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When More Is Less: A Counterintuitive Effect of Distractor Frequency in the Picture–Word Interference Paradigm

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Pictures were shown with superimposed word distractors of high and low frequency. Low-frequency distractors produced greater interference on picture naming than did high-frequency distractors. This distractor frequency effect was not affected by manipulations that facilitated or hindered distractor recognition. Interference was reduced for distractors that were read aloud several times prior to being shown in the picture-naming task. Together these findings suggest that the distractor frequency effect has its locus at some stage of lexical access for production. Other findings further constrain hypotheses about which level of speech production is involved in the effect. The distractor frequency effect has implications for models of lexical processing in speaking as well as for accounts of picture–word interference and the frequency effect.

Two effects, reliably observed in picture naming, have received much attention from researchers interested in word production: the name frequency and the word interference effects. The first effect refers to the observation that pictures with high-frequency (HF) names are named faster and more accurately than pictures with low-frequency (LF) names (e.g., Oldfield & Wingfield, 1965). The second effect refers to the fact that it takes longer to name a picture when it is shown along with a word. The Stroop effect, obtained in the color-naming task, is perhaps the best known case of word interference. The phenomenon of word interference can be observed with all sorts of pictures (not only colors) and all sorts of words (not only semantically related words; for reviews, see Deyer, 1973; Glaser, 1992; MacLeod, 1991). For example, it takes longer to name the picture *dog* when it is shown with the word *cup* compared with when the picture is shown with a nonsense string of letters (e.g., *uvc*). The interest in the effects of frequency and word interference originates in part from the view that these effects involve the selection of the pictures' names rather than other stages of picture naming (e.g., picture recognition or meaning retrieval), and, therefore, they could be used to inform theories of lexical access (Caramazza, Costa, Miozzo, & Bi, 2001; Dell, 1990; Jescheniak & Levelt, 1994). One type of evidence cited in support of the claim that the frequency effect has its locus at some stage of lexical access is the observation that the effect disappears (or is considerably reduced) in tasks that do not require oral naming (e.g., Bartram, 1976; Jescheniak & Levelt, 1994; Wingfield, 1967). Thus, for example, the time needed to recognize whether a spoken name matches a picture is statistically identical for common and rare objects (Wingfield, 1968). Analogously, the strong interference effect produced by semantically related words is not found when words are superimposed on pictures presented for judgments as to whether the pictures are new or old (e.g., Schriefers, Meyer, & Levelt, 1990).

Current models of word production have proposed various accounts for the effect of word interference (e.g., Caramazza & Costa, 2000; Glaser & Glaser, 1989; Levelt, Roelofs, & Meyer, 1999; Roelofs, 1992; Schriefers et al., 1990; Starreveld & La Heij, 1996), but they share a core assumption about the process of lexical selection. Widespread consensus holds that in the course of word retrieval, the semantic system activates the lexical nodes of a set of related words. For example, if a speaker wants to produce the word *dog*, the lexical nodes of *cat*, *fox*, *animal*, *leash*, and so on are activated. The lexical node with the highest activation level is selected for further processing. The selection process is assumed to be sensitive to the relative activation levels of all lexical nodes—the more similar the activation levels of the target word's lexical node and other lexical nodes, the more difficult the selection decision. In other words, selection is a competitive process, based on the relative activation levels of lexical nodes.

This general assumption about the lexical selection process provides the basis for explaining a variety of findings obtained in the picture–word interference paradigm. One such finding, originally demonstrated by Klein (1964) and replicated in a number of studies since then, is that word distractors (e.g., *cup*) interfere more than nonword distractors (e.g., *cuv*). Nonword distractors do not strongly activate specific lexical nodes and, therefore, are expected to interfere less than do word distractors, which strongly activate specific lexical nodes. The assumption of selection by competition also provides an explanation for the finding that the largest inter-

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ference is observed with semantically related picture–word pairs (e.g., *dog–fox*; Klein, 1964; Lupker 1979; Lupker & Katz, 1982; Rosinski, Golinkoff, & Kukish, 1975). To account for this result, it is assumed that semantically related word distractors reach a very high level of activation, thereby providing stiff competition for the selection of the target response (Klein, 1964; Roelofs, 1992; Schriefers et al., 1990; Starreveld & La Heij, 1996). The logic of this assumption is as follows. We mentioned earlier that a common assumption of current theories of lexical access is that a given semantic representation activates not only its corresponding lexical node but also, to a lesser degree, the lexical nodes of related words. To illustrate, the concept *dog* activates the lexical nodes *dog*, *fox*, *raccoon*, *cat*, and so on. Because of this property of the lexical system, the lexical node of the semantically related distractor *fox* is activated both by the word distractor *fox* and by the related picture *dog*, but the lexical node of an unrelated word (e.g., *cup*) is activated only by the word distractor itself (*cup*). As a consequence, the activation level of a semantically related distractor (*fox*) is higher than that of an unrelated distractor (*cup*). And assuming that selection difficulty is an inverse function of the similarity in activation levels of the target and distractor lexical nodes, related distractors are expected to lead to greater interference than are unrelated distractors.

Additional assumptions are needed to explain why distractors produce interference rather than facilitation. One explanation is that the amount of activation from the target lexical node to the distractor node is greater than the reverse activation flow. Continuing with our example, larger activation is received by the distractor *fox* from the picture *dog* than by the picture *dog* from the distractor *fox*. This assumption could be motivated in various ways (see Allport, Tipper, & Chmiel, 1985, for a discussion of this point). The most straightforward is that the target node reaches a higher level of activation than the distractor node because the former is coming through the attended channel (picture). If it is also assumed that the activation sent from one node to another is proportional to the activation level of the node sending the activation, then it would follow that the target lexical node will send larger activation to the distractor node than vice versa.

In essence, current theories of word production explain the phenomenon of word interference in terms of relative activation levels of lexical nodes: If a distractor activates a lexical node, there is interference, and interference is proportional to the level of activation of the distractor. We refer to this explanation of the effect of word interference as the *relative activation hypothesis*. A more detailed characterization of the mechanisms underlying the effect of word interference could be obtained by considering the role of word frequency in lexical access. Various explanations have been given for the role of word frequency in lexical access. According to one explanation, HF words are processed faster because they reach a higher level of activation than LF words do. This arises because HF words have higher resting activation levels (e.g., McClelland & Rumelhart, 1981). This difference in activation levels has the implication that an HF word needs less activation to reach a selection threshold and thereby can be retrieved faster than an LF word (see Figure 1A). We refer to this explanation of the word frequency effect as the *activation level hypothesis*. An important consequence of this hypothesis is that given equal amounts of activation, HF and LF lexical nodes would reach different levels of activation at some specified point in time in the course of lexical access, with HF words reaching the higher levels of activation. A precise prediction follows from this assumption about activation levels for the degree of interference produced by HF and LF word distractors. If word distractors interfere in proportion to their activation levels, as assumed in the relative activation account, HF distractors would be expected to interfere more than LF distractors (for a similar prediction, see Klein, 1964). Note, however, that this prediction only follows if word frequency affects activation level at the processing stage where lexical selection competition occurs; otherwise, distractor frequency should have no effect on naming latencies in the picture–word interference paradigm.

Another explanation of the word frequency effect is based on the assumption that frequency determines the selection threshold of lexical nodes (e.g., Jescheniak & Levelt, 1994; Morton, 1969). On this assumption, HF words have lower selection threshold settings than LF words (see Figure 1B). We refer to this explanation of the word frequency effect as the *selection threshold hypothesis*. A property of the selection threshold hypothesis that is of particular relevance here is the assumption that at stages preceding selection, frequency does not affect a node's activation level. That is, if HF and LF nodes receive equal amounts of activation, they would presumably reach identical levels of activation. Hence, if the degree of interference in the picture–word interference task depends on the distractors' activation levels, HF and LF distractors should produce equal amounts of interference.

In sum, depending on the assumptions one makes about the role of frequency in determining a lexical node's activation level, different results are expected for the effect of distractor word frequency in the picture–word interference paradigm. The activation level hypothesis of the frequency effect predicts that HF distractors should interfere more than LF distractors; in contrast, the selection threshold hypothesis predicts that HF and LF distractors should interfere equally. One result that is not expected by either account is greater interference for LF words than for HF words. This outcome is not expected because no current account of lexical activation assumes that LF words reach higher levels of activation than HF words do.

The results of two studies in which the effects of distractor interference were investigated are consistent with the relative activation hypothesis and seem to favor the resting level explanation of the effect of frequency. With the Stroop color-naming task, Fox, Shor, and Steinman (1971) and Klein (1964) found that HF words interfered more than LF words did. Fox et al. (1971) also obtained greater interference for HF distractors than for LF distractors in a task in which participants named the position of the word in a square (i.e., up, down, left, right). In this task, HF position word distractors interfered more than LF word distractors with the choice of the appropriate position descriptor.

However, there are several reasons for caution in interpreting these results. First, only very small sets of items were used in the two studies (a maximum of four HF and four LF words in each study). Second, the words were not matched for factors that have since been shown to affect word recognition (e.g., number of neighbors or spelling-to-sound regularity). Thus, we cannot rule out the possibility that the different effects obtained with HF and LF distractors could be the result of these uncontrolled factors. Third, the four LF words that Klein (1964) used in his study (*sol*, *eft*, *helot*, *abjure*) are extremely rare, as demonstrated by the fact

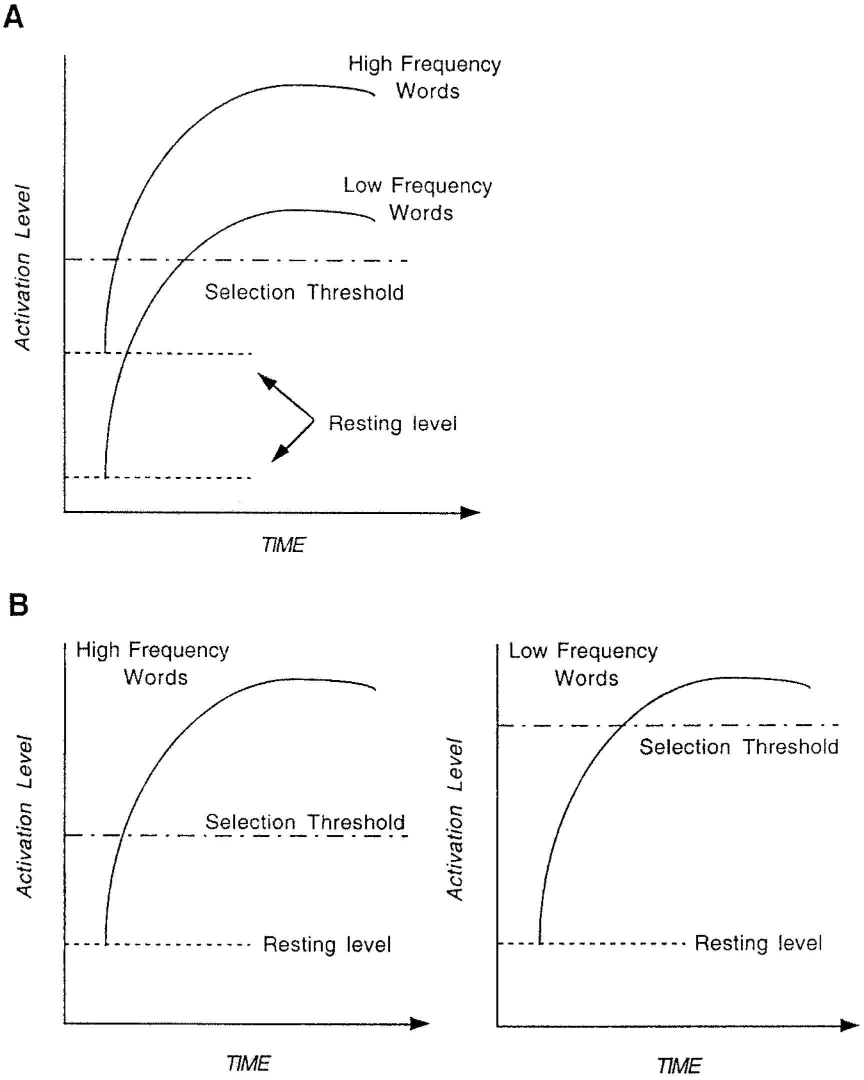

Figure 1. Schematic illustration of the activation level and the selection threshold assumed by the activation level hypothesis (A) and by the selection threshold hypothesis (B) for high- and low-frequency words.

that none of them is listed in the Francis and Kucera (1982) corpus. These rare words, if not known by the participants, would have been functionally equivalent to nonwords and hence would have interfered much less than HF words. Finally, in a study investigating the effect of distractors' grammatical gender in Dutch, La Heij, Mark, Sander, and Willeboordse (1998, Experiment 3b) reported a seemingly contrasting finding: More interference was observed for low- rather than high-familiarity distractors. In short, it is unclear from the available literature whether and how distractor frequency might affect word interference.

In this article, we report an extensive investigation of the role of distractor frequency in the picture–word interference task. The results of our investigation provide a direct test of the claim that word distractors interfere with the selection of the target lexical nodes in proportion to their respective levels of activation. The article is organized into three sections. First, we establish that distractor frequency modulates the interference effect in the picture–word interference paradigm and the direction of the modulation. To anticipate our results, we found that contrary to the expectations derived from the activation level and selection threshold hypotheses, HF words interfere less than LF words do. Next, we rule out an input account of the distractor frequency effect. That is, we show that manipulations known to affect word recognition do not interact with distractor frequency but that manipulations known to affect word production do interact with distractor frequency. Finally, we describe a series of experiments in which we attempted to establish the locus of the distractor frequency effect within the lexical access process in speech production. To anticipate our results once again, we found that the semantic relatedness and frequency of the distractor do not interact but that the phonological relatedness and frequency of the distractor do interact, suggesting a fairly peripheral output locus of the frequency effect. This pattern of results raises difficult questions for the interpretation of results obtained with the picture–word interference paradigm. More generally, our experimental results provide a severe challenge to current models of the processes involved in lexical selection during speech production.

Experiment 1: Distractor Frequency

The objective of Experiment 1 is to firmly establish whether—and if so, how—distractor frequency modulates the effect of word interference observed in the picture–word interference task. For this purpose, we compared HF and LF unrelated word distractors. We took two precautions to maximize the likelihood of observing an effect of distractor frequency. First, we selected stimuli from the two extremes of the frequency distribution: very common words ($>$ 80 counts per million; e.g., *water, house*) and relatively unfamiliar words ($<$ 15 counts per million; e.g., *fern, dove*). Second, we controlled for several factors known to affect word reading and distractor interference, including concreteness, grammatical class, word length, consonant–vowel (CV) structure, spelling-to-sound regularity, sound-to-spelling consistency, number of neighbors, bigram frequency, and position of word distractors within the pictures. Furthermore, to replicate the effect of distractor frequency, we tested two lists of pictures and words: List A and List B. Each list was shown to a different group of participants. We also varied the proportion of LF words in the list. LF words appeared more often in List A (44% of the trials) than in List B (12% of the trials). This manipulation was introduced to rule out the possibility that the effect of distractor frequency varied as a function of the number of LF words included in the list, as had been the case for Glanzer and Ehrenreich (1979) in their lexical (word–nonword) decision task. Finally, in an attempt to define the boundaries of the effect of distractor frequency, we factorially varied the frequency of the names of the target pictures in List A.

There is a growing literature on the issue of whether the effects of word frequency are better described in terms of the age at which a word is learned (*age of acquisition* [AoA]; see, e.g., Barry, Morrison, & Ellis, 1997; Brown & Watson, 1987; Carroll & White, 1973; Gilhooly & Logie, 1980). Word frequency and AoA are highly correlated, and this also holds for the distractors used in our experiments. Furthermore, word frequency and concept familiarity (an index of how frequently people encounter or think of a given object) are also confounded in our stimuli. Therefore, we cannot rule out that AoA, concept familiarity, or a combination of both could be the variable underlying any observed effect of distractor frequency. Our use of the term *frequency* is not intended to prejudge this issue: It simply reflects our use of frequency norms. We leave the issue of characterizing the independent contributions of frequency, AoA, and concept familiarity to future investigation.

Method

Participants

In this and the following experiments, participants were native speakers of English attending either Harvard University or Columbia University. They were paid for their participation. Twenty-six participants were tested with List A and 20 participants with List B. The participants who were asked to rate the stimuli (see below) were from the same pool.

Material

Both picture names and word distractors were controlled for frequency. We used *cumulative* frequency—the summed frequency of singular and plural forms of a noun as listed in Francis and Kucera's (1982) corpus. For List A, we selected 40 pictures: 20 with HF names (range = 90–393 counts per million; $M = 180$), and 20 with medium-frequency names (range = 16–30 counts per million; $M = 23$). The 20 pictures in List B have names in the medium-frequency range ($M = 33$ counts per million). Each picture was paired with two semantically and phonologically unrelated words, one HF and the other LF. The picture–word pairs used in Experiment 1 are reported in Appendix A. HF and LF words were controlled for AoA, concept familiarity, and concreteness. Three different groups of 10 participants rated AoA, concept familiarity, and concreteness on a 7-point scale where 1 indicated early age, very unfamiliar, or abstract, respectively. For the AoA norms, we followed the procedure of Gilhooly and Logie (1980). If not stated otherwise, two-tailed t tests were used to compare the parameters of HF and LF words, and the significance threshold was set at .05. Separate analyses were carried out to evaluate the appropriateness of the distractors selected for List A and List B. As expected, HF words were acquired earlier and were more familiar than LF words (see Table 1). To avoid possible effects of grammatical class, we only selected nouns for the lists. LF words were significantly more abstract than HF words were in List A ($p < .001$) but not in List B ($t < 1$; see Table 1). In List A, HF and LF words had identical CV structures and length (number of letters); in List B, words were only matched for length ($t < 1$). HF and LF words were also controlled for number of neighbors and word mean bigram frequency (means are reported in Table 2). Data about these parameters were obtained from the English Lexicon Project database (Balota et al., 2002). HF and LF words did not differ in their number of neighbors in either list ($p = .21$); however, in both lists, HF words had marginally significant higher mean bigram frequencies (ps = .06); we will return to this difference in the *Results* section of Experiment 1. For the spelling–sound consistency variable, we report three measures. The first indicates the probability with which a letter or letter cluster maps onto a particular phoneme (Berndt, Reggia, & Mitchum, 1987; for both lists, HF vs. LF words, ts < 1). The second (*feedforward consistency*) involves word orthographic bodies (e.g., *-int* in *pint*) and refers to the number of words in which a given body maps onto the same phonology (friends) or onto a different phonology (enemies; Ziegler, Stone, & Jacobs, 1997). The third measure (*backward consistency*) considers the number of words in which a phonological body (e.g., the /*-int*/ of /*pint*/) corresponds to the same orthographic body (friends) or to a different orthographic body (enemies; Ziegler et al., 1997). For feedforward and backward consistency, data are only available for monosyllabic words. These factors were not controlled in List A, because only 60% of the words were monosyllabic; they were controlled in List B, where 38 out of 40 words (95%) were monosyllabic (see the summary in Table 2). HF and LF distractors of List B were comparable in terms of feedforward and backward consistency (ps $> .12$). Finally, to ensure that participants from

Table 1
Mean Measurements of the High-Frequency (HF) and Low-Frequency (LF) Word Distractors Shown in Experiments 1–2

	List A		List B	
Distractor variable	HF words	LF words	HF words	LF words
Age of acquisition (years)[a]	3.5	7.2*	4.3	7.7*
Concept familiarity	5.6	2.7*	5.3	3.3*
Concreteness	5.9	5.6*	3.9	4.1

[a] Procedure from Gilhooly and Logie (1980).
* Difference between HF and LF words significant at $p < .001$.

Table 2

Mean Measurements of the High-Frequency (HF) and Low-Frequency (LF) Word Distractors Shown in Experiments 1–4

	Experiments 1–2					
	List A		List B		Experiments 3–4	
Distractor variable	HF	LF	HF	LF	HF	LF
Frequency	287	3*	348	5*	340	4*
Length (number of letters)	4.8	4.8	5.9	5.9	4.5	4.5
Number of neighbors[a]	4.9	3.7	6.4	5.8	5.7	4.0
Word mean bigram frequency[b]	6,621	5,536	6,602	4,856	5,310	5,239
Grapheme–phoneme consistency[c]	.86	.86	.89	.93	.87	.91
Feedforward consistency[d]						
Number of friends	7.6	6.6	10.0	7.2	7.2	6.0
Number of enemies	0.8	1.1	1.0	0.8	1.3	0.8
Backward consistency[e]						
Number of friends	7.6	6.8	10.0	13.8	7.9	6.6
Number of enemies	4.8	5.7	10.5	4.6	6.4	3.4

[a] Coltheart's *N* count, a crude measure of a word's neighborhood density, obtained from the English Lexicon Project database (Balota et al., 2002). [b] Data from the English Lexicon Project database (Balota et al., 2002). [c] This is a parameter with a 0–1 range ($1 =$ maximum predictability) that is based on the probability with which each grapheme or graphemic cluster of a word maps onto a particular phoneme (Berndt et al., 1987). [d] Number of words in which a given orthographic body is phonologically realized as in the word distractor (friends) or differently (enemies; Ziegler et al., 1997). [e] Number of words in which a given phonological body is orthographically realized as in the word distractor (friends) or differently (enemies; Ziegler et al., 1997).

* Difference between HF and LF word distractors significant at $p < .001$.

our pool were highly likely to know the LF words included in the experiment, we asked 10 students to indicate if any word's meaning or pronunciation was unknown to them. None of the students found any of the words to be unknown.

Filler picture–word pairs were included to modulate the proportion of LF distractors presented in the experiment. List A contained 36 fillers, which were obtained by pairing a set of 18 pictures with 11 LF words (< 15 counts per million) and 25 medium-frequency and HF words (> 16 counts per million). Thus, in List A, LF distractors appeared in 44% of the trials (51 out of 116). A larger number of fillers (120) were included in List B. Forty of these fillers were obtained by pairing each of the pictures described above with 2 HF words. The remaining 80 fillers were obtained by pairing a new set of 20 pictures with 80 HF and medium-frequency words. Thus, in List B, LF words accounted for only 12% of the distractors (20 out of 160). In each list, fillers served as warm-up stimuli at the beginning of each block. All pictures appeared twice in List A and four times in List B. In both lists, distractors were shown only once.

Procedure

The following procedure was used in all of the picture–word interference tasks reported in this article. Pictures were centered at fixation. Words were typed in capital letters in Geneva 20-point bold font and were positioned in the area around fixation. For a given picture, words always appeared in the same location. Stimuli of the various experimental conditions were evenly distributed across the blocks. In a block, a given picture appeared once. Lists A and B both included four blocks. Trials were randomized with the constraint that (a) stimuli of the same condition were not to appear on more than three consecutive trials and (b) stimuli of the various conditions appeared with roughly the same frequency in the initial, middle, and final parts of a block. Only one trial randomization was used: Order of block presentation varied across participants. Participants were tested individually in a dimly lit testing room and seated at a distance of about 80 cm from the computer screen. The experiment started with a naming task aimed at familiarizing participants with the pictures and their names. Pictures were shown on a computer screen for unlimited exposure and without superimposed words. When participants produced a name other than the expected one, they were corrected. Such instances were very rare. Before the experiment proper, participants performed a long practice block in which all the pictures were presented twice with a superimposed distractor. The distractors shown in the practice trials were not used in the experimental blocks. Instructions emphasized response speed and accuracy.

A trial was structured as follows: Participants initiated the trial by pressing the space bar on the keyboard; the fixation point, a cross, appeared for 700 ms and was immediately replaced by the stimulus. Stimuli were removed as soon as participants responded or after 700 ms. Stimulus presentation was controlled by the PsychLab program (Bub & Gum, University of Victoria, British Columbia, Canada). Response latencies were measured by means of a voice key (Lafayette Instrument, Lafayette, IN). The experimenter recorded the responses manually.

Analyses

Responses scored as errors included (a) production of an unexpected name, (b) verbal disfluencies (stuttering, utterance repairs, production of nonverbal sounds that triggered the voice key), and (c) recording failures. Responses exceeding a participant's mean by 3 standard deviations (outliers) were excluded from analyses. Responses to fillers were not analyzed. The criteria outlined here for errors, outliers, and fillers were followed in all of the picture–word interference tasks reported in the present article except when noted otherwise. For response latencies, we report F_1 analyses (based on subjects' means) and F_2 analyses (based on items' means). F_1 analyses were replicated with participants' errors as the dependent variable. Error rates are typically low in the picture–word interference paradigm, and error analyses are rarely significant. We also report Cohen's *d*, an effect size index based on the standardized difference between the means. (Effects with *d*s in the 0–.29 range are considered small in size, those in the .30–.59 range medium in size, and those in the .60–.80 range large in size.)

In both lists, we used a fully within-subjects design and we analyzed distractor frequency (high vs. low) as a within-subjects variable. List A allowed us to examine the effect of picture-name frequency, which was treated as a within-subject variable in F_1 analyses and as a between-subject variable in F_2 analyses.

Results

List A

Errors and outliers accounted for 2.2% and 1.4% of the responses, respectively. Responses were 32 ms faster for pictures with HF names as compared with those with medium-frequency names (see Table 3), $F_1(1, 25) = 90.6$, $MSE = 304.2$, $p < .0001$; $F_2(1, 38) = 10.1$, $MSE = 2{,}021.3$, $p = .002$; $d = .65$. More important, responses were 18 ms slower for LF distractors than for HF distractors, $F_1(1, 25) = 35.1$, $MSE = 2{,}139.2$, $p < .0001$; $F_2(1, 38) = 16.8$, $MSE = 313.9$, $p = .0002$; $d = .34$. The interaction between target frequency and distractor frequency did not approach significance (*F*s < 1).

List B

Errors and outliers were observed in 1.3% and 1.0% of the trials, respectively. Naming latencies were 19 ms slower for pictures paired with LF distractors than for those paired with HF distractors (see Table 3), $F_1(1, 19) = 12.6$, $MSE = 281.4$, $p < .01$; $F_2(1, 19) = 4.5$, $MSE = 758.4$, $p < .05$; $d = .32$.

Two results deserve further discussion. First, in List A, LF distractors were significantly more abstract than were HF distractors. Although greater interference has been reported for abstract distractors (Lupker, 1979), an account of the effects reported here in terms of concreteness is in conflict with the results achieved when using List B, where greater interference was found for LF distractors even though HF and LF distractors were equated for concreteness (but see also Experiment 3 for converging results). Second, in both lists, word mean bigram frequency was marginally greater ($p = .06$) for LF distractors. To determine whether word mean bigram frequency was responsible for the HF-LF distractor difference found in Experiment 1, we ran a combined post hoc analysis on the responses to Lists A and B. We selected a group of 48 HF-LF pairs that were matched for word mean bigram frequency (means: HF = 1,569, LF = 1,473; $t < 1$), number of neighbors (means: HF = 17.5, LF = 18.2; $t < 1$), and Berndt et al.'s (1987) spelling-to-sound consistency (means: HF = .87, LF = .90), $t(96) = -1.21$, $p = .22$, but that differed in frequency (mean counts per million: HF = 464, LF = 4), $t(96) = 2.16$, $p = .03$. With this subset, naming latencies were reliably longer for LF distractors than for HF distractors (means: 730 vs. 713 ms), $F_2(1, 48) = 17.4$, $MSE = 6{,}844.5$, $p = .0001$; $d = .42$. The results of these post hoc analyses make it unlikely that word mean bigram frequency was responsible for the results found in Experiment 1.[1]

Table 3
Picture-Naming Latencies (ms) for High-Frequency (HF) and Low-Frequency (LF) Word Distractors Shown in Experiment 1

	Picture name/frequency		
Words/effect	High	Medium	Frequency effect[a]
List A			
LF words	708	742	−34
HF words	692	723	−31
Distractor frequency effect[b]	16	19	
List B			
LF words	738		
HF words	719		
Distractor frequency effect[b]	19		

[a] Difference between pictures with HF and medium-frequency names. [b] Difference between LF and HF word distractors.

Discussion

We found that LF distractors interfered with the production of target responses more than HF distractors did, a result that is surprising and in conflict with the expectations derived from the relative activation hypothesis of word interference and prevalent accounts of the effect of frequency on the activation level of lexical nodes. We refer to this effect as the *distractor frequency effect*. It is unlikely that this effect is a spurious finding.[2] We obtained the result with two large lists of stimuli, and we carefully controlled for numerous factors known to affect word reading, including word length, grammatical class, number of neighbors, word mean bigram frequency, concreteness, and spelling-to-sound regularity. In short, it does not seem likely that a variable other than frequency is responsible for the observed difference between HF and LF distractors. Other findings of Experiment 1 help clarify various aspects of the distractor frequency effect. The proportion of LF distractors shown in the experiment did not modulate the effect, because effects of comparable magnitude were observed when LF distractors appeared in 44% and in 12% of the trials. Moreover, the results of the trials in which List A was used reveal that the effect of distractor frequency generalizes across pictures with names from a wide range of frequencies. Finally, we found that the magnitude of the distractor frequency effect is similar for pictures shown with HF and medium-frequency noun distractors.

Before we explore the implications of the distractor frequency effect for claims about lexical access in word production, an alternative interpretation of the results must be considered. Perhaps the locus of the effects observed in Experiment 1 is not at the level of lexical selection for production but at the input level. It could be argued that the observed frequency effect reflects interference induced by relative difficulties in recognizing HF and LF word distractors. If such were the case, the frequency effect obtained in our experiments would not be relevant to issues about lexical access in language production. Next, we articulate an *input hypothesis* that may account for the finding of greater interference with LF words, and Experiments 2 and 3 will test this hypothesis.

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[1] In all the other experiments reported in this article, HF and LF distractors were better balanced in terms of bigram frequency (*p*s > .23), yet we consistently found a reliable difference between HF and LF distractors.

[2] Max Coltheart (personal communication, February 1999) reanalyzed the data of a series of Stroop color-naming experiments he carried out. He found greater interference for LF word distractors than for HF word distractors. These results further attest to the robustness of the effect of distractor frequency.

The Effect of Distractor Frequency: An Input Effect?

Participants in the picture–word interference paradigm cannot avoid recognizing the distractor words even though they are instructed to ignore them and to concentrate on the pictures. In this paradigm, word recognition seems to be a task that participants perform automatically, in the sense of unintentionally or involuntarily. However, if one took the term *automatically* in the previous sentence to also mean that no resources are expended in the process of word recognition, one would then have to reject out of hand the possibility that the distractor frequency effect has an input locus. On the view that word recognition does not require processing resources, there would be no basis for the claim that the effect of distractor frequency reflects differences in the resources needed to recognize HF and LF distractors. However, this view is not uncontroversial (see Besner, Stolz, & Boutler, 1997, for a critical analysis of the notion of automaticity in the picture–word interference paradigm), and, to the best of our knowledge, no clear evidence shows that word recognition occurs automatically, in the sense of not requiring processing resources. In light of these considerations, it seems that an input locus for the distractor frequency effect cannot be discounted on strictly theoretical grounds. Therefore, we chose to assess empirically whether an input resource account can explain the observed distractor frequency effect.

The picture–word interference task can be conceived of as a sort of dual processing task. When two tasks are performed simultaneously, one task interferes with the other and performance is less efficient. The difficulty in performing simultaneous tasks presumably results from the fact that the cognitive system has limited capacity: When more than one task is performed at the same time, fewer resources can be allocated to each task (e.g., Kahneman, 1973; Navon & Gopher, 1979; Pashler, 1994; Wickens, 1980). The resources that are allocated to word recognition in the picture–word interference task are subtracted from the picture-naming process, and consequently the latter task is performed less efficiently. One may reasonably assume that the additional task interferes in proportion to the resources needed for its execution: the more resources, the more interference. As demonstrated in innumerable studies (e.g., Foster & Chambers, 1973; Monsell, Doyle, & Haggard, 1989), LF words are more difficult to recognize than HF words. Consistent with this observation, it could be argued that more resources are needed for recognizing LF words than HF words. And if the degree of interference on picture naming is proportional to the resources taken up by the secondary word recognition task, we would expect greater interference from LF words than HF words. We refer to this explanation of the distractor frequency effect in picture-word naming as the *input interference* account.

Given the relation between reading difficulty and word interference postulated by the input interference account, one can derive the following predictions. First, if word recognition becomes more difficult, word interference should increase. Second, as word recognition becomes easier, word interference should decrease. These predictions are tested in the next two experiments.

Experiment 2: Alternated-Case Distractors

Previous investigations have demonstrated that case alternation impairs word recognition. For example, in three experiments, Mayall, Humphreys, and Olson (1997) observed that reading latencies were between 50 and 78 ms slower for alternated-case words than for lowercase words. Similar disrupting effects were observed with alternated-case letters in a variety of tasks, including letter identification (e.g., McClelland, 1976), lexical decision (e.g., Besner & McCann, 1987), and semantic categorization (Mayall & Humphreys, 1996). To be consistent with these results, it should be harder to recognize word distractors shown with alternated-case letters and, as predicted by the input interference account, we should find greater interference for distractors in this format. However, there are reasons for thinking that the latter expectation may not be met. Previous research in which word recognition in the Stroop color-naming task was slowed down has not revealed an effect of this manipulation on the magnitude of the interference effect. Using a Stroop task, Dunbar and MacLeod (1984) showed the word distractors upside down and/or backward. Although it took participants longer to read upside down and backward words, these distractors interfered as much as distractors presented with a canonical orientation. Experiment 2 was designed to confirm this effect in the context of the picture–word interference paradigm.

Method

Participants

Twenty-four native English speakers, divided into two groups (Groups 1 and 2), took part in Experiment 2.

Material and Procedure

We used the list of 40 pictures and 40 HF-LF word pairs of List A of Experiment 1 (see Appendix A). Word distractors were presented in two formats: alternated case (e.g., *hAnD*) and single (upper) case (e.g., *HAND*). We prepared two word lists, each comprising the 40 HF–LF word pairs. A word pair appeared in different formats in the two lists. For example, the picture *chair* appeared with the HF distractor *HAND* in one list and with the distractor *hAnD* in the other list. Upper- versus alternated-case words were equally represented in the two lists. In both lists, picture–word pairs were presented in the same order. Participants were presented with only one list. This precaution was taken to avoid the possibility that a preceding presentation of the word reduced the effect of case alternation. Each list was shown to a different group of 12 participants. Fillers ($N = 40$) were also presented and were created by pairing a picture with an unrelated single-case word. Alternated-case words were shown on one third of the trials. Picture–word pairs ($N = 120$) were presented in three blocks of 40 trials. Examples of alternated-case words were shown during practice trials.

Results and Discussion

Errors accounted for 3.3% of the responses, outliers for 1.8%. We analyzed two within-subjects variables: distractor frequency (high vs. low) and case (single vs. alternated). As is evident from Table 4, responses were slower for pictures paired with LF distractors than with HF distractors, $F_1(1, 23) = 33.1$, $MSE = 234.1$, $p < .0001$; $F_2(1, 39) = 27.5$, $MSE = 472.6$, $p < .0001$. The distractor frequency effect with single-case words had an effect size of .32. As in Experiment 1, response latencies were faster for pictures with HF versus LF names, $F_1(1, 23) = 9.2$, $MSE = 924.7$, $p = .005$; $F_2(1, 38) = 6.4$, $MSE = 3{,}425.4$, $p = .01$; $d = .27$, and picture-name frequency did not affect the size of the distractor

Table 4
Picture-Naming Latencies (ms) for High-Frequency (HF) and Low-Frequency (LF) Word Distractors Shown in Experiment 2

	Distractor case		
Words/effect	Alternated	Single	Case effect[a]
LF words	712	716	−4
HF words	696	696	0
Distractor frequency effect[b]	16	20	

[a] Difference between word distractors with alternated and single case.
[b] Difference between LF and HF word distractors.

frequency effect (Fs < 1). Most important, there was no effect of distractor case (Fs < 1). We can thus conclude that contrary to expectations derived from the input interference account, the distractor format does not affect naming latencies and does not modulate the effect of distractor frequency.

A possible criticism is that the null effects of case alternation reflect a lack of power in our experimental design. However, it should be noted that the effect sizes of case mixing, ranging between 50–78 ms in word reading and between 65–143 ms in lexical decision (data from Mayall & Humphreys, 1996; Mayall et al., 1997), far exceed the effect size of about 20 ms observed with the distractor frequency effect. As our experimental design had the power to reveal this latter effect, it would also have the power to reveal the larger effect of case alternation, if there were any. In essence, a power argument does not seem to apply here. Furthermore, our results are in accord with those of Dunbar and MacLeod (1984) who, in a very similar task (the Stroop task), also failed to find an effect of the ease of word recognition on the magnitude of interference effect on picture (color) naming. The convergence of results increases our confidence that the null result is a real effect.

Experiment 3: Lexical Decision Plus Picture-Naming Task

The input interference account predicts that interference should decrease when word recognition becomes easier. A number of studies have shown that participants are faster and more accurate in discriminating between word and nonword stimuli when the stimuli are repeated (e.g., Forbach, Stanners, & Hochaus, 1974; Foster & Davies, 1984; Humphreys, Besner, & Quinlan, 1988; Kirsner & Speelman, 1996; McKone, 1995; Norris, 1984; Ratcliff, Hockley, & McKoon, 1985; Scarborough, Cortese, & Scarborough, 1977; Scarborough, Gerard, & Cortese, 1979; Theios & Muise, 1977). Suppose that words repeatedly shown for lexical decision are later presented as distractors in a picture–word interference task. The expectation, which is consistent with the input interference account, is that repeated words should interfere less than new ones. This prediction is based on the following chain of reasoning. Repeated words are recognized more easily and hence are discriminated faster (and more accurately) than new words in the lexical decision task. This means that fewer resources have to be devoted to recognizing repeated words. However, if distractors' interference depends on the resources needed for their recognition, repeated distractors are expected to interfere less. This prediction was tested in Experiment 3, where participants first performed a lexical decision task on words that were then used as distractors in a picture–word interference task.

Method

Participants

Two groups of 12 participants (Groups 1 and 2) took part in Experiment 3.

Material

We selected 40 words that were HF ($M = 340$, range = 142–717 counts per million) and highly familiar (mean ratings = 5.8) and 40 words that were LF ($M = 4$, range = 1–8 counts per million) and less familiar (mean ratings = 2.7; $p < .001$). HF and LF words had the same length (number of letters) and were controlled for number of neighbors, $t(78) = 1.70$, $p = .09$; word mean bigram frequency, $t < 1$; and Berndt et al.'s (1987) measure of grapheme-to-phoneme consistency, $t(78) = -1.71$, $p = .09$ (means are reported in Table 2). (Ziegler et al.'s 1997 consistency measures were not used because data were not available for 30% of the multisyllabic distractors.) Finally, HF and LF words did not differ in concreteness (mean ratings: 5.6 vs. 5.3; $t < 1$). We created two lists (List A and List B), each composed of 20 pairs of HF and LF words. Paired words had the same length and CV structure. These words were used as targets in the lexical decision task and as distractors in the picture-naming task. In the latter task, pairs from Lists A and B were superimposed on 20 pictures that had names in the medium-frequency range ($M = 39$ counts per million). (These were not the pictures used in Experiment 1, because we wanted to replicate the results with new materials.) Thus, each picture was matched with 2 HF words and 2 LF words (picture–word pairs are listed in Appendix B). For the lexical decision task, we selected 30 filler words and created 90 nonwords by changing one letter in common words (e.g., *roof* → *roop*). Words were shown in the same font but in lowercase in the lexical decision task and in uppercase in the picture-naming task. A set of 20 pictures was shown in the picture-naming task and served as filler. Each filler picture was paired with 4 unrelated words that were not shown in the lexical decision task.

Procedure

Lexical decision. Participants were presented with one list of HF-LF pairs (List A for Group 1 and List B for Group 2). Each list was repeated three times. Filler words and nonwords were shown once. Stimuli were divided into three blocks (Blocks 1–3), each composed of 40 words from List A or B, 10 filler words, and 30 nonwords. Trials were randomized with the constraint that stimuli requiring the same response were not presented in more than three consecutive trials. Only one randomization was used. The order of block presentation varied across participants. A training block of 60 trials preceded the experiment proper. A single trial initiated with the presentation of the fixation point (a cross), which remained on the screen for 700 ms and was replaced by the target word after a 60-ms interstimulus interval. Targets remained in view for 400 ms or were automatically removed if the response was initiated earlier. The intertrial interval was 1 s long. Participants responded by pressing different keys with their left and right hands. The response "word" was assigned to the left or right key depending on participants' hand dominance. Instructions emphasized both accuracy and speed. Outliers (responses that exceeded 3 standard deviations from a participant's mean) were removed from analyses. In the analyses, we considered two variables: word repetition (Block 1 vs. 2 vs. 3) and distractor frequency (high vs. low). These variables were treated as within-subjects variables, with one exception: In F_2 analyses, distractor frequency was considered a between-subjects variable.

Table 5
Response Latencies (ms) for High-Frequency (HF) and Low-Frequency (LF) Word Distractors Shown in Experiments 3–4

	Presentation			Picture naming/distractor		
Words/effect	First	Second	Third	Repeated	New	Repetition effect[a]
			Experiment 3: Lexical decision			
LF words	573	551	538	745	740	5
HF words	508	502	485	697	706	−9
Difference	65	49	53			
Distractor frequency effect[b]				48	34	
			Experiment 4: Reading aloud			
LF words	552	528	535	713	727	−14
HF words	516	511	525	678	688	−10
Difference	36	17	10			
Distractor frequency effect[b]				35	39	

[a] Difference between word distractors repeated in a preceding task (lexical decision or reading aloud) and new word distractors (presented for the first time). [b] Difference between LF and HF word distractors.

Picture naming. Each picture appeared four times: twice with words shown in the lexical decision task and twice with new words. For example, participants in Group 1 saw a given picture with the following words: once each with an HF and an LF word from List A, which they had seen in the lexical decision task, and once each with an HF and an LF word from List B, which they had not seen in the lexical decision task. The picture-naming task included a total of 160 trials (half of which were fillers). Distractors repeated in the lexical decision task were shown in 25% of the trials. Two within-subjects variables were analyzed in this task: distractor frequency (high vs. low) and presentation in the preceding lexical decision task (old vs. new).

Experiment Structure

At the beginning of the experiment, participants named all the pictures. They then performed the practice block of the picture–word interference task. Each picture in this practice task was presented twice. Participants then were introduced to the lexical decision task, practiced the task, and performed the experimental blocks. Finally, they returned to the picture–word interference task for the experiment proper.

Results

Lexical Decision Task

Errors were observed on 2.7% of the trials, and 1.5% of the responses were trimmed because of outliers. As can be seen in Table 5, correct decision latencies were faster for HF than for LF words, $F_1(1, 23) = 209.8$, $MSE = 527.2$, $p < .0001$; $F_2(1, 78) = 39.0$, $MSE = 5{,}400.6$, $p < .0001$; $d = .63$. Response latencies decreased with repetition, $F_1(2, 23) = 6.9$, $MSE = 1{,}460.5$, $p = .002$; $F_2(2, 78) = 12.3$, $MSE = 1{,}492.3$, $p < .0001$. The difference between the decision latencies for the first and the third presentations was 35 ms for LF words and 23 ms for HF words. These differences were not statistically significant, as shown by the lack of interaction between target frequency and number of repetitions, $F_1 < 1$; $F_2(2, 156) = 1.2$, $p = .30$. Errors were less numerous for HF words than for LF words (0.9% vs. 4.5%), $F_1(1, 23) = 11.5$, $MSE = 1.8$, $p = .002$, and decreased with repetition (4.2% vs. 2.0% vs. 1.8%), $F_1(2, 23) = 3.2$, $MSE = 0.6$, $p < .05$. The error analysis also revealed an interaction between word frequency and number of repetitions, $F_1(1, 46) = 3.7$, $MSE = 0.6$, $p = .02$; $d = .74$, which reflects the fact that LF words benefited more than HF words did from repetition. This conclusion was confirmed by further analyses showing that error rate declined as a function of repetition for LF distractors (2.4% vs. 1.1% vs. 1.0%), $F_1(2, 23) = 3.79$, $MSE = 4.7$, $p = .03$, but not for HF distractors (0.2% vs. 0.2% vs. 0.3%; $F_1 < 1$).

Picture-Naming Task

Errors and outliers accounted for 2.9% and 2.4% of the responses, respectively. Two major results were obtained in this task (see Table 5). First, naming latencies were nearly identical for distractors shown for lexical decision and for distractors presented for the first time in the picture-naming task (means: 721 ms vs. 724 ms; *F*s < 1). Second, greater interference was found for LF as opposed to HF distractors, $F_1(1, 23) = 49.4$, $MSE = 814.5$, $p < .0001$; $F_2(1, 19) = 56.9$, $MSE = 599.0$, $p < .0001$; $d = .65$.[3] The interaction between the two variables (presentation in the lexical decision task and distractor frequency) approached significance in the by-subjects analysis, $F_1(1, 23) = 3.2$, $p = .08$, but not in the by-items analysis ($F_2 < 1$). Although not significant, the results of the interaction deserve consideration. Interference decreased by 9

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[3] As mentioned above, the HF and LF distractors of Experiment 3 were marginally different (*p*s = .09) for number of neighbors and grapheme-to-phoneme consistency measures. Because these variables were poor predictors of the naming latencies (*r*s > .06; *F*s < 1), it seems unlikely that they contributed to the distractor frequency effects observed in Experiment 3. This conclusion holds also for Experiment 4, in which we used the material of Experiment 3; low coefficient correlations (*r*s > .06) were also found in Experiment 4.

ms (ps $> .23$) for HF repeated words and increased by 5 ms (Fs $<$ 1) for LF repeated words, and this explains the trends toward interaction in the by-subjects analysis.

The results of error analyses converge with those from the reaction times. Errors were more common for pictures paired with LF distractors than for pictures paired with HF distractors (3.7% vs. 2.2%), $F_1(1, 23) = 2.3$, $MSE = 0.5$, $p < .05$; $d = .37$. However, errors were similarly distributed for pictures paired with new and repeated distractors (3.3% vs. 2.6%; $F_1 < 1$).

Discussion

In Experiment 3, we examined whether the repeated presentation of a word for lexical decision affected the degree of interference that it produced in picture naming. Words that were repeated three times in the lexical decision tasks and that received increasingly faster responses in that task produced a level of interference in the picture–word interference task similar to that of words never presented in the lexical decision task. These results contradict expectations based on the input interference account of the distractor frequency effect in picture–word naming, which predicts a reduction of interference. It should also be noted that in the lexical decision task, repetition reduced the error rate especially for LF words, a finding indicating that repetition rendered the recognition of LF words easier. If repeated words were recognized more easily, the input interference account would also predict a reduced effect of distractor frequency for repeated words. Contrary to this expectation, the frequency effect was nearly identical for repeated and nonrepeated words.[4] Thus, the results of Experiments 2 and 3 do not provide support for the input interference account of the distractor frequency effect.

The Effect of Distractor Frequency: An Output Effect?

In the preceding experiments, we repeatedly observed that LF word distractors interfere more than HF word distractors in picture naming. This finding is problematic for the relative activation hypothesis of word interference in lexical access—that is, for the view that interference depends on the level of activation of the distractor's lexical node. However, the effect of distractor frequency is problematic for this view only if there is convincing evidence that such effect occurs at a stage of lexical access for production. Thus far we have only provided negative evidence for this possibility. That is, the results of Experiments 2 and 3 show that the effect of distractor frequency does not originate at the word recognition stage. Experiment 4 was an attempt to obtain positive evidence for an output locus for the distractor frequency effect. For this purpose, we asked participants to read a set of words out loud several times before these were used as distractors in the picture–word interference task.

Experiment 4: Reading Aloud Plus Picture Naming

The frequency effect in word production can be considered a specific form of the more general effect of stimulus repetition: Words that are produced frequently have their lexical information retrieved faster and more accurately than do words that are produced infrequently. This analogy between the effects of frequency and repetition suggests that we may be able to reproduce the effects of frequency by having speakers repeatedly select a word for oral production. There are results that support this intuition. For example, in picture and word naming, repeated words are produced faster and more accurately than nonrepeated words are (e.g., Jescheniak & Levelt, 1994; Masson & Freedman, 1990; McKone, 1995). If repeated production had the same effect on distractor frequency, we should find that repeated naming of distractor words would attenuate the interference they produce in the picture–word interference task. That is, it would be as if the repeated production of words increased their frequency. And because HF distractors interfere less, interference should decline for repeated distractors. This possibility was tested in Experiment 4. Participants read a list of words aloud several times; later, the words appeared as distractors in a picture-naming task. The question addressed in this experiment is whether less interference is found for words that, prior to being used as distractors in the picture-naming task, have been produced several times in the reading task.

The repeated production of a word in the reading task could affect visual word recognition processes, lexical access processes for production, or both. Consequently, if we were to find that words repeatedly produced in the reading task interfered less when shown as distractors in the naming task, the result would be open to (at least) two possible interpretations. One interpretation is that repeated words interfere less because they are recognized more easily. Alternatively, repeated words may interfere less because they are selected more easily for speech production. However, the results of Experiment 3 rule out the first of these interpretations. In that experiment, manipulations that demonstrably facilitated word recognition did not cause a decrease of interference. Therefore, a result showing reduced interference for word distractors that were previously named in a word-naming task could be attributed specifically to the fact that distractors were repeatedly selected for production. By further inference, we would be allowed to conclude that word-production mechanisms play a critical role in the effect of distractor frequency.

Method

Participants

Two groups of 12 participants (Groups 1 and 2) took part in Experiment 4.

Material and Procedure

Experiment 4 was essentially a replication of Experiment 3, with one difference: A reading task (not a lexical decision task) preceded the picture-naming task. For the reading task, the 60 nonwords of Experiment 3 were substituted with 60 words, which served as fillers (30 additional filler words were from Experiment 3). The filler words varied in

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[4] If anything, the distractor frequency effect tended to be larger for the repeated distractors (49 vs. 33 ms; this difference only approached significance, $p = .08$, in the by-subjects analysis; $F_2 < 1$). We ran a replication of Experiment 3 with a new set of 48 picture–word pairs and with 36 participants. In the lexical decision task, words were repeated twice. The results were similar to those of Experiment 3. Decision latencies and error rates decreased for repeated words and especially for LF words. In contrast, no differences (Fs < 1) were observed in the picture–word interference task between repeated and nonrepeated distractors.

length and grammatical class (nouns, verbs, adjectives, and function words) and were controlled for spelling-to-sound regularity: Half of the fillers were regular (e.g., *tile*), the other half were irregular (e.g., *vein*). By having fillers that varied across several dimensions, we hoped to obtain a list that was as representative as possible of the variety of words of the language. Stimulus order and modality of presentation in the reading task were the same as in the lexical decision task of Experiment 3. The picture-naming task was identical to that described in Experiment 3. Participants were instructed to name the words as rapidly and accurately as possible. To familiarize them with the experimental procedure, we had the participants perform a 10-trial practice block. Responses were scored and analyzed as in Experiment 3.

Results

Reading Aloud Task

A total of 1.6% of the responses were excluded because of outliers. As can be seen in Table 5, responses became faster in going from Block 1 to Block 3, $F_1(2, 23) = 3.5$, $MSE = 705.9$, $p < .05$; $F_2(2, 78) = 10.7$, $MSE = 4{,}210.5$, $p < .0001$, and were faster for HF words than for LF words, $F_1(1, 23) = 43.2$, $MSE = 368.8$, $p < .0001$; $F_2(1, 78) = 6.3$, $MSE = 4{,}210.5$, $p < .01$; $d = .39$. The interaction between these variables was significant, $F_1(2, 46) = 11.7$, $MSE = 168.5$, $p = .0001$; $F_2(2, 156) = 8.8$, $MSE = 382.6$, $p < .001$. We carried out further analyses to determine whether HF and LF words were equally affected by repetition. The effect of repetition was highly significant for LF words, $F_1(2, 46) = 6.3$, $MSE = 535.0$, $p < .01$; $F_2(2, 78) = 17.2$, $MSE = 335.6$, $p < .0001$. With HF words, the effect of repetition was close to significance in the F_1 analysis, $F_1(2, 46) = 3.1$, $MSE = 339.4$, $p = .053$; it was significant in the F_2 analysis, $F_2(2, 39) = 3.9$, $MSE = 429.5$, $p = .02$; and post hoc analyses (Newman–Keuls) revealed a significant difference only between the second and the third blocks. Errors account for 1.7% of the responses, an amount too small for analysis.

Picture-Naming Task

Errors occurred in 2.2% of the trials and outliers accounted for 1.9% of the responses. As Table 5 shows, distractors that were repeated in the reading task interfered less than distractors that were shown for the first time did. The difference between old and new words, although small (12 ms), was highly significant, $F_1(1, 23) = 30.8$, $MSE = 108.5$, $p < .0001$; $F_2(1, 19) = 11.0$, $MSE = 251.9$, $p < .01$; $d = .17$. Moreover, we replicated the effect of distractor frequency: Naming latencies were 38 ms slower for LF distractors than for HF distractors, $F_1(1, 23) = 113.2$, $MSE = 302.3$, $p < .0001$; $F_2(1, 19) = 63.9$, $MSE = 444.8$, $p < .0001$; $d = .57$. Finally, there were no traces of interaction between these two variables (Fs < 1).

Discussion

In Experiment 4, interference declined for distractors that were read aloud several times before being used as distractors in the picture-naming task. These results contrast with those of Experiment 3. In that experiment, repeated presentation of words for lexical decision did not reduce interference in the picture–word interference task. That repetition had different consequences in Experiments 3 and 4 was confirmed by the results of an omnibus analysis in which we considered the picture-naming latencies of both experiments. Of interest is that the three-way interaction Task × Distractor Repetition × Distractor Frequency approached significance ($p = .06$) in the by-subjects analysis. Our rationale for using distractor repetition was to reproduce the effect of frequency. That is, the repeated production of distractors was intended to functionally increase their frequency, thereby reducing their ability to interfere in the picture-naming task. A reduction of interference was associated with reading aloud, a task that involves word production, but not with lexical decision, a task that does not require word production. This pattern of results invites the conclusion that the distractor frequency effect has its locus at the stage of lexical access for production.

One finding of Experiment 4 is somewhat puzzling: the discrepant effects of repetition as a function of word frequency. That is, in reading aloud, repetition affected LF words more than HF words, but in the picture–word interference task, repetition affected HF and LF distractors equally. One might have expected similar effects of repetition in the two tasks on the assumption that in both cases, the effect is due to a functional increase of frequency. However, we should note that the effect of repetition found in the picture–word interference paradigm had a relatively small size (12 ms). Experiment 4 probably did not have sufficient power to reveal differences between HF and LF distractors, given that the effect is so small. If anything, our data seem to go in the right direction, as the effect of repetition in the picture–word interference paradigm was larger (albeit unreliably) for LF distractors than for HF distractors (14 vs. 10 ms; see Table 5).

The Temporal Account

At this point, two elements of the distractor frequency effect are clear. First, it is robust, having been replicated in several experiments and with various sets of stimuli. Second, all the evidence gathered thus far points to the conclusion that it involves mechanisms for word production rather than word recognition. That is, its locus seems to be at a point between the selection of word meaning and the activation of word phonology.

Our results undermine the relative activation hypothesis of the effect of distractor words in the picture–word interference paradigm. This hypothesis assumes that the degree of interference produced by a distractor word is determined by the level of activation of its lexical node relative to that of the target word: The more similar the two levels of activation, the greater the interference. As discussed in the introduction of this article, the predictions that follow from this account for the effects of distractor frequency depend in part on other assumptions about the mechanisms underlying the frequency effect in lexical access. If the frequency effect in word production reflects differences in activation levels, the relative activation hypothesis predicts greater interference for HF words in the picture–word interference paradigm. In contrast, the hypothesis that the frequency effect originates from differences in selection thresholds predicts that we should not find differences between HF and LF distractors. Neither prediction has been confirmed by our results, thereby undermining the relative activation hypothesis of distractor word effects in the picture–word interference task.

It should be noted that the finding of greater interference for LF distractors is problematic for the relative activation hypothesis only if HF distractors reach activation levels that are either higher than or similar to those of LF distractors at the point in time at which target selection occurs. However, what if the activation levels of HF distractors were not uniformly higher than those of LF distractors but varied as a function of the temporal relation between target and distractor activation? And what if at the point in time at which the target lexical nodes in the picture–word interference task are selected, the activation levels of LF distractors were actually higher than those of HF distractors? These ideas are articulated in the account below.

The observation that naming latencies are shorter for words than for pictures (e.g., Cattell, 1886; Fraisse, 1969; Potter & Falconer, 1975; Theios & Amrhein, 1989) suggests that words can activate their lexical representations in the output lexicon faster than pictures can. Consistent with this observation, it is possible that at the point when the name of a picture is sufficiently activated for selection to occur, the word distractor has already reached its peak level of activation and, because it is not selected, has started to decay. One might further suppose that activation decay is more likely to occur earlier for HF distractors than for LF distractors. For example, because HF words are recognized faster, they can also activate their lexical nodes in the output lexicon earlier than LF words can and then start to decay sooner. Figure 2A schematically represents this situation. In this scenario, there is a brief period during which LF distractors have higher activation levels than HF words, leading to greater interference by LF distractors, as predicted by the relative activation hypothesis.[5] This explanation is a specific implementation of the relative activation hypothesis, but because it emphasizes the temporal aspects of distractor activation, we refer to it as the *temporal account* of the distractor frequency effect.

Several aspects of the results of the experiments reported thus far can be used to assess the plausibility of the temporal account, an account that predicts that factors affecting the temporal relationship between picture-name selection and the activation of distractor words will modulate distractor interference. Case alternation of distractors is one such factor. Presenting words with mixed-case letters slows recognition, as evidenced by the sizable increase in naming and lexical decision latencies observed with these stimuli (see, e.g., Besner & McCann, 1987; Mayall & Humphreys, 1996). This would translate into the prediction of a reduced effect of interference for alternated-case distractors (see Figure 2A). But this prediction is inconsistent with the finding of Experiment 2, which showed that case alternation does not reduce the distractor frequency effect. Further predictions follow from the temporal account for the factor Picture Name Frequency. Because the frequency of the picture names affects the speed with which those names are retrieved, the temporal account predicts a smaller distractor frequency effect and perhaps even a reversal for HF picture names. However, these expectations were not confirmed by the data of Experiments 1 and 2. In fact, the distractor frequency effect remained unchanged between HF and LF picture names. In sum, the manipulation of factors—Case Alternation and Picture-Name Frequency—that could have produced results consistent with the temporal account did not, in fact, produce such evidence. This conclusion further undermines the relative activation hypothesis of distractor word effects in the picture–word interference task.

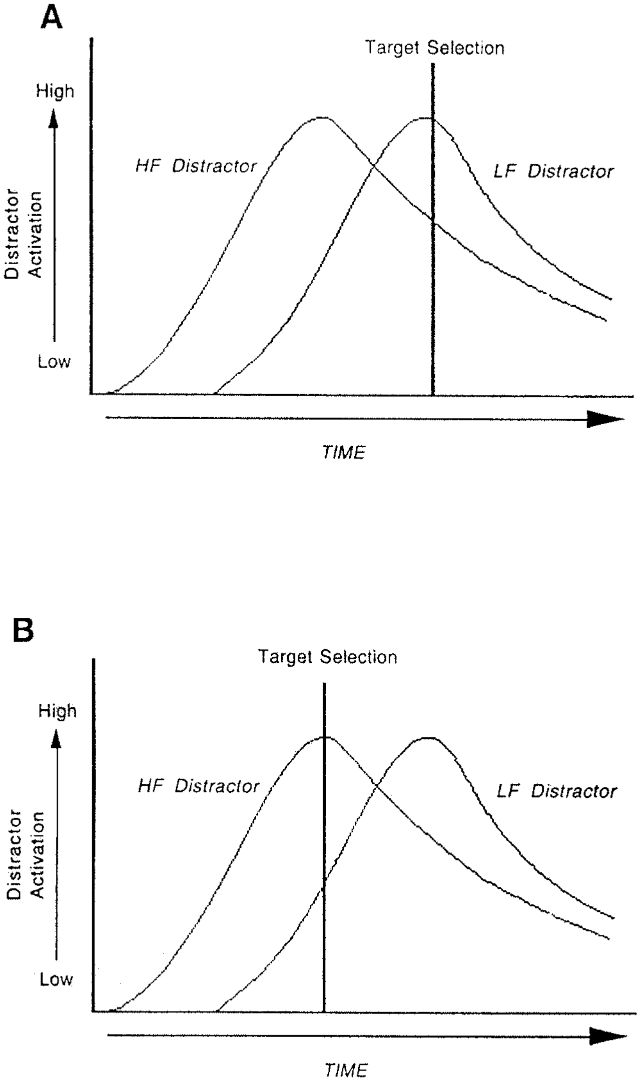

Figure 2. A: Schematic illustration of the temporal account of the distractor frequency interference effect. At the point in time at which target selection occurs, low-frequency (LF) distractors are more activated than high-frequency (HF) distractors. This leads to greater interference levels for LF distractors. The shape of the activation function is hypothetical. B: Schematic illustration of the result predicted by the temporal account when picture presentation is anticipated (positive stimulus onset asynchrony). When picture selection takes place, activation is supposedly greater for HF than for LF distractors. Thereby, greater interference is expected for HF distractors (see the General Discussion section for a detailed examination of these issues).

On the Nature of the Distractor Frequency Effect

Before discussing the implications of the distractor frequency effect, we shall attempt to better characterize the nature of this

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[5] It is important to stress here that the activation levels reached by distractor words are not sufficiently large to lead to selection for production. As already noted, this assumption is highly plausible because participants only extremely rarely produce the distractor word instead of the target response. This fact is naturally explained by assuming that the lexical nodes of distractor words are not selected for production.

effect. In the next set of experiments, we address this issue by exploring the relation between the effect of distractor frequency and two other effects consistently obtained with the picture–word interference task. One is the semantic effect: the finding that interference is greater with distractors semantically (categorically) related to the picture (as in the pair *fox–dog*). The other is the phonological effect: the finding of reduced interference with phonologically related picture–word pairs (e.g., *doll–dog*; Briggs & Underwood, 1982; Lupker, 1982; Meyer & Schriefers, 1991; Rayner & Posnansky, 1978; Underwood & Briggs, 1984). A shared assumption among current accounts of the phenomenon of picture–word interference is that different mechanisms underlie the semantic and the phonological effects (see, e.g., Lupker, 1982; Roelofs, 1992; Schriefers et al., 1990; Starreveld & La Heij, 1996). It is commonly supposed that mechanisms related to the interplay between semantic and lexical processing are responsible for the semantic interference effect, whereas mechanisms related to the processing of phonological features are involved in the phonological facilitation effect. Importantly, direct empirical evidence indicates that the effects occur at different levels of the lexical access process. Perhaps the strongest evidence involves the time course of the semantic interference and the phonological facilitation effects. The time course of word interference can be determined by anticipating or delaying when distractors appear relative to picture presentation—that is, by varying stimulus onset asynchrony (SOA). The semantic interference and the phonological facilitation effects have different time courses, and, within certain time regions, only one of these effects is detectable: semantic interference occurs at earlier SOAs than does phonological facilitation (Damian & Martin, 1999; Schriefers et al., 1990).

We reasoned that by examining the relation between distractor frequency and the semantic and phonological relatedness of the distractor to the target word, we could gain insight into the locus of the distractor frequency effect within the lexical access process. For example, evidence that phonologically related distractors modulate the effect of distractor frequency would suggest that mechanisms implicated in the production of the phonological facilitation effect are also the basis of the distractor frequency effect. Analogous conclusions can be reached by determining whether the distractor frequency effect has a time course similar to that of the semantic interference effect or the phonological facilitation effect, or by investigating whether the distractor frequency effect is influenced by the same variables that affect the semantic interference or the phonological facilitation effects. If it can be established that the distractor frequency effect and either the semantic interference or the phonological facilitation effect have similar temporal courses or are susceptible to the influences of identical variables, this would invite the conclusion that the effects have a common locus within the lexical access process. In the next two experiments (Experiments 5 and 6), we explore the relation between the effects of distractor frequency and semantic interference. These are followed by an experiment (Experiment 7) in which we investigate the relation between distractor frequency and phonological facilitation.

Experiment 5: Semantic Interference Effect, Distractor Frequency Effect, and SOA

The temporal profile of distractor interference can be examined by varying when word distractors appear with respect to the pictures—that is, by varying SOA. With visually presented distractors, the effect of semantic interference has been shown to arise within a region between ±100 ms around picture presentation (e.g., Damian & Martin, 1999; Glaser & Düngelhoff, 1984; Glaser & Glaser, 1989; Schriefers et al., 1990; Starreveld & La Heij, 1996; Schriefers & Teruel, 2000). In Experiment 5, we explore whether the effects of distractor frequency and semantic relatedness have analogous time courses. Distractor category relation and frequency were factorially varied so that pictures were matched with HF and LF semantically related distractors and with HF and LF semantically unrelated distractors. To illustrate, the picture *bench* appeared with the related words *chair* (HF) and *stool* (LF) and with the unrelated words *rock* (HF) and *dune* (LF).

Method

Participants

Three groups of 16 participants took part in Experiment 5. Each group saw the stimuli at only one SOA.

Material and Procedure

Nineteen pictures with names within the medium-frequency range (16–78 counts per million, $M = 38$) were paired with four word distractors: (a) an HF semantically related word, (b) an LF semantically related word, (c) an HF semantically unrelated word, and (d) an LF semantically unrelated word. The complete list of picture–word pairs can be found in Appendix C. Yoking the four distractor groups, we obtained sets of related and unrelated distractors matched for frequency and sets of HF and LF distractors matched for semantic relatedness. Distractors were controlled for length (number of letters), number of neighbors, word mean bigram frequency, and Berndt et al.'s (1987) measure of grapheme-to-phoneme consistency (see Table 6). (Ziegler et al.'s, 1997, numbers of enemies and friends were not included because norms were not available for the bisyllabic words used in Experiment 5.) We carried out two-factor (Relatedness × Frequency) analyses of variance (ANOVAs) to examine these parameters. No sign of interaction was found between distractor relatedness and distractor frequency ($ps > .27$). The yoked (HF + LF) groups of related and unrelated distractors did not differ for any of these parameters ($ps > .27$) except for grapheme-to-phoneme consistency, which was significantly higher for related distractors than for unrelated distractors (.92 vs. .86), $F(1, 72) = 5.5$, $MSE = 0.073$, $p = .02$. The yoked (related +

Table 6
Mean Measurements of the High-Frequency (HF) and Low-Frequency (LF) Word Distractors Shown in Experiment 5

	Semantic relatedness			
	Related distractors		Unrelated distractors	
Distractor variable	HF	LF	HF	LF
Frequency	203	4	184	3*
Length (number of letters)	4.5	5.7	4.4	5.1
Number of neighbors[a]	7	3	6	3
Word mean bigram frequency[a]	1,680	1,662	1,846	1,542
Grapheme–phoneme consistency[a]	.93	.91	.88	.84

[a] For an explanation of these parameters, see Table 2 and the *Method* section of Experiment 1.
* Difference between HF and LF word distractors significant at $p < .001$.

Table 7

Picture-Naming Latencies (ms) and Effects (ms) for High-Frequency (HF) and Low-Frequency (LF) Word Distractors Shown in Experiment 5

	SOA/semantic relatedness								
	−100 SOA			0 SOA			100 SOA		
Words/effect	Related	Unrelated	SRE	Related	Unrelated	SRE	Related	Unrelated	SRE
LF words	770	744	26	765	749	16	763	764	−1
HF words	740	720	20	740	721	19	737	740	−3
Distractor frequency effect[a]	30	24		25	28		26	24	

Note. SRE = Semantic relatedness effect; SOA = Stimulus onset asynchrony.

[a] Difference between LF and HF word distractors.

unrelated) groups of HF and LF distractors differed significantly for length (number of letters; means: HF = 4.4, LF = 5.4), $F(1, 72) = 8.6$, $MSE = 16.1$, $p = .004$, and for number of neighbors (means: HF = 6.7, LF = 3), $F(1, 72) = 8.6$, $MSE = 16.1$, $p = .004$. For grapheme-to-phoneme consistency and word mean frequency, *F*s were less than 1. We included a large number of filler stimuli (116) to reduce the incidence of related stimuli (18%) and to minimize the likelihood that participants would develop strong expectations about the relationship between pictures and words. Filler stimuli were created by pairing 29 pictures with 4 unrelated words. Given the large number of stimuli (192) used in the present experiment, we opted for a design in which participants saw the stimuli at only one SOA. Two different randomizations were created and used with an equal number of participants (for the randomization procedure, see the *Procedure* section of Experiment 1).

The presentation procedure for the 0 SOA condition was the one used in the previous experiments. In the –100 SOA condition, after the fixation point, the word appeared alone for 100 ms. The word was then replaced by a picture–word pair that stayed on the screen for 600 ms (or was automatically removed if the response was initiated earlier). In the 100 SOA condition, the picture was shown after the fixation point, and 100 ms later the word appeared on the picture. The picture and the word remained on the screen together for up to 600 ms, unless the response was initiated earlier.

Separate ANOVAs were carried out for each SOA to examine the variables semantic relatedness (related vs. unrelated distractors) and distractor frequency (HF vs. LF). Both variables were treated as within-subjects variables. Analyses of the semantic interference and the distractor frequency effects were both based on the responses given to 76 picture–word pairs.

Results and Discussion

The error rates at 0, −100, and 100 SOA were 3.3%, 3.8%, and 3.8%, respectively. The responses trimmed because of outliers were 1.4% at 0 SOA, 1.2% at –100 SOA, and 1.3% at 100 SOA. As can be seen in Table 7, slower response latencies were found for LF distractors at all SOAs ($ps \leq .01$; *d*s ranging between .19 and .38); semantically related distractors produced greater interference than did unrelated distractors at 0 and –100 SOAs ($ps \leq .02$; *d*s = .45 and .26, respectively) but not at 100 SOA ($Fs < 1$). Interactions between the variables semantic relatedness and distractor frequency were not significant at any SOA ($Fs < 1$). Semantically related and unrelated distractors were not matched for grapheme-to-phoneme consistency; moreover, HF and LF distractors differed in length (number of letters) and number of neighbors. Post hoc analyses were carried out to determine whether these differences affected the semantic and the frequency effects. The differences between the grapheme-to-phoneme consistencies of related and unrelated distractors were correlated with the semantic interference effect (related–unrelated reaction time differences). Correlations were also computed between word length differences and the distractor frequency effect (LF-HF reaction time differences) as well as between the number of neighbors differences and the distractor frequency effect. Separate correlations were carried out for each SOA. The correlation coefficients were not significant ($p > .09$), a finding suggesting that grapheme-to-phoneme consistency, length, and number of neighbors[6] did not contribute significantly to the effects observed in Experiment 5. Taken together, the results of Experiment 5 show that the distractor frequency and the semantic interference effects have different time courses, indicating that it is unlikely that identical mechanisms are involved for the two effects; rather, they suggest that different mechanisms are responsible for the two effects.

Sternberg's (1969) additive-factors logic provides a tool for determining whether effects originate at common or distinct levels of processing. In experiments in which two effects are concurrently manipulated, statistical interaction is the most likely relation between effects having common sources; statistical additivity is expected if the effects originate at different levels of processing. The finding that at 0 and –100 SOAs, no traces of interaction were found between the variables semantic relatedness and distractor frequency indicates that the loci of the semantic interference and the distractor frequency effects are at distinct levels of processing and converge with the findings that the two effects have different time courses. Results further confirming the dissociability between the two effects are presented in the next experiment.

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[6] Converging evidence relevant to understanding the relationship between the frequency effect and SOA was obtained in an additional experiment that manipulated SOA. We tested 36 speakers and used the material of Experiment 1, which included HF and LF distractors matched for length and number of neighbors (see the *Method* section of Experiment 1). Effects of distractor frequency were observed at –100, 0, and 100 SOAs ($ps < .05$).

Experiment 6: Picture–Word Repetition

In his seminal study of color naming, Stroop (1935) found that the interference produced by color words diminished with practice, a finding replicated in recent investigations of the color-naming task (see, e.g., Dulaney & Rogers, 1994; MacLeod, 1998; Roe, Wilsoncroft, & Griffiths, 1980). Practice seems not to influence the frequency effect observed in picture naming, as illustrated quite dramatically by the results of the picture-naming experiment carried out by Levelt, Praamstra, Meyer, Helenius, and Salmelin (1998). Even after participants named the pictures eight times, the size of the frequency effect remained unaltered (see also Jescheniak & Levelt, 1994; but see Griffin & Bock, 1998). Why practice has different effects for word interference and word frequency remains to be explained. However, here we are interested in exploring the consequences of picture-name repetition on the effects of distractor frequency and semantic relatedness. If the distractor frequency effect and the semantic interference effect arise at the same level of processing, they should be affected in the same way by stimulus–response repetition. That is, because practice reduces the magnitude of the semantic interference effect, it should also reduce the magnitude of the distractor frequency effect if the two effects share a common mechanism. Thus, an investigation of the modulation of the effects of distractor frequency and semantic relatedness produced by stimulus–response repetition may provide another opportunity to demonstrate the dissociation between the two effects. In Experiment 6, we examined whether the size of the semantic interference and the distractor frequency effects varied in the same way as a function of repetition of picture–word pairs.

Method

Participants

Twenty native English speakers participated in Experiment 6.

Material and Procedure

We selected two lists of 18 pictures (Lists A and B). Each picture appeared with a pair of distractors (see the complete list in Appendix D). In List A, a picture (e.g., *lion*) was paired with a semantically (categorically) related distractor (e.g., *tiger*) and with an unrelated distractor (e.g., *pearl*). Related and unrelated distractors were identical in length (number of letters) and were matched for frequency (means: related = 56 counts per million, unrelated = 59 counts per million; $t < 1$). Each picture of List B was paired with two unrelated words of the same length: an HF word (M = 354 counts per million) and an LF word (M = 2 counts per million; $p < .001$). HF and LF distractors did not differ significantly in number of neighbors (*M*s = 2.6 vs. 1.6; $p = .22$), word mean bigram frequency (M = 1,657 vs. 1,529; $t < 1$), and Berndt et al.'s (1987) measure of grapheme-to-phoneme consistency (*M*s = .873 vs. .889; $t < 1$). (Ziegler et al.'s, 1997, numbers of enemies and friends are not reported because norms are not available for the bisyllabic words used in Experiment 6.) Three additional pictures were paired with six unrelated words and served as warm-up stimuli at the beginning of each block. In the experiment proper, each picture was presented 10 times: 5 times each with the two distractors. Consequently, for the effects of semantic relatedness and distractor frequency, we obtained 5 data points per participant per word. Pictures and words were distributed across 10 blocks, appearing only once in each block. Within a block, items were randomized in such a way that at least three unrelated stimuli intervened between semantically related pairs. Two item randomizations were prepared and used with equal numbers of participants (10). Blocks were administered with the following procedure. If in block x a picture appeared with a related distractor, in block $x \pm 1$ it appeared with an unrelated distractor; if in block x a picture was paired with an unrelated distractor, in block $x \pm 1$ it was paired with a related distractor. The same criteria held for HF and LF distractors. So pictures shown in block x with HF distractors appeared in block $x \pm 1$ with LF distractors and vice versa. Blocks were shown in five different orders. Otherwise, the procedure was as in Experiment 1.

We examined three within-subjects variables: (a) semantic relatedness (related vs. unrelated pairs), (b) distractor frequency (HF vs. LF), and (c) distractor presentation (Presentation 1, 2, 3, 4, or 5). We carried out two separate analyses: In one, we considered List A and focused on the variables semantic relatedness and distractor presentation; in the other, which involved List B, we were concerned with the variables distractor frequency and distractor presentation. By means of these analyses, we can determine the extent to which stimuli–response repetition modulates the semantic interference and distractor frequency effects.

Results and Discussion

Erroneous responses were observed in 2.6% of the trials and were significantly more numerous with related pairs than with unrelated pairs (means: 3.6% vs. 1.5%), $F_1(1, 19) = 24.5$, $MSE = 0.29$, $p = .0001$. Responses exceeding a participant's mean response time by 3 standard deviations (outliers) accounted for 2.2% of the trials with related pairs, and their proportion was even higher in the first four experimental blocks (5.7%). These figures were exceptionally high if we consider that outliers represented 1.2% of the responses to unrelated pairs (0.7% in the first four blocks). Because of their uneven distribution, outliers were not removed, and we opted for a trimming procedure that included the elimination of responses exceeding 2 s. The latter responses accounted for 0.5% of the total number of trials, and analyses showed that they were evenly distributed across experimental conditions (*F*s < 1). In Lists A and B, responses tended to be faster with repetition (see Figure 3), as demonstrated by the finding of significant effects of distractor presentation in both lists (*p*s ≤ .0001). With List A, responses were slower for pictures paired with related distractors than for those paired with unrelated distractors (*M*s = 777 vs. 739 ms), $F_1(1, 19) = 33.9$, $MSE = 2{,}227.8$, $p < .0001$; $F_2(1, 17) = 19.1$, $MSE = 3{,}380.9$, $p < .01$; $d = .65$. With List B, LF distractors produced slower responses than HF distractors did (*M*s = 768 vs. 731 ms), $F_1(1, 19) = 90.6$, $MSE = 737.6$, $p < .0001$; $F_2(1, 17) = 43.2$, $MSE = 1{,}392.8$, $p < .0001$; $d = .74$. As evident in Figure 3, repetition attenuated the semantic relatedness effect but did not change the effect of distractor frequency (see also Table 8). This conclusion was confirmed by the results of ANOVAs that revealed a significant interaction between distractor presentation and semantic relatedness, $F_1(4, 76) = 7.8$, $MSE = 576.4$, $p < .0001$; $F_2(4, 68) = 6.6$, $MSE = 6{,}584.8$, $p = .001$, but not between distractor presentation and distractor frequency (*F*s < 1). Further indication that repetition affected the semantic and the frequency effects differently comes from analyses carried out on the results of both lists, in which the triple interaction List × Repetition × Effect was significant, $F_1(4, 76) = 4.4$, $MSE = 2{,}447.2$, $p = .003$; $F_2(4, 136) = 4.2$, $MSE = 2{,}202.5$, $p = .003$. Thus, the results of Experiment 6 reveal a further dissociation between the semantic relatedness and the distractor frequency effects: Repetition attenuated the former but not the latter effect. The results of this experiment converge with those obtained in

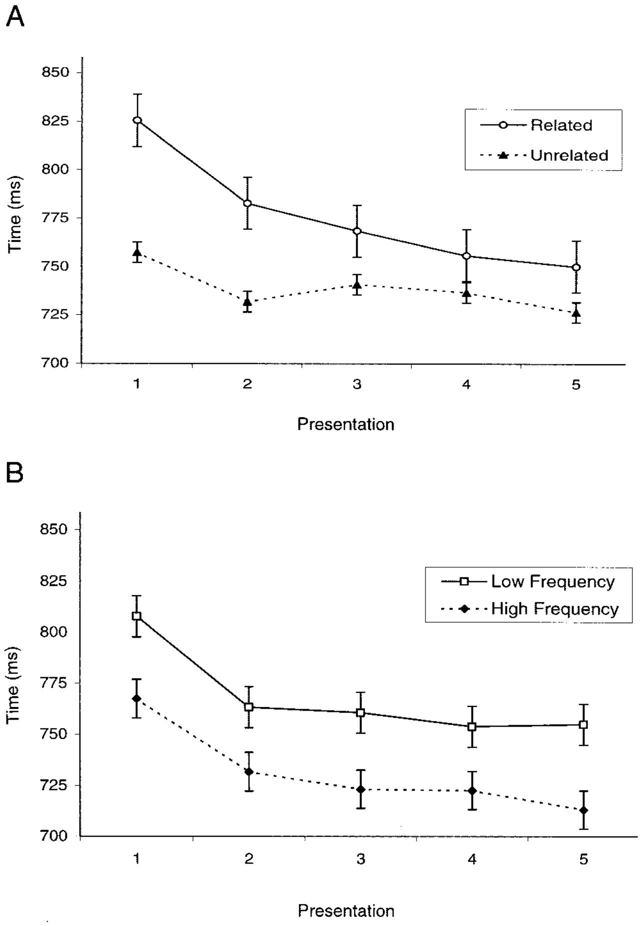

Figure 3. Effect of picture–word repetition on picture naming. Vertical lines depict standard errors of the means. A: Semantically related versus unrelated distractors. B: High-frequency versus low-frequency distractors.

Experiment 5, which also demonstrate that the effects of semantic relatedness and distractor frequency are independent of one another. In short, in two experiments, we have obtained clear evidence that the distractor frequency effect does not arise at the level where the semantic interference effect has its locus. We turn next to the investigation of the relation between the phonological facilitation effect and the distractor frequency effect.

Experiment 7: Phonological Facilitation and Distractor Frequency Effects

A phonologically related distractor such as *wall* interferes less with the naming of the picture *ball* than does an unrelated distractor such as *road*. This effect of phonological facilitation is the result of mechanisms different from those that cause the effect of semantic interference. This conclusion is supported by the fact that the phonological facilitation and the semantic interference effects have different time courses (e.g., Schriefers et al., 1990; Starreveld & La Heij, 1996). Experiment 7 focuses on the relation between the phonological facilitation and the distractor frequency effects, and it addresses the question of whether the same mechanism is involved in the two effects. To this end, we jointly manipulated the distractors' frequency and their phonological relatedness to the picture names so as to obtain picture–word pairs comprising HF and LF related distractors (e.g., *ball–wall* and *ball–shawl*) and HF and LF unrelated distractors (e.g., *ball–road* and *ball–flake*). We were interested in determining whether the size of the distractor frequency effect is comparable for phonologically related and unrelated distractors. Within the framework of Sternberg's (1969) additive-factors logic, evidence of comparable effect sizes (additive effects) would suggest that distinct mechanisms underlie the effects of distractor frequency and phonological relatedness. In contrast, evidence of different effect sizes (interaction) indicates that the two effects most likely have a common source.

Method

Participants

Nineteen native English speakers took part in Experiment 7.

Material and Procedure

Twenty-three pictures with names of middle-range frequency were paired with four groups of word distractors: (a) HF phonologically related words, (b) LF phonologically related words, (c) HF phonologically unrelated words, and (d) LF phonologically unrelated words. Frequency was greater than 100 counts per million for HF distractors and less than 19 counts per million for LF distractors. Distractors were 3–6 letters long and were controlled for number of neighbors, word mean bigram frequency, grapheme-to-phoneme consistency (Berndt et al., 1987), and number of friends and enemies (Ziegler et al., 1997; see the means in Table 9). To be consistent with the purposes of Experiment 7, we tested whether these parameters varied between HF and LF related distractors, as well as between HF and LF unrelated distractors (results are reported in Table 9). One difference was significant at the .05 level: number of feedforward enemies with unrelated distractors. Most important, two-factor (Relatedness × Frequency) ANOVAs revealed nonsignificant ($ps > .10$) interactions for each of these parameters, a finding suggesting that the several parameters controlled for in Experiment 7 were well-balanced across the four distractor groups. All picture–word pairs were semantically unrelated. The list of stimuli used in this experiment can be found in Appendix E. The material also included a list of 24 filler pictures, each of which paired with four unrelated distractors. Filler pictures were introduced to keep the proportion of trials with phonologically related distractors relatively low (24%). Picture–word pairs of the different experimental conditions were equally distributed in four blocks. Pictures appeared once per block. Within a block, stimuli were randomized with the constraint that at least two unrelated stimuli intervened between phonologically related stimuli. Two item randomizations were used. Block order of presentation was randomized across participants. Analyses considered two within-subjects vari-

Table 8
Effect (ms) Observed in Experiment 6

	Presentation				
Effect	1–2	3–4	5–6	7–8	9–10
Semantic relatedness effect[a]	69	51	27	19	23
Distractor frequency effect[b]	41	31	38	31	32

[a] Difference between mean response times with related and unrelated word distractors. [b] Difference between mean response times with low-frequency and high-frequency word distractors.

Table 9
Mean Measurements for the High-Frequency (HF) and Low-Frequency (LF) Word Distractors Shown in Experiment 7

	Phonological relatedness							
	Related distractors				Unrelated distractors			
			HF vs. LF				HF vs. LF	
Distractor variable	HF	LF	*t* (44)	*p*	HF	LF	*t* (44)	*p*
Frequency	231	6	6.2	.0001	233	4	6.4	.0001
Length (number of letters)	3.9	4.2	−1.7	.09	3.9	4.2	−1.3	.18
Number of neighbors[a]	12	9	3.2	.055	8	7	1.2	.34
Word mean bigram frequency[a]	1,819	1,711	<1		1,242	1,628	−1.6	.09
Grapheme–phoneme consistency[a]	.94	.96	<1		.92	.89	<1	
Feedforward consistency[a]								
Number of friends	11.1	10.0	<1		6.3	7.7	<1	
Number of enemies	0.9	0.8	<1		1.6	0.2	2.4	.02
Backward consistency[a]								
Number of friends	11.1	10.8	<1		6.2	7.8	<1	
Number of enemies	4.4	3.7	<1		5.3	3.2	<1	

[a] For an explanation of these parameters, see Table 2 and the *Method* section of Experiment 1.

ables: phonological relation (related vs. unrelated distractors) and distractor frequency (HF vs. LF).

Results and Discussion

Errors and outliers were observed in 2.2% and 1.2% of the trials, respectively. Response latencies were faster for phonologically related pairs than for unrelated pairs (see Table 10), $F_1(1, 18) = 97.4$, $MSE = 492.2$, $p < .0001$; $F_2(1, 22) = 111.4$, $MSE = 507.9$, $p < .0001$; $d = .77$. Responses were slower for pictures paired with LF distractors, $F_1(1, 18) = 25.8$, $MSE = 168.0$, $p = .0001$; $F_2(1, 22) = 11.7$, $MSE = 596.6$, $p < .01$; $d = .33$. Most important, the interaction between the variables phonological relatedness and distractor frequency was significant, $F_1(1, 18) = 12.2$, $MSE = 197.4$, $p < .01$; $F_2(1, 22) = 12.6$, $MSE = 277.0$, $p < .01$. The latter result is explained by the slower responses for LF versus HF distractors with unrelated pairs (*M*s = 772 vs. 743 ms), $F_1(1, 19) = 24.6$, $MSE = 8{,}479.1$, $p < .0001$; $F_2(1, 22) = 24.8$, $MSE = 10{,}290.0$, $p < .0001$; $d = .44$, but not with related pairs (*M*s = 709 vs. 706 ms; *F*s < 1). The most striking result of Experiment 7 is the disappearance of the distractor frequency effect with phonologically related distractors.

Table 10
Picture-Naming Latencies (ms) and Effects (ms) for High-Frequency (HF) and Low-Frequency (LF) Word Distractors Shown in Experiment 7

	Phonological relatedness		
Words/effect	Related	Unrelated	Phonological facilitation effect[b]
LF words	709	772	−63
HF words	706	743	−37
Distractor frequency effect[a]	3	29	

[a] Difference between LF and HF word distractors. [b] Difference between phonologically related and unrelated word distractors.

Interim Summary: On the Locus of the Distractor Frequency Effect

To shed light on the nature of the effect of distractor frequency, we attempted to define its relation to the effects of semantic interference and phonological facilitation. The results are clear-cut. The effects of semantic interference and distractor frequency have different time courses and do not interact statistically. Furthermore, we identified a variable—stimulus–response repetition—that affects the magnitude of the semantic interference effect but not the magnitude of the distractor frequency effect. Together, these findings suggest that different mechanisms are responsible for the effects of semantic interference and distractor frequency. Contrasting results emerged with phonologically related distractors, where distractor frequency and phonological facilitation were found to interact. This finding invites the conclusion that common mechanisms are responsible for the effects associated with phonological facilitation and distractor frequency. Further evidence pointing to the same conclusion comes from consideration of the time course of the two effects. With visually presented distractors, various studies have reported an effect of phonological facilitation at negative, zero, and positive SOAs (Damian & Martin, 1999; Starreveld & La Heij, 1996). As reported in Experiment 5, the effect of distractor frequency has a similar time course, extending from –100 to 100 SOAs. Thus, the pattern of results reported in this section suggests that the distractor frequency effect has its locus at the same level of lexical access in production as the phonological facilitation effect does: the level of phonological encoding. This is the stage of lexical access at which a word's phonological content is retrieved and organized to serve as the input to articulatory processes.

General Discussion

The research reported here establishes several results. First, LF distractor words interfere more than HF distractors in the picture–word interference paradigm. This counterintuitive effect is remarkably robust, having been replicated in many experiments (Experiments 1–7) and with various materials, and it has an appreciable size—in most of the experiments, indexes of effect size (Cohen's *d*s) revealed effects of medium or large magnitudes. The distractor frequency effect is not modulated by the frequency of the picture name (Experiments 1 and 2), nor does the effect vary as a function of the proportion of LF distractors presented in the experiment (see Lists A and B in Experiment 1). Furthermore, the distractor frequency effect is observed at various SOAs (−100, 0, and 100 ms). Because we systematically controlled various parameters known to affect word reading and distractor interference, it is extremely unlikely that factors other than frequency (and/or AoA and/or concept familiarity) are responsible for the distractor frequency effect obtained in our experiments. Our results are consistent with those of La Heij et al. (1998; Experiment 3b), who also observed greater interference for LF distractors. Thus, a sizable number of results disconfirm the claim that distractor interference is positively correlated with distractor frequency. This thesis was based on the findings of two older studies that reported greater interference for HF distractors (Fox et al., 1971; Klein, 1964). However, as argued in the introduction to this article, these studies are methodologically limited. And we now have direct experimental evidence that word distractor interference is inversely proportional to the word's frequency.

A second major result is that the effect of distractor frequency is modulated by factors that affect lexical access in production (Experiment 4) but not by factors that affect word recognition (Experiment 2 and 3). We explored in some detail the possibility that the distractor frequency effect reflects relative difficulties in recognizing words of different frequency. Various manipulations designed either to facilitate or to hinder distractor word recognition had no overall effect on distractor interference and did not affect the size of the distractor frequency effect. These results exclude word recognition as the locus of the distractor frequency effect. By contrast, we did obtain evidence suggesting that distractor frequency has its effect at some stage of lexical access for production. One crucial finding is that interference declined for distractors that were read aloud several times prior to being shown in the picture-naming task (Experiment 4), indicating that the repeated production of the distractor words in the reading task is functionally equivalent to increasing the frequency of those words. This result, taken together with the observation that interference did not decline when word distractors were repeated for lexical decision—a task that does not require the selection of the word for production—invites the inference that the locus of the distractor frequency effect is at the output level.

Our research has also led us to several conclusions concerning the relationship among distractor frequency and semantic and phonological relatedness in the picture–word interference task, which further restrict the possible locus of the distractor frequency effect. We have found that distractor frequency and semantic relatedness do not interact (Experiment 5), that the effects of these variables have different time courses (Experiment 5), and that there is one factor (picture–word repetition) that modulates the semantic relatedness effect but leaves the distractor frequency effect unaltered (Experiment 6). A different pattern of results obtains between distractor frequency and picture–word phonological relatedness: Phonological relatedness modulates the effect of distractor frequency (Experiment 7) and the two effects have similar time courses (Experiment 5). These results allow the conclusion that the locus of the distractor frequency effect appears to be at the same level where phonological facilitation effects arise in the picture–word interference paradigm: namely, at the level of phonological encoding. This conclusion is supported by the finding that distractor frequency interacts with phonological but not semantic relatedness and by the finding that the time course of the distractor frequency effect is similar to that of phonological facilitation.

Together, these results have a number of implications for theories of lexical access in word production, as well as for accounts of the distractor frequency effect and of the picture–word interference paradigm. These implications are discussed in turn below.

Lexical Selection in Word Production: Something Is Missing

To explain how lexical selection takes place in word production, researchers have appealed to mechanistic accounts based on activation levels. It is assumed that the lexical node with the highest level of activation is selected, whereas selection time depends on whether other nodes are activated at the same time (e.g., Roelofs, 1992). Selection time is expected to be longer if a large number of nodes are activated or if competing nodes reach high activation levels. These assumptions provided the basis for the relative activation hypothesis, a general account of the effects of interference that words produced in the picture–word interference task. The findings that greater interference is associated with LF distractors and that the effect arises at the level of lexical access in speech production are problematic for the relative activation hypothesis. According to this hypothesis, interference is directly proportional to the activation level reached by the distractor's lexical node, and, therefore, the expectation is that HF words would interfere more than LF words, contrary to the systematic pattern of results reported here.

Earlier we argued that it is possible to imagine a variant of the relative activation hypothesis, the temporal account, which might actually predict higher interference for LF words than for HF words in specific contexts. This account exploits the possibility that HF and LF words reach their peak levels of activation at different points in time. Specifically, if it were assumed that at the point in time at which lexical selection is occurring HF distractors had already passed their peak level of activation and LF distractors are roughly at their maximal activation level, then LF distractors would be expected to interfere more than HF distractors do (for a schematic illustration of this account, see Figure 2A). Although such an account provides a reasonable explanation of the finding of greater interference for LF distractors, it fails to explain other results of our experiments. Two such results are the contributions of case alternation and picture-name frequency to the magnitude of the distractor frequency effect. Other results that are problematic for the temporal account emerged in experiments in which we manipulated SOA.

As shown in Figure 2B, the temporal account predicts that if distractor word presentation is delayed, a frequency reversal should appear. That is, at positive SOAs, HF distractors should interfere more than LF distractors. This expectation is based on the following reasoning. At positive SOAs, it is less likely that HF words would have reached their peak level of activation and begun to decay. This should lead to higher activation levels for HF relative to LF words at the point in time at which the picture name is to be selected. As a consequence of this discrepancy between the activation levels of HF and LF distractors, greater interference should be observed with HF words than with LF words at positive SOAs. However, no frequency reversal was observed at 100 SOA in two experiments (Experiment 5 and the experiment mentioned in footnote 6). In both cases, the frequency effect had its usual direction of greater interference for LF distractors. One may argue that these results could reflect the choice of a relatively short SOA. In other words, it is possible that the reason we failed to observe greater interference for HF words than for LF words is because at 100 SOA, the activation levels of HF words were already past their peak. Perhaps longer SOAs are needed to tap into the stage of activation where HF words are just reaching their peak activation. To evaluate this possibility, we carried out an experiment in which we used two SOAs: 0 and 200 ms. Sixteen participants were presented with the picture–word pairs used in Experiment 1 ($N = 80$). Picture–word pairs were shown at two SOAs (0 and 200 ms). At 0 SOA, we found an effect of distractor frequency ($p < .05$). At 200 SOA, HF and LF distractors produced similar response latencies (623 vs. 626 ms, respectively; $Fs < 1$). This result, too, is incompatible with the temporal account and casts further doubt on the relative activation hypothesis, of which it is a particular instantiation.

The failure of the relative activation hypothesis to account for the distractor frequency effect reported here, along with a number of other findings that emerged in our experiments, call into question the explanations of lexical selection in the context of distractor words. Clearly, we have to reevaluate claims about the structure of the lexical access process that have been based on results found while using the picture–word interference paradigm.

An Alternative Account: Active Blocking of Distractor Selection

An appealing aspect of the relative activation account is that it attempts to explain the phenomenon of distractor word interference on the basis of the same general principles that are involved in lexical selection. However, the failure of this account to explain the effect of distractor frequency suggests that some other mechanism is at play in the phenomenon of word interference. One possibility is that the picture–word interference paradigm implicates mechanisms for suppressing the selection of the distractor lexical nodes. Perhaps the target word cannot be selected for production until the distractor's lexical node has been actively blocked. In this scenario, one of the factors determining word interference is how quickly distractor selection can be blocked so that target selection can proceed, unhindered by the distractor. If distractor selection can be blocked early, target selection will only suffer minimal delay; if distractor selection is blocked late, target selection will incur commensurately greater delay. Thus, if a picture's name cannot be selected until the distractor has been blocked, target selection would be expected to occur later with LF distractors than with HF distractors because the LF distractors become available as potential responses to be blocked later than HF distractors do.[7]

Our account is in line with other models of the interference effects and of naming that also postulate inhibitory mechanisms (Eriksen & Schultz, 1979; Tipper, 1985; Wheeldon & Monsell, 1994). Importantly, a number of empirical results suggest distractor blocking (e.g., Allport et al., 1985; Lowe, 1979; Neill, 1977; Tipper, 1985; for a review, see Fox, 1995; Tipper, 2001). For example, Neill (1977) reported that in the Stroop color-naming task, it is harder to name an ink color (e.g., green) if the same word for the color (*green*) appeared as a distractor in the preceding trial. This result is consistent with the blocking hypothesis: If responses to distractor words are suppressed, it should then be harder to produce these words on the successive trial. Our account also assumes there is a processing bottleneck, as the lexical selection mechanism is engaged in processing one word at a time. In this respect, our account is in line with Ferreira and Pashler's (2002) recent proposal of a central processing bottleneck at the level of lexical node selection for word production.

The active blocking account can explain the distractor frequency interference effect. However, this opens the issue of how to explain the semantic interference and phonological facilitation effects in the picture–word paradigm. First consider the semantic interference effect. The phenomenon to be explained is that semantically related picture–word pairs (e.g., *dog–fox*) lead to greater interference than unrelated picture–word pairs (e.g., *dog–car*) in the picture–word interference task. This phenomenon has typically been explained as follows (e.g., Roelofs, 1992; Starrevelt & La Heij, 1996): Semantically related distractors are more highly activated than unrelated distractors because the former (but not the latter) receive activation from both the word and the picture (e.g., the distractor lexical node *fox* receives activation from the word *fox* and from the picture *dog* because it is semantically related to *fox*). Given the assumption that lexical selection is a competitive process in which the selection of the most highly activated node (the target) is affected by the activation levels of other lexical nodes, the selection of the target node is slowed in proportion to the degree of competition it receives—the higher the activation levels of the distractors, the slower the selection of the target node. However, if we were to adopt the active blocking account of distractor interference in the picture–word interference task, we would have to give up the assumption of selection by competition and, therefore, we would have to give up the explanation of the semantic interference effect in terms of selection competition at the lexical node level.

What evidence supports the claim that the locus of the semantic interference effect is at the lexical level? Perhaps the strongest evidence is that the effect of semantic interference is not obtained in picture-recognition tasks, tasks that do not require verbal responses (Levelt et al., 1991; Schriefers et al., 1990): If the locus of

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[7] The active blocking account is not incompatible with the result showing that the effect of distractor frequency disappears at positive SOAs. When distractor presentation is delayed beyond a certain point, there is no need to block its lexical selection because target selection has already started.

the semantic interference effect is at the lexical level, semantic interference should only be found with tasks that require oral responses (Glaser & Glaser, 1989; Levelt et al., 1999; Schriefers et al., 1990; Starreveld & La Heij, 1996). Conversely, if the effect of semantic interference was to arise at the semantic level, it would be obtained in all sorts of semantic processing tasks, including those that do not require spoken production. Accordingly, the observation that semantic interference is not found in tasks like picture recognition invites the conclusion that the locus of the semantic interference effect is not at the semantic level. However, this conclusion is based on the assumption that the same semantic information is critically involved in picture-recognition and picture-naming tasks. But it is not clear that this assumption is defensible.

For example, consider the task used by Schriefers et al. (1990). Participants were asked to remember a list of pictures and later were tested in a new–old picture recognition test in which pictures appeared with both related and unrelated superimposed words. Recognition latencies were nearly identical for pictures paired with related and unrelated words (for a similar finding, see Levelt et al., 1991). However, as pointed out by Meyer (1996), the possibility cannot be excluded that picture recognition in these tasks relies predominantly on episodic and not semantic information. If this is the case, the results of these tasks could not be used to draw conclusions about the locus of the effect of semantic interference. In other words, we do not have compelling evidence against the possibility that the semantic interference effect in the picture–word interference paradigm reflects semantic-level processes. Other findings cited in support of the lexical hypothesis of the effect of semantic interference come from the Stroop color-naming task. But these findings do not represent strong evidence against the hypothesis of a semantic source of the effect either. It has been found that compared with the size of the interference effect as seen in the classical Stroop color-naming task, the size of the interference effect is reduced in nonverbal response variants of the Stroop color task (e.g., key pressing, card sorting, tone humming). However, the interpretation of these findings is far from straightforward. First, some studies do not report a decrease of interference with these sorts of tasks (e.g., Lupker & Katz, 1981, Experiment 1; Roe et al., 1980; White, 1969). Second, it is not obvious that the magnitude of the interference effect should remain constant between verbal and nonverbal response tasks that differ on several critical dimensions (response latencies, number of response alternatives, past experience, etc.).

A tentative explanation of the semantic mechanisms responsible for the semantic interference effect follows.[8] In the picture–word interference task, the semantic system is confronted with the problem of discriminating between the representations activated by pictures and words. This conflict must be resolved in order to proceed with selection of the concept that is to be expressed in the naming task. It is possible that the determination of which concept is to be processed further for naming depends in part on categorical information about the picture and word stimuli. Categorical information can be acquired from a picture relatively quickly. In many cases, it is sufficient to have partial information about an object's structural components in order to recognize its category. For example, pieces of information like "head" and "leg" versus "wheel" and "door" are sufficient to discriminate between the domains of *animals* and *vehicles.* Thus, at the earliest stages of processing, when information from the picture has just started to accumulate, there might be enough information for determining the category of the picture (e.g., *animal*) but not the identity of a specific object (e.g., *dog*). This categorical information could be used to distinguish between the conceptual and semantic representations of pictures and words of different categories. In contrast, when the target and the distractor are from the same category, more information (and time) is needed to discriminate between them. The categorical relation between target and distractor would thus determine how easily targets and distractors can be discriminated and how quickly the target's concept can be selected or how quickly the distractor's semantic representation can be suppressed. Importantly, it is well established that categorical information plays a crucial role in the effect of semantic interference, as demonstrated by the fact that this effect can only be obtained with categorically related picture–word pairs (e.g., *dog–fox*) and not with associated picture–word pairs (e.g., *dog–leash*; Lupker, 1979). The explanation of the effect of semantic interference provided here, which emphasizes categorical information, seems thus to capture a fundamental aspect of this effect.

Converging evidence in support of this account of the semantic interference effect is provided by a set of observations that places the effects of semantic relatedness in the context of the picture–word interference paradigm. A clear fact has emerged from this research: A semantic relationship between target and distractor does not necessarily lead to semantic interference. In fact, semantic interference is only obtained when the semantic relationship between the target and the distractor is categorical (e.g., *dog–fox*) and the response to be produced is at the same level of categorization as the distractor (picture: *dog*; distractor: *fox*). In all other cases investigated, semantic relatedness between the picture and the distractor has led to facilitation. For example, when participants are required to produce the name of the picture's semantic category (e.g., produce "animal" for the picture of a dog), a semantically or categorically related distractor (e.g., *fox*) facilitates naming whereas an unrelated distractor (e.g., *carpet*) does not (Caramazza & Costa, 2001; Costa, Mahon, Savova, & Caramazza, in press; Glaser & Glaser, 1989; see also Vitkovitch & Tyrrell, 1999, for a subordinate-level naming task). The fact that the type of the semantic relationship between target and distractor modulates the polarity of the effect (facilitation vs. interference) invites the inference that the semantic effects occur at the semantic level, perhaps along the lines we have suggested here.

Further evidence for separating the locus of the semantic interference and the distractor frequency effects is provided by the results of Experiments 5 and 6. In Experiment 5, we found that the effects of these two variables do not interact, as would be expected if the semantic interference effect arises at the level of semantic processing and the distractor frequency effect arises at the lexical node selection stage. In Experiment 6, the semantic interference effect (not the distractor frequency effect) declined with distractor repetition, as would be expected if the semantic interference and the distractor frequency effects arise at different levels.

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[8] Our explanation differs from prior accounts that also located the semantic effects at the semantic level (Luo, 1999; Seymour, 1977) because we propose that word distractors also affect lexical selection.

We have argued that the distractor frequency and the semantic interference effects arise at different levels of lexical access—the lexical node selection and semantic levels, respectively. What about the phonological facilitation effect? The results of Experiment 7, in which we obtained an interaction between phonological relatedness and distractor frequency, suggest that the phonological facilitation and distractor frequency effects arise at the same level of lexical processing. This possibility is quite plausible. Phonological facilitation reflects priming of the word form (phonology) of the target response. If the target response primes phonologically related distractors, we would expect the obtained interaction.

In sum, the active blocking account can explain the distractor frequency effect. The effect of semantic interference would be problematic for this account if such an effect originated at the lexical level. Nevertheless, there does not seem to be compelling evidence in support of the lexical hypothesis of the semantic interference effect (Caramazza & Costa, 2000, 2001). Furthermore, it is possible to formulate a plausible explanation of the semantic interference effect in terms of processes occurring at the semantic level. The effect of picture–word interference is thus viewed as a combination of interfering effects arising at distinct levels of processing: semantic and lexical. And, at each of these levels, different features of the distractors are critical: semantic category versus word frequency.

Implications for Models of Lexical Selection

To this point, we have discussed the effects of distractor frequency on picture naming in terms of a fairly general (and neutral) model of lexical access. We have referred to lexical access and lexical selection without further commitment to the nature of the lexical representations involved in the selection process. This choice was motivated by the desire to give as general an account of the distractor frequency interference phenomenon as possible. We now consider specific models of lexical access and whether they can accommodate the reported results.

A model that has wide currency in the area of speech production is the one proposed by Levelt and collaborators (Levelt et al., 1991, 1999; Jescheniak & Levelt, 1994; Schriefers et al., 1990). This model is based largely on reaction time data, mostly from the picture–word interference paradigm but also from other naming tasks. The model makes explicit claims about the mechanism of lexical selection and the locus of the frequency effect in picture naming and, therefore, our results provide a critical test of the model. A central feature of this model is the hypothesis that two distinct levels of lexical representation are accessed in the course of word production (see also Dell, 1990; Garrett, 1980; Roelofs, 1992; but for an alternative view, see Caramazza, 1997; Caramazza & Miozzo, 1997). The first stage involves access to the word's lemma, a representation that specifies the syntactic properties of the word (its grammatical class and various diacritics associated with that grammatical class, e.g., tense for English verbs). The second stage involves access to the word's lexeme (or morphemic representations), which specifies the phonological content of the word. The selection mechanism for both lemmas and lexemes follows the principle of relative activation: Selection is a direct function of the target's relative level of activation. Within this model, the effect of word interference is assumed to involve competition for lemma selection. However, the model further assumes that frequency is a property of lexeme representations and that lemma activation and selection are not sensitive to word frequency (Jescheniak & Levelt, 1994). Therefore, because word interference is supposed to reflect lemma selection processes and because lemma selection is not frequency sensitive, the model wrongly predicts that distractor frequency should have no effect in the picture–word interference paradigm.

The model faces major difficulties even if two of its critical assumptions are modified to accommodate the observed distractor frequency effect. We could reject the assumption that frequency is a property of lexemes and propose instead that it is a lemma-level property (see Dell, 1990). In this case, the lemma nodes of HF distractors would have higher levels of activation than the lemma nodes of LF distractors. But because of the way in which lemma selection operates, the model makes the wrong prediction of greater interference for HF distractors than for LF distractors. This prediction follows from the assumption that the speed with which a lemma node is selected is a direct function of the discrepancy in the activation levels between the target and distractor lemmas. That is, target selection is fast for distractors with low levels of activation and slow for distractors with high levels of activation. Alternatively, we could modify the model's assumption that word interference occurs at the lemma level and assume instead that it can also occur at the lexeme level. This modification fares no better than the previous one. That is, because the model follows the principle of relative activation, it would wrongly predict that HF distractors should interfere more than LF distractors. Thus, modifying the model to allow distractors to interfere at the level of lexeme selection does not explain the distractor frequency interference effect.

In the computational lexical access model WEAVER++, Roelofs (1996, 1997) has taken a different approach in implementing the effect of word frequency observed in picture naming. The model, like that of Levelt and collaborators (Levelt et al., 1991, 1999; Jescheniak & Levelt, 1994; Schriefers et al., 1990), postulates two layers of lexical nodes (the lemmas and the lexemes). At both layers, selection mechanisms operate on the basis of the principle of relative activation. Distractors are assumed to hinder the selection of the target's lemma in proportion to their activation level: The higher their activation, the greater their interference. Of particular interest here is the hypothesis that frequency does not affect a node's activation level but rather the procedure for *selection verification*. The model assumes that further processing of a selected node can only proceed after it has been verified that the node is linked to a node selected at the preceding stage of processing. For example, it is not until it has been verified that a selected lexeme corresponds to a previously selected lemma that the lexeme's phonological segments can be retrieved. Verification time varies as a function of word frequency—it is faster for HF words than for LF words. This account of how frequency affects lexical access makes the straightforward prediction that distractor frequency should not affect the level of interference in the picture–word interference paradigm. This is because distractors are not selected and because verification procedures only apply to selected nodes. Thus, no mechanism in this model explains the effect of distractor frequency in the picture–word interference task. Our finding of a strong effect of distractor frequency seriously challenges Roleofs's implementation of the effect of word frequency.

Conclusions

The results reported in our study firmly establish the finding that distractor word interference in picture naming is inversely correlated to the frequency of the distractor and that the locus of this effect is at the level of word-form selection in lexical access for production. From the perspective of current accounts of the phenomenon of word interference, the reported frequency effect is paradoxical. These accounts fail to predict the distractor frequency effect because they focus too narrowly on the notion of relative activation in lexical selection. To provide an adequate explanation of the effect of distractor frequency and an accurate description of the phenomenon of word interference, other mechanisms need to be taken into consideration. From this perspective, we explored the possibility that the effect of distractor frequency involves mechanisms for the active inhibition of distractors. Given this assumption, we had to further modify our understanding of the locus of interference effects in the picture–word interference paradigm. For example, we found that the effects of distractor frequency and semantic interference arise at different levels of the lexical access process. Finally, it is clear that the distractor frequency interference effect seriously challenges a popular model of lexical access (Levelt et al., 1999) that has been based largely on results with the picture–word naming paradigm.

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Appendix A

Picture–Word Pairs of Experiment 1

List A						*List B*		
Pictures, high frequency	Words/frequency		Pictures, medium frequency	Words/frequency		Pictures	Words/frequency	
	High	Low		High	Low		High	Low
Bottle	Girl	Harp	Cake	Rock	Tusk	Ladder	State	Brawl
Chair	Hand	Fern	Flag	Wine	Lute	Bone	Small	Chant
Train	Head	Bait	Ladder	Box	Bib	Rope	Help	Brag
Finger	Wall	Cuff	Rope	Plant	Frock	Arrow	Town	Dusk
Bridge	Money	Patio	Axe	Hospital	Pendulum	Candle	Learn	Glove
Sun	Body	Tofu	Onion	Rifle	Lasso	Bus	Clear	Tide
Ball	Office	Alcove	Fork	River	Tulip	Flag	Heart	Shrill
Boat	Eye	Ewe	Arrow	Forest	Cavern	Lamp	Tree	Dune
Radio	Church	Crutch	Guitar	Knife	Spine	Cow	Game	Mulch
Bed	Street	Strait	Bell	King	Wasp	Pipe	Spend	Deem
Gun	City	Lava	Candle	Blood	Broom	Corn	Boat	Slam
Dog	Field	Pouch	Envelope	Window	Turban	Drum	Art	Woo
Tree	Doctor	Pulpit	Barrel	Paper	Comet	Bowl	That	Ant
Heart	Student	Florist	Lamp	Page	Maze	Fish	Bank	Skid
Horse	Room	Bead	Lion	Sea	Rye	Iron	Tone	Scrub
Table	Child	Clown	Drum	Hotel	Robot	Moon	Career	Choir
Book	Water	Camel	Pipe	Ship	Claw	Piano	Depth	Spine
Door	Woman	Bacon	Shirt	Glass	Crust	Tongue	Snake	Marsh
Foot	House	Sieve	Tank	Floor	Sleet	Cat	Goal	Tact
Car	School	Spleen	Tent	Fire	Dove	Lion	Man	Cask

(*Appendixes continue*)

Appendix B

Pictures and Words Shown in Experiments 3 and 4

	List/word frequency			
	List A		List B	
Pictures	High	Low	High	Low
Anchor	Music	Coral	Paper	Comet
Arrow	Plant	Frock	Light	Torch
Bell	City	Lava	Eye	Ewe
Candle	Street	Strait	Field	Pouch
Cup	Body	Tofu	River	Tulip
Drum	Water	Camel	Woman	Bacon
Duck	House	Gnome	Child	Clown
Fish	Night	Marsh	Church	Crutch
Flag	Dog	Key	Hair	Loaf
Foot	Town	Vest	Court	Vault
Hat	Table	Valve	Air	Owl
Kite	School	Spleen	Hand	Fern
Lemon	Voice	Crate	Money	Patio
Necklace	Fire	Dove	Food	Quiz
Pear	Gun	Hog	Cell	Cask
Pepper	Head	Bait	War	Wig
Pig	Name	Bale	Girl	Harp
Pipe	Horse	Badge	Wall	Cuff
Rope	Office	Alcove	Doctor	Pulpit
Tent	Class	Scalp	Book	Reel

Appendix C

Pictures and Words Shown in Experiment 5

	Related distractor/frequency		Unrelated distractors/frequency	
Picture	High	Low	High	Low
Bench	Chair	Stool	Rock	Dune
Bowl	Cup	Mug	Wire	Ape
Pitcher	Bottle	Decanter	Circle	Diesel
Fork	Plate	Ladle	Gate	Knoll
Bus	Car	Trolley	Girl	Pulpit
Moon	Sun	Comet	Song	Germ
Submarine	Boat	Raft	Blood	Pillar
Flower	Tree	Moss	Hair	Malt
Tent	House	Shack	Word	Plum
Tongue	Eye	Nostril	City	Chisel
Shirt	Hat	Mitten	Desk	Robot
Cake	Bread	Muffin	Ring	Turban
Brain	Heart	Spleen	Fire	Froth
Nurse	Teacher	Plumber	Dollar	Tartar
Pilot	Doctor	Chef	Field	Loaf
Rocket	Airplane	Helicopter	Corner	Badminton
Tail	Leg	Hoof	Lady	Valve
Mouse	Dog	Raccoon	Film	Cider
Cow	Horse	Donkey	River	Lava

Appendix D

Pictures and Words Shown in Experiment 6

	Words from List A			Words from List B	
Picture	Related	Unrelated	Picture	High frequency	Low frequency
Bed	Couch	Tower	Anchor	Center	Pebble
Bread	Pizza	Stamp	Arrow	Party	Lasso
Car	Taxi	Lamp	Balloon	Wife	Harp
Cup	Mug	Gel	Bottle	College	Syringe
Desk	Table	Heart	Candle	Picture	Vanilla
Duck	Swan	Raft	Church	People	Shrimp
Guitar	Violin	Castle	Door	Family	Helmet
Gun	Rifle	Wheel	Envelope	Field	Gnome
Hand	Foot	Room	Flag	House	Crust
Horse	Donkey	Pallet	Frog	Class	Gorge
Knife	Fork	Nest	Hat	Water	Broom
Lion	Tiger	Pearl	Ladder	Market	Dragon
Moon	Star	Gold	Leaf	Street	Vendor
Nose	Mouth	Radio	Needle	Doctor	Galley
Onion	Carrot	Bucket	Pipe	Court	Waltz
Pear	Apple	Globe	Ring	Body	Cask
Saw	Hammer	Puppet	Rope	Office	Podium
Shirt	Jacket	Camera	Ruler	Police	Trench

Appendix E

Pictures and Words Shown in Experiment 7

	Related distractor/frequency		Unrelated distractor/frequency	
Picture	High	Low	High	Low
Ball	Wall	Shawl	Road	Flake
Brain	Plane	Crane	Horse	Marsh
Cross	Loss	Gloss	Size	Pulse
Crown	Town	Gown	Word	Duck
Deer	Fear	Sneer	Game	Farce
Door	Store	Pore	Blood	Hoop
Drill	Hill	Sill	Fire	Cart
Egg	Leg	Peg	Bed	Ant
Fan	Plan	Clan	List	Heir
Gun	Sun	Ban	Eye	Mop
Hand	Land	Strand	Name	Barge
Hook	Book	Nook	Girl	Snag
Knife	Life	Strife	Work	Prank
Mouse	House	Blouse	Place	Ledge
Nail	Sale	Pail	Club	Cord
Nest	Test	Pest	Hour	Haze
Net	Set	Pet	Law	Bin
Plate	Rate	Bait	Bill	Germ
Shark	Park	Spark	Food	Clump
Star	Car	Jar	Air	Rib
Stool	Pool	Mule	Film	Herb
Tank	Bank	Plank	Farm	Spoon
Tent	Cent	Vent	Foot	Dune

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