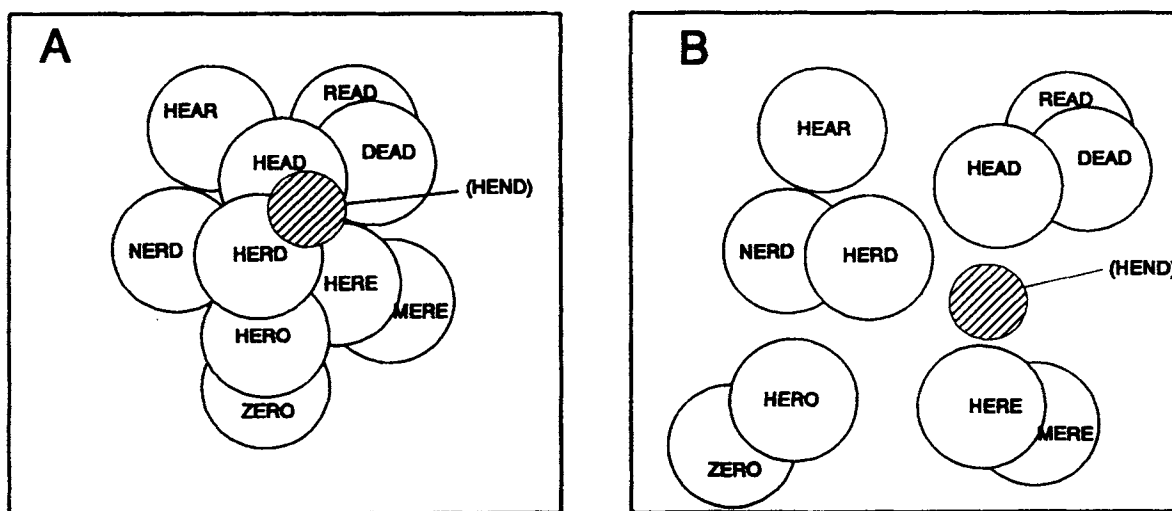


Figure 3. The *HERD* neighborhood, before and after recoding. In (A), overlap between receptive fields is determined by individual letters. In (B), overlap is determined by bodies and onsets. The cross-hatched area represents the area stimulated by the nonword *hend*.

have any orthographic features in common. On the other hand, low-*N* neighbors, which have not been recoded, still have substantial overlap at the letter level and hence show priming. However, as the child's reading vocabulary develops further, clumps begin to develop again, even in the remapped regions. Therefore, in areas in which many words share the same body, the same pressure for remapping develops. This time, recoding takes place in terms of antibodies, which serves once again to stretch the representational space. The consequence is that priming will no longer be observed for neighbors that share a high-frequency body.⁵ Priming now depends on sharing an antibody.

The important aspect of this theory is the hypothesis that (a) priming from a one-letter-different prime may be weaker for high-*N* targets than for low-*N* targets because high-*N* words tend to be coded more richly in terms of higher order units, such as bodies and antibodies, and (b) priming is controlled by overlap in these higher order units. Low-*N* words, however, are coded in terms of single letters, and hence priming for these words is unaffected by overlap in terms of bodies or antibodies.

This theory is compatible with most of the results reported in our article. It explains why priming can be found for high-*N* words that share a low-frequency body with the prime (Experiment 1a) because in the remapped body space, substantial overlap between prime and target is maintained. However, if prime and target share a high-frequency body, no priming is obtained because these words would have been recoded in terms of some other higher order unit; hence, the overlap in the body does not support priming. It also explains why no priming is obtained if the body is not shared (Experiment 1b) because high-*N* words that do not share a body essentially have no orthographic overlap. In a similar vein, it explains the effect of antibody frequency (Experiment 3). The fact that letter-level priming effects are found for low-*N* words when both the body and the antibody are disrupted (Experiment 5) is consistent with the model because these words are still coded in terms of their individual letters. This leaves the effects reported in Experiment 2, which are more difficult to explain.

In Experiment 2, it was found that low-*N* words that share a high-frequency body with the prime do not show priming (e.g., *frive-DRIVE*), although they do show priming when the body is disrupted (e.g., *drice-DRIVE* and *drave-DRIVE*). Experiment 5 confirmed the latter priming effect and demonstrated that this priming could not have been due to a shared antibody. The critical result is the absence of priming in Experiment 2a when the body is shared (*frive-DRIVE*). This result appears to indicate that overlap at the body level suppresses priming from the letter level if the number of body neighbors is high. This creates several problems for the remapping explanation. The first problem is that remapping is supposed to occur only for words in high-density regions, and therefore higher order units such as the body should be irrelevant for a low-density word such as *drive*. However, to understand why the body is relevant, it is important to realize that it is not individual words that get recoded but rather regions of lexical space. So, if a cluster of words has been broken up by introducing a body code for *ive*, then this will affect all words that have this body, regardless of whether the word is low *N* or high *N* and regardless of whether it was a member of the original cluster.

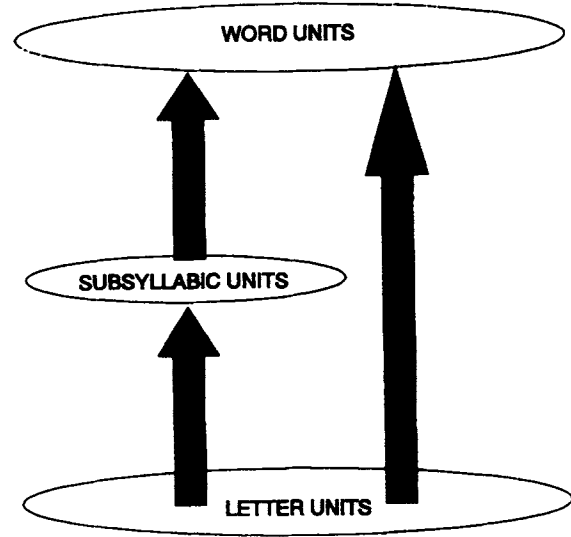


Figure 4. Possible activation model in which word-units are directly activated by a letter channel and indirectly by a subsyllabic channel.

This means that *drive* is now forced into a cluster consisting of other *ive* words (e.g., *live*, *jive*, *hive*, *strive*, *dive*, and *chive*). When this cluster eventually becomes dense enough, recoding takes place again, this time in terms of antibodies. This splits up the *ive* words, and *drive* now moves into a cluster with *drink* and *drip*. This explains why *drice* primes *DRIVE* but *frive* does not: Only *drice* contains the antibody of the target. However, we now have a problem explaining how *drave* is capable of priming *DRIVE* because this prime does not contain the antibody. This suggests that *drive* somehow retains its properties as a low-*N* word, which is not at all compatible with the spatial model. However, as we show below, this is not the only approach that has difficulties with these findings.

As an alternative to the remapping model, we might consider adopting an activation model in which there are two ways to activate word units: one route through letter-to-word connections and another, more indirect route involving letter-to-syllable connections and syllable-to-word connections, as shown in Figure 4 (very similar notions are expressed in Taft, 1991, p. 81). If priming is seen as the direct result of the prime's tendency to activate the unit for the target (i.e., cross-activation), then the problem is to specify the conditions that control the strength of the cross-activation in each of the two routes. If it is assumed that in either route the tendency for a target to be cross-activated is inhibited by the presence of many neighbors, then we could explain why priming occurs for low-*N* words but not for high-*N* words when the subsyllabic route is not involved (Experiment 5). Body frequency and antibody frequency are irrelevant to priming in these cases because the subsyllabic activation system does not produce any

⁵ We assume for purposes of exposition that remapping takes place first in terms of bodies, and then antibodies, but there is no reason why the reverse should not be assumed or that both types of remappings take place simultaneously.

cross-activation when both the body and the antibody are disrupted across prime and target. However, when the body or the antibody is intact, cross-activation through the subsyllabic route is strong, but the amount of priming produced now depends on how many body neighbors or antibody neighbors the target has.

Again, this theory does not explain the suppression effect found with the *five-DRIVE* condition in Experiment 2a. Although cross-activation from the prime in the subsyllabic system is inhibited as a result of the large number of body neighbors, there should still be cross-activation in the letter system. Evidently, the inhibition produced in the subsyllabic system must be great enough to suppress the activation from both sources. The only problem with this account is that the same argument should apply to low-*BF* items that are high *N* (e.g., *perd-HERD*). That is, the inhibition generated by the letter neighbors should also suppress cross-activation from the syllable system. This is not the case, however, as shown by the results of Experiment 1a, in which priming was observed for low-*BF* items despite their being high *N*. To accommodate this finding, we need to postulate that the syllable system somehow takes precedence over the letter system. That is, once the prime activates the body or the antibody of the target, then all letter-level effects become irrelevant.

The precedence effect is not the only problem to be faced by this type of model, which emphasizes competitive interaction between word units. In addition, we need to be able to explain how neighbors can have such a strong inhibitory effect on cross-activation from a nonidentical input without having a corresponding effect on activation from an identical input. That is, if the presence of neighbors can completely eliminate the activation induced in the target *HERD* by the prime *herd*, then it should have a similar effect when the prime is *herd*. However, there is no sign that repetition priming is affected by neighborhood density, as shown by Forster and Davis (1984) and Forster et al. (1987). This same problem arose in the case of the diffusion assumption discussed in our introduction, in which cross-activation was assumed to be divided equally amongst all of the neighbors. A further and more difficult problem for this approach is to explain how a word prime could ever facilitate the processing of its neighbor, even in the lowest density neighborhood. In models such as the interactive-activation model proposed by McClelland and Rumelhart (1981), the competition between neighbors virtually guarantees that the prime will have an inhibitory effect rather than a facilitatory effect, because when the target is presented, one of its competitors will already be strongly activated (see Segui & Grainger, 1990, and Forster, Dupoux, & Haan, 1990, for demonstrations of this effect).

This latter problem does not arise in an alternative model of priming, namely, the entry-opening model of form priming originally put forward by Forster and Davis (1984) and subsequently extended in Forster (1989). In this model, orthographic representations of words are scanned by a serial search mechanism that marks the representations that correspond closely to the input stimulus. The words corresponding to these representations become candidates for further analysis, and to carry out this analysis, the full lexical entry for each candidate must be "opened," a process analogous to opening a file in a

disk operating system. Candidate entries normally stay open only until the input word has been identified, but the masking procedure prevents complete identification of the prime so that entries opened by the prime remain open during processing of the target. If one of these open entries is the entry for the target (as it will be when the target is a close match for the prime), then the processing of the target is facilitated by virtue of the savings in not having to reopen the entry. To explain the effects of neighborhood density, we can assume that the criterion for a close match takes neighborhood density into account (a version of the detector tuning hypothesis discussed earlier). In effect, close matches are ignored in a dense neighborhood but exact matches are not. One possible motivation for this restriction is that it keeps the number of candidates to a reasonable number.

To capture the distinction between letter and subsyllabic coding, we would need to assume that the orthographic representations are coded in such a way that a match can be detected by using either type of coding. To make this possible, we would need a preprocessor that codes the input stimulus in terms of the individual letters, the onsets and bodies, and the antibodies and codas. We would then need three separate search processes operating in parallel, one for each type of code. Whether an entry gets opened by any of these searches depends on the degree of overlap between the input code and the entry and the number of other words that match this entry to the same degree (i.e., the number of neighbors). This account predicts that a prime could open the entry for the target if the target word is low *N*, low *BF*, or low *ABF*. If the target word is low *N*, then the letter-oriented search for the prime will open the entry for the target. If the target is high *N*, but contains a low-frequency body, then the body-oriented search will open the entry, but only if the prime contains the body. Similarly, if the target is high-*BF* but contains a low-frequency antibody, then the antibody-oriented search will open the entry, but only if the prime contains the antibody.

However, like the other models, the entry-opening model does not explain the suppression effect in Experiment 2a for low-*N* items, such as *five-DRIVE*. Although the body-oriented search might fail to open the entry for the target (because there are too many other words that contain the same body), the letter-oriented search should still succeed because the target has only one neighbor at the letter level. However, no priming is observed in this case. To accommodate this result, we would have to propose that any lexical entry that shares a high-frequency body with the current stimulus is excluded from the candidate list by the body-oriented search and cannot subsequently be reinstated by the letter-oriented search (but not vice versa).⁶ It is hard to see why such a restriction should be imposed.

It appears that the effects observed in Experiment 2 create problems, whatever model we adopt. If there were no priming

⁶ It might be argued that it is premature to speculate about the explanation of this suppression effect until we are more certain of its existence. However, in an earlier version of Experiment 2 that is omitted in our article, precisely the same finding was obtained. Priming for items such as *five-DRIVE* was only 4 ms, but for items such as *drice-DRIVE*, it was a significant 19 ms.

for *drave*–*DRIVE*, then the remapping theory would be consistent with the data. If we assume a dual-activation model, then we have trouble explaining the absence of priming for *frive*–*DRIVE*. Similarly, if there was priming for *frive*–*DRIVE*, then the entry-opening model (Forster & Davis, 1984) could account for the results. There seems to be no model that predicts priming when the body is disrupted but no priming when it is preserved. Further research is required to determine whether these results can be replicated with new materials.

One potentially interesting issue raised by this research concerns the nature of the developmental process that controls the way in which the coding of words changes as a function of experience. As described here, the reader learns to make increasingly finer discriminations by coding input patterns in terms of higher order combinations of features. Clearly, this kind of learning is well suited to a connectionist network in which a back-propagation learning algorithm is used (e.g., Seidenberg & McClelland, 1989). It is of interest to consider whether a network trained to recognize and pronounce printed words would naturally develop a set of hidden units that corresponds to bodies and antibodies. This would be the case if we found that words with the same body (and likewise words with the same antibody) tended to activate the same set of hidden units while words with different bodies (or antibodies) tended to activate different hidden units. Seidenberg and McClelland (1989, p. 544) claimed that this is indeed the case, at least as far as bodies are concerned. They argued that in written English, the pronunciation of the vowel is more influenced by the subsequent letters than by the preceding letters, and this correlation is reflected in the connection weights. Presumably, this means that some hidden units would come to represent the joint properties of the vowel and the subsequent consonants, that is, the body. Seidenberg and McClelland were able to show that two words with the same body activated more hidden units in common than did two unrelated words, but this evidence alone is not compelling because one needs to show that other forms of orthographic overlap (e.g., sharing a torso) do not lead to the same outcome.⁷ Another possible outcome is that the hidden units will exhibit quite arbitrary characteristics and will pick up whatever features of a word serve to distinguish it from other words, regardless of how idiosyncratic or inconsistent these features might be. If the human learning of higher order orthographic units has similar properties, then we might expect to find that any substring that is correlated with a particular word (and is found in relatively few other words) could prime that word, even though it has many letter neighbors. The evidence from Experiment 4 addresses this issue and indicates that there is at least one low-frequency substring (the torso) that fails to do so. Of course, this result does not establish that all substrings would behave the same way. For example, it might be that readers use discontinuous units, such as *d__ri* or *pi__t*, as proposed by Mozer (1987).

The alternative to this statistical view is that the choice of orthographic units is motivated by linguistic properties, which in the case of English appear to be phonological in nature. For example, it could be that the orthographic body is chosen as a unit because it corresponds to a unit used to code spoken words, namely the rime of the syllable. The problem with this

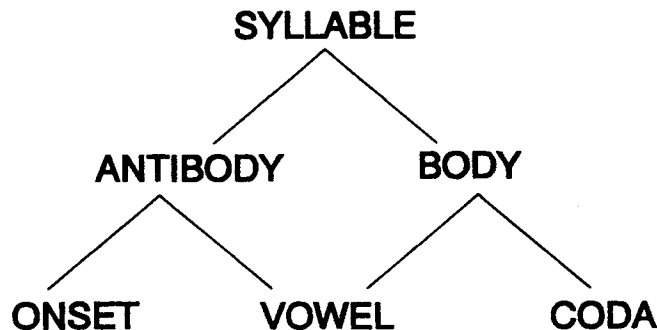


Figure 5. Interlocking model of syllable structure, in which the syllable is composed of two overlapping units.

approach is that it works only for languages having a script that is capable of representing subsyllabic constituents. It does not work for nonalphabetic scripts, such as Chinese or Japanese kanji, because there is nothing in these scripts that corresponds to bodies or onsets.⁸ Presumably, in these cases it makes no sense to talk of body or antibody frequencies or *N*, and hence some completely different conception of neighborhood density will have to be developed. Of course, this assumes that density constraints on orthographic form priming actually exist in such scripts, which has not yet been demonstrated.

Another issue concerns the possibility that bodies and antibodies might be thought to violate standard assumptions about syllabic structure because these constituents overlap, with the vowel being assigned to both, as shown in Figure 5. Although this type of interlocking structure is certainly unusual, it is not totally incompatible with current approaches to syllable structure (e.g., Hyman, 1985; Goldsmith, 1990). It is interesting that many of the arguments used by Clements and Keyser (1983) against the conventional vowel-coda grouping could be taken as evidence for an onset-vowel grouping. Their argument was that there was just as much evidence in English favoring an onset-vowel grouping as favoring a vowel-coda grouping, which led them to propose instead a tripartite structure, in which the onset, the vowel, and the coda function as independent units at the same level. However, this evidence could also be interpreted as support for a dual body–antibody representation.

It should be mentioned that there is another study that has examined word bodies in a masked priming paradigm but that obtained results that are not entirely consistent with those reported in our article. Bowey (1990) found that word bodies were effective as primes compared with other units matched on bigram frequency (e.g., although *CLIP* was primed by *IP*, *DUSK* was not primed by *SK*). However, unlike the present experiments, this priming was observed even though the bodies were of high frequency (e.g., *IP*). Furthermore, Bowey observed no

⁷ As noted by Taft (1991, p. 121), an examination of the errors made by the Seidenberg and McClelland (1989) network suggests that the hidden units did not systematically represent bodies.

⁸ This problem does not arise for Japanese kana because these characters represent morae, which correspond roughly to cv sequences, that is, antibodies.

priming from antibodies, although there are several differences in procedure. In Bowey's procedure, there is complete overlap between prime and target because every letter in the prime is contained in the target. Also, the prime was presented for 120 ms before being masked, and it is possible that different processes were at work as compared with when the prime was presented for only 50–60 ms. It remains to be seen whether the facilitatory effects of antibodies and high-frequency bodies are under the control of the exposure time of the prime, but if so, the picture would be even more complex.

A similar question is raised by the work of Ferrand and Grainger (1992). By using the same priming paradigm as we used in our experiments, they found no orthographic priming for four-letter French targets (e.g., *lonc*–*LONG* and *slan*–*CLAN*) at a prime duration of 64 ms, but at 32 ms, there was a substantial effect. Because these targets were four letters in length, it seems likely that they were high *N*,⁹ and hence the absence of priming at 64 ms is to be expected because it is unlikely that these targets accidentally contained low-frequency bodies or antibodies that were preserved in the prime. However, the reappearance of priming at 32 ms for the same items suggests that density is irrelevant at this prime duration, just as Bowey's data suggest that it might also be irrelevant at longer prime durations. If these effects can be replicated, then it would appear that there is something special about a prime duration of 50–60 ms.

Another issue raised by the work of Ferrand and Grainger (1992) concerns the role of purely phonological processes in masked priming. Ferrand and Grainger found that an orthographic neighbor could produce priming in a high-density environment if it was phonologically identical to the target (e.g., in French, *lont*–*LONG*), but this effect was obtained only for 64-ms primes and not for 32-ms primes. This suggests that priming can be mediated by phonological similarity as well as orthographic similarity but only if sufficient time is allowed to develop a phonological representation of the prime. The fact that phonological priming is found in the absence of orthographic priming (e.g., *lont*–*LONG* vs. *lonc*–*LONG* at 64-ms stimulus onset asynchrony) might seem to create problems for the present approach because it seems to imply that entirely different density constraints must apply, depending on whether priming is mediated by phonology or orthography. However, it is important to realize that the phonological primes are in fact identity primes, whereas the orthographic primes are merely form-related primes, and because the density constraint applies only to form-related primes, there is no reason why priming should not be obtained when the prime is homophonic with the target. If instead we used primes that were phonologically similar but nonidentical to the target (e.g., in English, *care*–*CHAIR*), then we would expect to find evidence for a density constraint in the phonological domain that corresponds to the constraints described in the orthographic domain.

Another issue that needs to be explored is whether body and antibody frequencies influence unprimed lexical decision times for word and nonword targets. By analogy with the effects of *N* demonstrated by Coltheart et al. (1977), high-*BF* nonwords (e.g., *SHRITE*) might be expected to take longer to classify than low-*BF* nonwords (e.g., *GRIMPSE*), with similar predictions for

high-*ABF* nonwords (e.g., *PRITE* vs. *BRUST*). Currently, it is not known whether this is the case, although it seems very plausible. The situation for word targets is slightly more complex, owing to disagreement about whether *N* has an inhibitory effect (Grainger et al., 1989), a facilitatory effect (Andrews, 1989), or no effect at all (Coltheart et al., 1977). The answer to this question must await further research, though there are some suggestions that the effect will turn out to be facilitatory. For example, Taft (1991) reported that words with a high body frequency take less time to respond to than words with a low body frequency when matched on *N* (e.g., *WHEEL* vs. *CLAIM*). Similarly, Brown (1987) found that words containing common orthographic rimes were named faster than words containing uncommon rimes.

Finally, it should be stressed that the results reported in this article deal only with monosyllabic words. Dealing with polysyllabic words raises a number of additional questions. For example, if it is assumed that the initial access to a lexical entry is strictly through its first syllable (as proposed in Taft, 1979), then the characteristics of the second syllable would be unimportant for priming. However, as mentioned earlier, Sanchez-Casas (1988) has reported priming effects for items such as *dred*–*HUNDRED*, which suggests that priming through the second syllable is possible. Thus it could be proposed that the bodies of noninitial syllables also play a role in priming (see Taft, 1992) and that there is a separate density constraint that applies to these units as well.

In summary, these experiments show that neighborhood density has to be understood as a complex, multilevel variable, suggesting that there are many different ways in which input features can activate lexical representations. The hypothesized effect of these multiple paths into the lexicon is to maintain a constant level of discriminability despite wide variations in neighborhood density.

⁹ Although perhaps not as high as in English because French appears to have fewer four-letter words than English.

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(Appendix follows on next page)

Appendix

Materials Used in Experiments 1–5

Materials Used in Experiments 1a and 1b

The following are high-*N* targets (uppercase) varying in body frequency. Primes are listed in the following order: related (body intact), related (body changed), and control.

High BF

feep weer bool WEEP; mip zop jow ZIP; phin chid pelk CHIN; gite kipe walf KITE; shat chan frob CHAT; cray trad swin TRAY; rawn larn cort LAWN; satch litch dourn LATCH; pum sim ras SUM; tod pog hee POD; woy jos meg JOY; nug teg bax TUG; knap snat glid SNAP; voo zoy pim ZOO; hoom doop teaf DOOM; bamp comp sert CAMP; vone zole gim ZONE; teep jeet fisk JEEP; san vin bis VAN; sump julp dete JUMP; tain goin losk GAIN; ork arl wep ARK; tump bamp leet BUMP; blay clab moid CLAY; mand sant tift SAND; fush hish fank HUSH; drit grib vand GRIT; veed neek bish NEED; ged rud pon RED; trew braw tich BREW

Low BF

perd hird lisk HERD; dir fid keb FIR; hoan loon burd LOAN; roan moin telm MOAN; lonk hank vare HONK; fave sace poin SAVE; boap soat beld SOAP; sorch porth filst PORCH; nuy bur det BUY; yal pag cof PAL; dup cum fah CUP; rup pum cay PUP; sep pel hig PEP; vel gep lod GEL; miet diel boak DIET; pilk sirk pien SILK; bil nol dap NIL; terb heab jint HERB; hilk misk farb MILK; teaf leam musp LEAF; mowl forl kint FOWL; selp helk nait HELP; pulk bolk dape BULK; fise wite plon WISE; pise rine quab RISE; cald balf sood BALD; jarb burb soin BARB; weef beel hoiil BEEF; gix sim tob SIX; blex flix bawn FLEX

Materials Used in Experiments 2a and 2b

The following are low-*N* targets (uppercase) varying in body frequency. Primes are listed in the following order: related (body intact), related (body changed), and control.

High BF

shree thren splan THREE; shrite sprote flench SPRITE; stog smot thip SMOG; cred brod chon BRED; pleach proach sloint PREACH; thwill threll swant THRILL; shrone thront splift THRONE; shart smark phole SMART; snee knoe slod KNEE; spile smide prend SMILE; slub clum stin CLUB; blan plag brog PLAN; flear cloar froin CLEAR; prue troe plon TRUE; trape drame thurl DRAPE; blouch slorch brilst SLOUCH; guail quall gloaf QUAIL; spail snoil plout SNAIL; pruck plick trine PLUCK; prot trob plab TROT; preck wresk plast WRECK; scress strass cloach STRESS; brust trush blaph TRUST; clain ploin croad PLAIN; frive drice flack DRIVE; screet streen thrain STREET; pround grount pleast GROUND; scrool schoop threep SCHOOL; scleen spleet chrove SPLEEN; shum chim slet CHUM; glub grum blim GRUB; gleeck sleeef groon SLEEK; crouit trouid claid TROUT; smoil spoll melch SPOIL; sclatch scretch flounge SCRATCH; blope slupe brusks SLOPE; cheel when cloon WHEEL; fress pross flone PRESS; shuare squale chealt SQUARE; shand stend chert STAND; grought brought glainst BROUGHT; trug thup prad THUG

Low BF

porld worlt panst WORLD; toard hourd teace HOARD; beud foud boin FEUD; foost boosh feech BOOST; thriek shrief twearn SHRIEK; sprict srint thwang STRICT; laist waint lound WAIST; sifth firth sulge FIFTH;

joem porm jark POEM; mearch searh mought SEARCH; clarge charge blunct CHARGE; dause caust tarsh CAUSE; tiece pieve tarsh PIECE; vearn leard vould LEARN; sluje fluce stong FLUKE; cref ched trid CHEF; trumb thimb brike THUMB; cluise craise blaunt CRUISE; firch barch fange BIRCH; tulb bulf tarf BULB; spelf sheld prind SHELF; croice chorce britch CHOICE; doint joint dauce JOINT; chowd cowl shurl CROWD; presh frest plont FRESH; spraight staught throunge STRAIGHT; parge lange pinth LARGE; clurch chunch slange CHURCH; prek tren plin TREK; jearn yeard jould YEARN; thuce trude shink TRUCE; guartz qualtz gearch QUARTZ; hinc zint helt ZINC; blonze brooze clatch BRONZE; grimipse glirpse spretch GLIMPSE; treme thime crift THEME; craim clait grint CLAIM; lird birk lonk BIRD; fign sirn fard SIGN; nype tupe nusk TYPE; gorth nerth gench NORTH; nizz fazz nart FIZZ

Materials Used in Experiment 3

The following are targets (uppercase) varying in antibody frequency. Primes are listed in the following order: related (antibody intact) and control.

High ABF

shrimb bleast SHRIMP; prite twalk PRIZE; guipe droot GUIDE; quane smint QUAKE; squark thrilp SQUAWK; scranth flought SCRATCH; swilk drote swill; snarch quearn SNATCH; flast prine FLASK; plusp frect PLUMP; trasp glune TRAMP; twirk plade TWIRL; thisk crale THICK; drave swork DRAPE; grast fline GRAFT; gnay shid GNAW; whish smalt WHISK; quile thurd QUITE; strint thwank STRICT; throbe splift THRONE; smact quope SMACK; plavue sterch PLAGUE; twince skulch TWINGE; gramp blint GRASP; whize knosk WHITE; blash whenk BLAST; brask chire BRASS; wrike swamb WRITE; clarp strin CLASP; slaft phoke SLANT

Low ABF

thrapp splick THRASH; brust chode BRUSH; treld glume TREND; quelt smark QUELL; squench throost SQUELCH; blesh whift BLESS; scrowl flunch SCROLL; plerge statch PLEDGE; shrep blask SHRED; grust flope GRUNT; prute twest PRUNE; twank plike TWANG; twelse skicth TWELVE; drenge swinch DREDGE; grote blunk GROPE; gnove shisk GNOME; whaze knept WHALE; guesh droak GUESS; quone thenk QUOTE; plicht fround PLIGHT; thown crade THORN; swelp drime SWELL; whard smink WHARF; slent phame SLEPT; wronk swith WRONG; stretch thwirst STRETCH; smelk quife SMELL; flest pramp FLESH; snurf quang SNUFF; clert strug CLEFT

Low BF

mearn doust YEARN; voint pauld JOINT; gorch nalp PORCH; rault poard VAULT; clinge plurst CRINGE; trumb snafe THUMB; speuth draint SLEUTH; thuce stamb TRUCE; spriek thward SHRIEK; nurch belge LURCH; lince horth MINCE; toard cuite HOARD; treme blisk THEME; sloff fruss SCOFF; wriff smelk WHIFF; fruke gramp FLUKE; binch lurve FINCH; wause teign CAUSE; spelf wript SHELF; plobe clush PROBE; starf drent SCARE; gooth weard BOOTH; fruise glooth CRUISE; smetch flunge SKETCH; dorth jinst NORTH; foost maive BOOST; plaise skerth PRAISE; gridge ploint BRIDGE; tryme snarp THYME; sweaf guoud SHEAF

Materials Used in Experiment 4

The following are targets (uppercase) varying in torso frequency. Primes are listed in the following order: related (torso intact) and control.

High-Frequency Torso

blouge craist BLOUSE; praive flourd PRAISE; drash theek BRASH; creet plind CREEP; troud blesh TROUT; clane swick PLANE; plice crout SLICE; frisp slund CRISP; prawl wholk CRAWL; trach glost TRACE; slint shoop FLINT; prawn quern PROWL; fresk plunt FRESH; shrief glound SHRIEK; spleet throak SPLEEN; frane smirt CRANE; drince bloost PRINCE; grune quald PRUNE; bronge plirst BRONZE; prush flemf CRUSH; flast twild FLASK; buile troff GUILF; grask shunk GRASP; trone clesk PRONE

Low-Frequency Torso

broin claud BROIL; cruem floit CRUEL; glake thoon FLAKE; skung plith SKUNK; cluce brend CLUCK; troke swint BROKE; plide croin SLIDE; flobe scaft GLOBE; plave whonk SLAVE; shact glord SHACK; slaze shoom BLAZE; slopt queck SLOPE; slepe prush SLEPT; sleuch gradge SLEUTH; claue threll CLAUSE; thade clisk SHADE; bluke drost FLUKE; gleft quard CLEFT; swerge plaint SWERVE; plove freld GLOVE; swirt trank SWIRL; buote triss QUOTE; skirm blosp SKIRT; trake clent BRAKE

Materials Used in Experiment 5

The following are targets (uppercase) varying in *N*. Primes do not contain body or antibody. Primes are listed in the following order: related and control.

High N

troin snaff TRAIN; griss yarnd GRASS; shoap glost SHEEP; sheur bryge SHEER; slent drolg SLEET; bronk staip BRINK; prine whurx PRONE; shuke twirf SHAKE; grete zoift GRATE; fluck plaje FLOCK; berb ghov BARB; harb vlar HERB; grepe choop GRAPE; brench shrung BREACH; grat tosk GRIT; flig dirn FLOG; steil coant STEEL; shont prist SHOUT

Low N

snaul jight SNAIL; knie grum KNEE; trut frap TROT; theg waip THUG; wrup hisk WRAP; queel narth QUELL; twoce barst TWICE; phuse skilp PHASE; whoff moith WHIFF; knaght smeach KNIGHT; queck sweel QUICK; blewd nirst BLEED; thunk serth THANK; chilk gelp CHALK; ploa cait PLEA; gniw hurm GNAW; truf minn TRUE; turch zeang TORCH

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