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Sequential effects in the lexical decision task: The role of the item frequency of the previous trial

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Two lexical decision experiments were conducted to determine whether there is a specific, localized influence of the item frequency of consecutive trials (i.e., first-order sequential effects) when the trials are not related to each other. Both low-frequency words and nonwords were influenced by the frequency of the precursor word (Experiment 1). In contrast, high-frequency words showed little sensitivity to the frequency of the precursor word (Experiment 2), although they showed longer reaction times for word trials preceded by a nonword trial. The presence of sequential effects in the lexical decision task suggests that participants shift their response criteria on a trial-by-trial basis.

In the lexical decision task, participants must decide as rapidly as possible whether a visually presented letter string is or is not a word. Although it is generally assumed that the lexical decision task directly taps the process of lexical access, lexical decision responses also appear to be influenced by a number of factors beyond lexical access (e.g., Balota & Chumbley, 1984; Grainger & Jacobs, 1996; Hino & Lupker, 1998; Pollatsek, Perea, & Binder, 1999). The composition of the list is one of the factors that appears to affect lexical decision responses (see Bodner & Masson, 2001; Ferrand & Grainger, 1996; Forster & Veres, 1998; Glanzer & Ehrenreich, 1979; Grainger & Jacobs, 1996; McKoon & Ratcliff, 1995; Stone & Van Orden, 1992, 1993).

One of the most well known demonstrations of context-sensitive behaviour in the lexical decision task is the frequency-blocking effect (Glanzer & Ehrenreich, 1979; see also Carreiras,

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Perea, & Grainger, 1997; Dorfman & Glanzer, 1988; Gordon, 1983; Stone & Van Orden, 1993): Participants make faster lexical decision responses to high-frequency words (and to nonwords) when the word list is composed of only high-frequency words than when the word list is composed of both high- and low-frequency words. It seems that when only high-frequency words are presented in the word list, aggressive response criteria can be adopted that—for approximately the same error rate—produce faster responding for both "yes" and "no" responses than that in a word list with high- and low-frequency words (see Grainger & Jacobs, 1996; Plaut, 1997). Thus, blocking effects are hypothesized to reflect context-dependent adjustments of the response criteria. More important, the fact that these effects have also been found with a within-subject design (e.g., speeded identification task: Grainger, Carreiras, & Perea, 2000; lexical decision task: Carreiras et al., 1997; naming task: Lupker, Brown, & Colombo, 1997) strongly suggests that participants shift their response criteria throughout the experiment. The question is *how* and *when* these changes take place (e.g., Gibbs & Van Orden, 1998; Gordon, 1983; Jared, 1997; Kello & Plaut, 2000; Kiger & Glass, 1981; Luce, 1995; Lupker, Brown, & Colombo, 1997; Lupker, Taylor, & Pexman, 1997; Strayer & Kramer, 1994a, 1994b; Treisman & Williams, 1984; Zevin & Balota, 2000).

Although models of word recognition typically assume independence across (unrelated) trials, most researchers would agree that the nature of the stimulus on trial $N - 1$ may affect recognition and/or responses on trial N. In the present study, we want to test such context sensitivity at a very dynamic level, by examining frequency-based criterion changes on a trial-by-trial basis. In this light, it is important to analyse whether frequency-blocking effects are the accumulated result of a whole series of small trial-by-trial adaptations, or whether they occur only after a string of a large number of successive items of the same type. For instance, Grainger and Beauvillain (1987) found that language blocking effects in bilinguals (i.e., a response time advantage for lists of words from one language compared to lists containing a mixture of words from both the bilingual's languages) were essentially due to the effects of the directly preceding trial in the mixed lists (i.e., a word from the same/different language).

If lexical decision times depend on the characteristics of the immediately preceding item (e.g., the frequency of the precursor item, as proposed by Gordon, 1983), current models of visual word recognition should be regarded as models for the psychological process occurring on any one trial, as subject to certain free parameters representing the discriminability of the stimuli (e.g., word/nonword overlap) and the intended accuracy of the participant, among other factors. These models would be evaluated with respect to the average performance of a number of participants over a series of trials (Laming, 1973). However, even if these models can capture the basic pattern of effects in the long run, these "static" accounts would neglect the microstructure of the experiment. Interestingly, a model that incorporates trial-to-trial fluctuations should be compatible with the model as a whole (Laming, 1973). This clearly places strong constraints on admissible models. We believe that gaining a better understanding of sequential dependencies in laboratory word identification tasks such as lexical decision is important for developing dynamic models of the underlying cognitive processes. As Luce (1995) pointed out, mathematical models in psychology should increase toward dynamic—rather than static—descriptions. Furthermore, sequential effects are not just random error, and we should try to account systematically for these trial-by-trial dependences (Gilden, 2001; Kelly, Heathcote, Heath, & Longstaff, 2001).

We should note that some models of visual word recognition do not make any claims concerning sequential (or blocking) effects. For instance, in the serial search model (Forster, 1976; Forster & Shen, 1996), either the participant has found the lexical entry or he or she has not, and then this model would not predict any sequential effects for word stimuli in the lexical system. Specifically, Bradley and Forster (1987; see also Forster, 1981) indicated that any frequency-blocking effect (and presumably any sequential effect) "is not attributable to faster access, but to a faster use of the products of access" (p. 128). Nonetheless, a number of computational models of visual word recognition have been proposed in the last years that explicitly include response criteria for making lexical decisions (e.g., dual-route cascaded, DRC, model, Coltheart, Rastle, Perry, Ziegler, & Langdon, 2001; multiple read-out model, MROM, Grainger & Jacobs, 1996). In the MROM, participants can use two intralexical response criteria to make a "yes" response (the M criterion, based on unique word identification; and the Σ criterion, based on global activation in the lexicon) and an extralexical response criterion to make a "no" response (the participant makes a "no" response when he or she has not made a "yes" response before reaching a time limit, the T criterion). (The DRC model uses these same mechanisms for "yes" and "no" responses.) The M criterion may not be strategically modifiable, as it represents a fixed property of the word identification system (Coltheart et al., 2001; Grainger & Jacobs, 1996; but see Grainger et al., 2000), whereas the Σ and T criteria can be strategically adjusted. Grainger and Jacobs (1996) proposed that strategic modifications of the Σ and T criteria (as a function of list characteristics) are responsible for any frequency-blocking effects obtained in the lexical decision task. In this way, the MROM captures most aspects of frequency-blocking effects obtained with the lexical decision task (see Grainger & Jacobs, 1996). Given an account of blocking effects in terms of criterion adjustments, an important question is whether the response criteria used on a given trial are determined by a combination of long-term (i.e., the list as a whole, the instructions) and short-term (trial-by-trial) processes.

In a recent study, Lima and Huntsman (1997) manipulated the lexical status of the previous trial in the lexical decision task when the trials in the stimulus list were not related to each other.[1] Lima and Huntsman (1997; Experiment 1) found that both word and nonword responses were significantly slower when the previous trial involved a nonword than when it involved a word (21 ms for word trials and 28 ms for nonword trials). (The word targets were of high frequency; median frequency: 47 occurrences per million.) Interestingly, the fact that there was no "same-response" repetition effect for the nonword targets strongly suggests that the mechanisms underlying sequential effects in the lexical decision task differ from those found in simple two-choice reaction time tasks—that is, tasks in which the participant is presented with one of two stimuli that are easy to discriminate and to each of which he or she is required to make a different simple response (for a review, see Kirby, 1980; Soetens, 1998). (Note that in simple two-choice tasks, the repetition of the same response is ordinarily accompanied by a facilitative sequential effect.) Instead, Lima and Huntsman (1997) suggested that

[1]There is some empirical evidence in priming studies that shows that lexical decision times are increased when a word target is preceded by a nonword trial compared to when it is preceded by an unrelated word trial (e.g., McNamara, 1992; Perea, 1997). However, in the previously cited studies, a number of the trials were related. Given that participants would be likely to use the information from the preceding trials, part of the obtained effects might be due to some strategic or integration processes.

there was a temporary inhibition effect after processing an unfamiliar letter string (i.e., a nonword).

The main goal of this paper is to examine the role of the item frequency of the immediately preceding trial (i.e., a first-order sequential effect) when the trials in the stimulus list are not related to each other. Specifically, we examine the effects of sequential dependencies in the visual lexical decision task by orthogonally manipulating the frequencies and lexicality of stimuli on precursor and target trials. To that end, the target word (or the target nonword) could be preceded by an unrelated high-frequency word, an unrelated low-frequency word, or a nonword. As Gibbs and Van Orden (1998) pointed out, it is important to find out whether or not the parameter/s responsible for strategic control in the lexical decision task may vary as a function of trial-by-trial changes in task demands. We should note that Gordon (1983) carried out a post hoc analysis of his frequency-blocking experiment. (Gordon's experiment was not explicitly designed to test for conditional effects, though.) The results showed that low-frequency words were responded to much faster when the precursor item was a high-frequency word (685 ms) than when the precursor item was a low-frequency word (765 ms); in addition, high-frequency words were responded to faster when the precursor item was a high-frequency word (513 ms) than when the precursor item was a low-frequency word (528 ms). However, no additional statistical analyses were provided. Furthermore, the magnitude of the sequential effect for the low-frequency words was surprisingly large (80 ms).

Interestingly, Strayer and Kramer (1994b; see also Treisman & Williams, 1984) suggested that fine-grained trial-by-trial adjustments reflect a gradual shift of the criterion settings over the course of a series of (similar) trials toward the optimal criterion. In this light, one could argue that stimuli are perceived as easy or difficult to process, and the response criteria are set as a function of the ongoing average of perceived difficulty on a trial-by-trial basis (see Taylor & Lupker, 1998, 2001). For instance, Taylor and Lupker (2001) found that both high- and low-frequency words are named faster when a high-frequency word had been presented in the previous trial than when another low-frequency word had been presented in the previous trial. Taylor and Lupker (2001) indicated that participants set a time criterion for responding in speeded tasks. In this light, an "easy" stimulus leads to an earlier time criterion than does a "difficult" stimulus. In other words, first-order sequential effects may reflect the relative speed of the previous response—that is, decisions following "slow" responses (or "difficult" stimuli) being slower than decisions following "fast" responses (see Lupker, Taylor, & Paxman, 1997; Taylor & Lupker, 2001, for evidence in the naming task).

If this reasoning can be extended to the lexical decision task (note that the previous account was proposed for the *naming* task rather than for a binary task), it should be found that responses on trials following a low-frequency word are slower than responses of trials following a high-frequency word. In other words, the criterion change induced by a successful classification of a high-frequency word would be to reduce the response criterion for a "yes" response (or a "no" response). This is actually the pattern of results reported by Gordon (1983). However, the story is more complicated. There is empirical evidence that shows a frequency-blocking advantage (if anything) for low-frequency words in the lexical decision task (i.e., faster response times in the pure list of low-frequency words; e.g., Glanzer & Ehrenreich, 1979; but see Gordon, 1983), especially when the word/nonword discrimination is difficult (e.g., using pseudohomophones in the nonword list; Stone & Van Orden, 1993) and when accuracy is stressed over speed (Dorfman & Glanzer, 1988). If participants use a more aggressive criterion for "yes" responses following a single high-frequency word (on a trial-by-trial basis), they should presumably respond faster to a low-frequency word when the previous trial is a high-frequency word than when the previous trial is a low-frequency word. However, this reasoning would *incorrectly* predict faster response times for low-frequency words in a mixed list of high- and low-frequency words than in a pure list of low-frequency words. (We delay a more detailed theoretical discussion of this issue until the General Discussion.)

Finally, Gordon (1983) suggested that first-order sequential item frequency effects should be more pronounced with lower frequency words because the slow growth of activation of these words might magnify reaction time changes produced by shifts in the response criteria (see earlier). In order to analyse this possibility, Experiment 1 examined the sensitivity of low-frequency words to such variations, whereas Experiment 2 examined the sensitivity of high-frequency words.

EXPERIMENT 1

The influence of the intertrial interval (ITI) was also analysed in Experiment 1. Previous research with simple two-choice reaction time tasks has shown that the pattern of sequential effects depends on the magnitude of the ITI (see Soetens, 1998, for a recent review). Specifically, response time patterns in experiments with short ITIs have been associated with *automatic* processes, whereas response time patterns in experiments with long ITIs have been associated with *strategic* processes. (Unfortunately, Lima & Huntsman, 1997, did not report the ITI used in their lexical decision experiments.) In this light, participants at a long ITI might try to make predictions about the nature of the upcoming trial (even when they are completely unrelated). For instance, Wagenaar (1972) suggested that participants tend to expect more alternations than repetitions in a series, which may induce faster response times to a nonword after a word trial—or a faster response time to a word after a nonword trial—at a long ITI. If this reasoning is correct, the pattern of sequential effects in the lexical decision task could differ as a function of the duration of the ITI. Alternatively, if participants modify their criterion settings based on the characteristics of the previous trial (Strayer & Kramer, 1994b; Taylor & Lupker, 1999), there would be no reason for that criterion to change as a function of the duration of the ITI.

Method

Participants

A total of 114 psychology students from the University of València took part in the experiment to earn extra course credit. All of them had either normal or corrected-to-normal vision and were native speakers of Spanish.

Materials

The target words were 42 low-frequency Spanish words (mean frequency: 22 per two million words; range: 11–28), which were selected from the Spanish word pool of Alameda and Cuetos (1995). Target words were preceded by three types of precursor trials: (1) high-frequency words (mean frequency: 709; range: 231–2226); (2) low-frequency words (mean frequency: 13; range: 6–19); and (3) nonwords. The precursor items were unrelated in orthographic/phonological form and in meaning to the target words.

The target nonwords were 42 stimuli constructed by changing an interior letter from medium-frequency Spanish words. Target nonwords were also preceded by three types of precursor trials: (1) high-frequency words (mean frequency: 337; range: 104–1335); (2) low-frequency words (mean frequency: 13; range: 5–18); and (3) nonwords. All the word and nonword stimuli were six letters in length.

The 84 word and nonword targets were divided into three groups of 14 word targets and 14 nonword targets each. Three stimulus lists were created by matching each of those targets with its high-frequency precursor trial, its low-frequency precursor trial, or its nonword precursor trial in a Latin square design. Each stimulus list contained 14 word targets preceded by a high-frequency word, 14 word targets preceded by a low-frequency word, 14 word targets preceded by a nonword, 14 nonword targets preceded by a high-frequency word, 14 nonword targets preceded by a low-frequency word, and 14 nonword targets preceded by a nonword. Participants were randomly assigned to one of the three stimulus lists. In addition, 14 nonword-word filler pairs and 14 nonword-nonword filler pairs were also used to complete the experimental material.

Procedure

Participants were tested in groups of 14 to 16 in a quiet room. Presentation of the stimuli and recording of reaction times were controlled by Apple Macintosh Classic II microcomputers. The routines for controlling stimulus presentation and reaction time collection were obtained from Lane and Ashby (1987) and from Westall, Perkey, and Chute (1986), respectively. On each trial, a fixation signal "> <" was presented for 200 ms on the centre of the screen. After a 50-ms blank, a lowercase letter string was presented on the centre of the screen. Participants were instructed to press one of two buttons on the keyboard ("ç" for yes and "z" for no) to indicate whether the letter string was a legitimate Spanish word or not. This decision had to be done as quickly and as accurately as possible. When the participant responded, the target disappeared from the screen. The intertrial interval was set at 1500 ms for one group (composed of 54 participants) and at 300 ms for the other group (composed of the 60 remaining participants). Presentation of the pairs was random within each group, and each participant received a different random order. Each participant received a total of 24 practice trials prior to the experimental trials. The session lasted approximately 12–16 min.

Results and discussion

Incorrect responses (5.6% for words and 3.8% for nonwords) were excluded from the latency analysis. To avoid the influence of outliers, all reaction times more than 2.0 standard deviations above or below the mean for that participant in all conditions were also excluded from the latency analysis (4.9% for words and 4.9% for nonwords). Participant and item analyses of variance (ANOVAs) based on the participants' and items' mean response latencies and error rates were conducted based on a 3 (type of precursor trial: high-frequency word, low-frequency word, nonword) × 2 (intertrial interval: 300 vs. 1500 ms) × 3 (list: List 1, 2, 3) design. The factor list was included in the statistical analysis to extract the variance due to the lists (see Pollatsek & Well, 1995). Effects were considered significant if $p < .05$. The statistical analysis of the nonword trials was identical to that of the word trials. The mean lexical decision latencies and error rates from the participant analysis are presented in Table 1.

Word trials. The ANOVA on the latency data showed that the main effect of the intertrial interval was significant, $F_1(1, 108) = 12.08$, $MSE = 15{,}033$; $F_2(1, 39) = 150.69$, $MSE = 897$: On average, participants had faster latencies with the longer ITI. The main effect of type of precursor trial was also significant, $F_1(2, 216) = 5.35$, $MSE = 985$; $F_2(2, 78) = 4.36$, MSE

TABLE 1
Mean lexical decision time[a] and error rates for the word and nonword targets in Experiment 1

		Type precursor trial					
		High-freq. word		*Low-freq. word*		*Nonword*	
Intertrial interval[a]		*M*	*Error rate*	*M*	*Error rate*	*M*	*Error rate*
1500	Low-freq. words	640	6.3	630	3.4	651	4.9
	Nonwords	717	3.8	728	4.1	739	4.2
300	Low-freq. words	690	6.4	681	5.2	686	7.3
	Nonwords	765	3.3	774	3.9	780	3.6

[a]In ms.

= 809. The interaction between the two factors was not significant, $F_1(2, 216) = 1.96$, MSE = 1433, $p > .14$; $F_2(2, 78) = 1.79$, MSE = 809, $p < .14$. Pairwise comparisons[2] showed that responses on trials following a low-frequency word were, on average, 9.5 ms faster than responses on trials following a high-frequency word, $F_1(1, 108) = 6.58$, MSE = 722; $F_2(1, 39)$ = 3.53, MSE = 844, $p < .068$. In addition, responses on trials following a low-frequency word averaged 13 ms less than responses on trials following a nonword, $F_1(1, 108) = 9.98$, MSE = 1010; $F_2(1, 39) = 9.87$, MSE = 790. Finally, the 3.5-ms difference between the responses on trials following high-frequency words and the responses on trials following nonword trials was not significant, $F_1(1, 108) = 0.81$, MSE = 1224; $F_2(1, 39) = 1.04$, MSE = 1095.

The ANOVA on the error data showed that the main effect of the intertrial interval was significant in the analysis by items, $F_1(1, 39) = 7.27$, MSE = 20.3; $F_1(1, 108) = 2.85$, MSE = 70.7, $p < .10$: On average, participants committed more errors with the shorter ITI. The main effect of type of precursor trial was also significant, $F_1(2, 216) = 3.67$, MSE = 40.8; $F_2(2, 78) = 4.13$, MSE = 21.5, and it did not interact with the ITI, $F_1(2, 216) = 1.26$, MSE = 40.8, $p < .14$; $F_2(2, 78) = 1.76$, MSE = 21.5, $p > .14$. Specifically, responses on trials following a low-frequency word were, on average, more accurate than responses on trials following a high-frequency word, $F_1(1, 108) = 5.60$, MSE = 42.7; $F_2(1, 39) = 5.61$, MSE = 31.5. In addition, responses on trials following a low-frequency word were, on average, more accurate than responses of trials following a nonword, $F_1(1, 108) = 4.86$, MSE = 43.0; $F_2(1, 39) = 10.91$, MSE = 14.2. Finally, the difference between the words following a high-frequency word and the words following a nonword did not approach significance, both Fs < 1.

Nonword trials. The ANOVA on the latency data also showed that the main effect of ITI was significant, $F_1(1, 108) = 5.89$, MSE = 29,148; $F_2(1, 39) = 190.81$, MSE = 688. The main effect of type of precursor trial was also significant, $F_1(2, 216) = 6.58$, MSE = 1448; $F_2(2, 78)$ = 10.59, MSE = 748. The interaction between the two factors was not significant, both Fs < 1. Pairwise comparisons showed that responses on nonword trials following a high-frequency

[2]We used Fisher's (1935) least significance difference (LSD) technique for performing the pairwise comparisons. As Levin, Serlin, and Seaman (1994) demonstrated, when the number of groups is equal to three, Fisher's LSD technique exhibits greater statistical power than do other commonly applied multiple-comparison procedures while holding the familywise Type I error at or below its nominal value.

word averaged 10 ms less than responses on trials following a low-frequency word, $F_1(1, 108) = 4.47$, $MSE = 1286$; $F_2(1, 39) = 5.11$, $MSE = 712$. In addition, responses on nonword trials following a high-frequency word averaged 18.5 ms less than responses of trials following a nonword, $F_1(1, 108) = 15.35$, $MSE = 1236$; $F_2(1, 39) = 24.15$, $MSE = 656$. The 8.5 ms difference between nonword trials preceded by a low-frequency word and nonword trials preceded by another nonword was statistically significant in the analysis by items, $F_2(1, 39) = 4.90$, $MSE = 878$; $F_1(1, 108) = 2.10$, $MSE = 1822$, $p > .14$. The analysis of the error data did not yield any significant effects (all ps > .20).

The tendency to respond faster to a stimulus that is of the same category (word, nonword) as the one preceding it only occurred for word trials, replicating earlier work by Lima and Huntsman (1997). But the more important—and intriguing—finding is the effect of the item frequency of the previous trial: Participants made more errors—and responded more slowly—to low-frequency words when they were preceded by a high-frequency word than when they were preceded by a low-frequency word. (We will return to this issue in the General Discussion.) For nonword trials, there was also an effect of the frequency of the preceding trial: nonwords were responded to faster when the preceding trial was a high-frequency word than when it was a low-frequency word or a nonword.

Finally, the magnitude of the sequential effects was not affected significantly by the duration of the ITI. In our experiment, participants responded faster when the ITI was set at 1500 ms than when it was set at 300 ms. The slower response times of the participants at the short ITI might reflect some sort of refractory period after the participants' response.

EXPERIMENT 2

Experiment 2 was designed to examine the presence of first-order sequential effects with high-frequency target words. Because the ITI did not appear to modulate the magnitude of the sequential effects in Experiment 1, the ITI was set at a constant 1500 ms.

Method

Participants

A total of 57 psychology students from the University of València took part in the experiment to earn extra course credit. All of them had either normal or corrected-to-normal vision and were native speakers of Spanish. None of them had participated in Experiment 1.

Materials

The target words were 42 Spanish words (mean frequency: 265 per two million words; range: 141–540), which were selected from the Spanish word pool of Alameda and Cuetos (1995). Target words were preceded by three types of precursor trial: (1) high-frequency words (mean frequency: 709; range: 231–2226); (2) low-frequency words (mean frequency: 13; range: 6–19); and (3) nonwords. The precursor items were unrelated in form and in meaning to the target words. The target nonwords were 42 stimuli constructed by changing an interior letter from medium-frequency Spanish words. Target nonwords were also preceded by three types of precursor trial: (1) high-frequency words (mean frequency: 337; range: 104–1335); (2) low-frequency words (mean frequency: 13; range: 5–18), and (3) nonwords. The construction of the three experimental lists was similar to that in Experiment 1. As in Experiment 1, 14 nonword–word filler pairs and 14 nonword–nonword filler pairs were used to complete the experimental material. All the word and nonword stimuli were six letters in length.

Procedure

The procedure was identical to that for Experiment 1, except that the ITI was set at a constant 1500 ms.

Results and discussion

Incorrect responses (4.8% for words and 2.5% for nonwords) were excluded from the latency analysis. As in Experiment 1, all reaction times more than 2.0 standard deviations above or below the mean for that participant in all conditions were excluded from the latency analysis (4.6% for words and 5.2% for nonwords). Participant and item ANOVAs based on the participants' and items' mean response latencies and error rates were conducted based on a 3 (type of precursor trial: high-frequency word, low-frequency word, nonword) × 3 (list: List 1, List 2, List 3) design. The mean lexical decision latencies and error rates from the participant analysis are presented in Table 2.

Word trials. In the analyses of response latencies, the effect of type of precursor trial was significant, $F_1(2, 108) = 7.05$, $MSE = 540$; $F_2(2, 78) = 5.69$, $MSE = 472$. Pairwise comparisons showed that there was virtually no difference between the word trials preceded by a high-frequency word and the word trials preceded by a low-frequency word (1 ms, both ps > .20). In addition, there was a significant effect of the lexical status of the item that had appeared during the previous trial: Responses on trials following a high-frequency word averaged 15 ms less than responses of trials following a nonword, $F_1(1, 54) = 9.82$, $MSE = 592$; $F_2(1, 39) = 8.39$, $MSE = 512$. Similarly, responses on trials following a low-frequency word averaged 14 ms less than responses of trials following a nonword, $F_1(1, 54) = 9.12$, $MSE = 615$; $F_2(1, 39) = 8.59$, $MSE = 436$.

The analysis of the error data did not yield any significant effects (all ps > .20).

Nonword trials. In the analyses of response latencies, the effect of type of precursor trial was significant, $F_1(2, 108) = 7.39$, $MSE = 1427$; $F_2(2, 78) = 11.42$, $MSE = 768$. Pairwise comparisons showed that responses on nonword trials following a high-frequency word averaged 24 ms less than responses on trials following a nonword, $F_1(1, 54) = 9.81$, $MSE = 1587$;

TABLE 2
Mean lexical decision time[a] and error rates for the word and nonword targets in Experiment 2

	Type precursor trial					
	High-freq. word		*Low-freq. word*		*Nonword*	
	M	*Error rate*	*M*	*Error rate*	*M*	*Error rate*
High-freq. words	612	1.9	613	1.1	627	1.5
Nonwords	748	2.1	772	2.8	772	2.6

[a]In ms.

$F_2(1, 39) = 21.49$, $MSE = 572$. In addition, responses to nonwords following a high-frequency word also averaged 24 ms less than responses to nonwords following a low-frequency word, $F_1(1, 54) = 24.62$, $MSE = 652$; $F_2(1, 39) = 18.62$, $MSE = 749$. There was virtually no difference between nonword trials preceded by a nonword and nonword trials preceded by a low-frequency word (less than 1 ms).

The analysis of the error data did not yield any significant effects (all ps $> .20$).

The results were clear-cut. For word trials, there was a significant nonword inhibition effect (i.e., longer response times after a nonword trial) but—unlike Experiment 1—there were no signs of a sequential item frequency effect.[3] In contrast, for nonword trials, there was a robust effect of the frequency of the preceding trial: latencies to nonwords were faster when the preceding trial was a high-frequency word than when it was a low-frequency word or a nonword.

GENERAL DISCUSSION

The present study has shown that lexical decision responses on a given trial can be influenced by the stimulus characteristics of the previous trial. Thus the presence of sequential effects in the lexical decision task appears to imply a dynamic model of the lexical decision task in which participants continually adjust their response criteria on a momentary, trial-by-trial basis. These response criteria are not only modulated by the lexical status of the previous item (Lima & Huntsman, 1997), but also by the difficulty (i.e., item frequency) of the previous item.[4]

Interestingly, the present results rule out an interpretation of sequential effects as a mere function of the perceived difficulty of the previous trial in the lexical decision task (i.e., decisions following "slow" responses being slower than decisions following "fast" responses, as occurs in the naming task; see Taylor & Lupker, 2001). If this interpretation were correct, latencies should have been shorter for trials following a high-frequency word than for those trials following a low-frequency word. However, we failed to obtain this pattern of results—at least for word trials—in the two lexical decision experiments (see Figure 1).[5]

There are a number of differences between the naming task and the lexical decision task that may account for these apparent discrepancies. In a naming task, there is a gradual accumulation of information about the correct item (i.e., it is an incremental task), and the issue is how much information needs to be collected before the participant starts to make his or her

[3]It could be argued that responses following an error might have contributed to some of the sequential effects found in the present experiments. For that reason, we re-examined the data by deleting the reaction times for word and nonword targets with an error in the preceding trial. The error-culled data were virtually identical to those given in Tables 1 and 2, and the statistical analyses based on these data did not change the pattern of significant results.

[4]It could be argued that some of the differences in Experiments 1 and 2 were due to the relative proportions of high-frequency and low-frequency words, which were not the same. However, in both experiments, participants were presented with a list of mixed stimuli rather than a pure list of stimuli, and it is only under pure lists that the type of item that is going to be presented on the next trial can be anticipated.

[5]We will focus on the effects of the item frequency of the previous trial rather than on the effects of the lexical status of the previous trial. The reason is that, for this latter variable, there is a confounding between lexical status of trial n–1 and the response made on trial n–1 (i.e., words and nonwords also require a different responses). We believe that focusing on those trials that require the same answer on trial n–1 (i.e., high- and low-frequency words) avoids these interpretive difficulties.

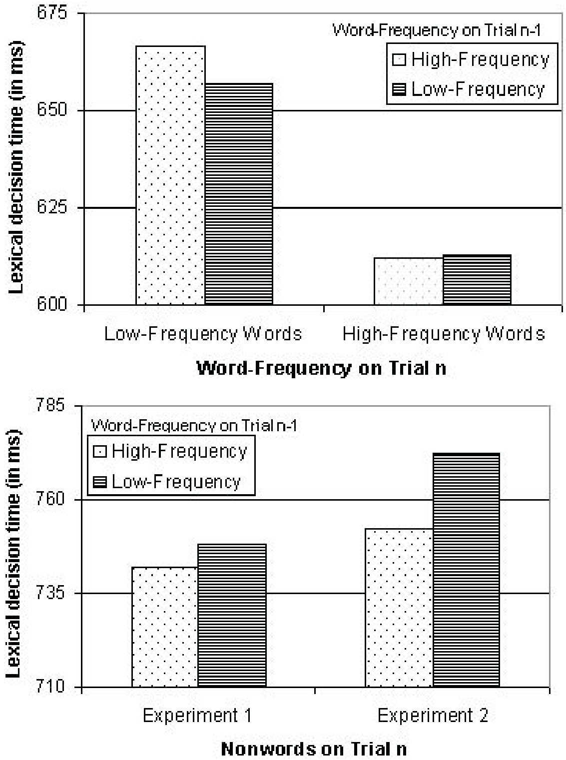

Figure 1. Lexical decision times as a function of the item frequency on trial n–1. The upper panel presents the results for word targets, and the lower panel presents the results for the nonword targets.

response. In contrast, the lexical decision task is not an incremental task with countless potential responses, but rather a two-alternative forced-choice task in which words are to be distinguished from nonwords.[6] In this light, it has been argued that the mechanisms underlying "yes" and "no" responses in a lexical decision task are fundamentally distinct (e.g., see Coltheart et al., 2001; Grainger & Jacobs, 1996). For instance, in the MROM (Grainger & Jacobs, 1996) and the DRC model (Coltheart et al., 2001), the response criteria for "yes" decisions depend on two "quality" criteria (i.e., a "yes" response would occur when a given threshold has been exceeded, either the corresponding to global activation or the one corresponding to unique word identification).[7] In contrast, the response criterion for "no" responses is not a

[6]We thank Ken Forster for suggesting this reasoning.

[7]The assumption that two different types of response criteria are responsible for making a "word" response in a lexical decision task is not new (e.g., see Balota & Chumbley, 1984; Monsell et al., 1989). This explanation allows the multiple read-out model (or the dual-route cascaded model) to capture some effects that occur for low-frequency words but not for high-frequency word (e.g., the effects of the number of "orthographic" neighbours, see Grainger & Jacobs, 1996). Keep in mind that low-frequency words in this model can be responded to on the basis of the Σ or the M criteria, whereas high-frequency words are mainly responded on the basis of the M criterion (Grainger & Jacobs, 1996).

"quality" criterion, but rather an extra-stimulus criterion, a time criterion (the so-called T criterion): when the participant has not made a "yes" response before reaching a deadline, he or she will assume that nothing has been retrieved, and he or she will make a "no" response (Coltheart, Davelaar, Jonasson, & Besner, 1977; see also Coltheart et al., 2001; Grainger & Jacobs, 1996; Monsell, Doyle, & Haggard, 1989; but see Stone & Van Orden, 1993).[8]

Interestingly, lexical decision times to nonwords in the present experiments follow the pattern predicted by the time criterion account (see Figure 1). Specifically, the deadline (or time criterion) for a "no" decision seems to be lowered after an "easy" stimulus. In this way, participants may use earlier settings of the T criterion after a high-frequency word, which speeds up response times to these nonwords, as actually occurred in the present experiments. This result is also consistent with the fact that responses to nonwords are faster when the word list is composed of only high-frequency words than when the word list is composed of high- and low-frequency words (see Grainger & Jacobs, 1996), and it suggests that frequency-blocking effects for nonwords may be the accumulated result of a series of small trial-by-trial adaptations.[9] It is worth noting that the deadline might have been set too early in a number of trials, which might have caused low-frequency words preceded by high-frequency words to have a higher percentage of errors than low-frequency words preceded by low-frequency words. (The same trend, although it was not significant, was found for high-frequency target words, see Experiment 2.) That is, the lower the deadline is set, the greater the number of false negative errors that are generated, hence the increase in error rate for low-frequency words preceded by a high-frequency word.

In sum, it seems that participants may use some time criterion for deciding that nothing has been retrieved, and this deadline is affected by trial-to-trial fluctuations in the same way as in the naming task. What is the nature of this effect? Taylor and Lupker (2001) suggested that sequential—and blocking—effects in the naming task could be produced by changes in the participant's estimation of a passage of time. For instance, Taylor, Lupker, and Gagné (2000) found that time seems to pass more rapidly after pronouncing an "easy" stimulus than after pronouncing a "difficult" stimulus. This distortion in the perceived time may cause an earlier time criterion after an easy stimulus than after a difficult stimulus, producing a sequential (or blocking) effect.

In addition, do participants need a deadline for a "yes" decision? As we said in the Introduction, the response criteria for "yes" are not extra-lexical (as in "no" responses) but intra-lexical (Coltheart et al., 2001; Grainger & Jacobs, 1996): Participants make a "yes" response when the activation level of a single lexical unit reaches the M criterion or when the summed lexical activity reaches the Σ criterion. Thus, one might argue that these response criteria are

[8]In any event, we should note that other models assume that there is a "no" boundary (i.e., a decision criterion for "no" responses) instead of a variable deadline for negative responses (e.g., in the framework of a random-walk model with two absorbing boundaries; Ratcliff, Gómez, & McKoon, 2001; Stone & Van Orden, 1993: see also Davis, 1999). Nonetheless, as Stone and Van Orden (1993) indicated, a variable deadline for "no" responses can be considered equivalent to a coordinate shifting of the decision criterion for "no" responses and the rate of processing in the nonword channel.

[9]Another proof of the independence between "yes" and "no" responses is that when the nonwords are not wordlike, the frequency-blocking effect vanishes for words, but not for nonwords (Carreiras et al., 1997). As predicted by the time criterion account, latencies to nonwords were faster in pure high-frequency lists than in mixed lists, and, in turn, latencies to nonwords were also faster in mixed lists than in pure low-frequency lists.

not likely to be a function of a time criterion. However, it seems that the response criteria for "yes" decisions can be adjusted as a function of the overall difficulty of the task (in a frequency-blocking experiment, see Grainger & Jacobs, 1996), and the question is whether or not these adjustments can also occur on a trial-by-trial basis. In the present study, responses to high-frequency words were not influenced by the presence of a high- or low-frequency preceding item (612 vs. 613 ms, respectively). Although the absence of first-order effects in certain conditions may simply imply that measurement sensitivity is not great enough to capture such fine adjustments, it could well be the case that a much larger concentration of familiar words is necessary before obtaining any sequential item-frequency effects for high-frequency words. Keep in mind that a word list composed of high-frequency words could induce participants to use more extreme response criteria for making "yes" responses than those induced in a mixed list with high- and low-frequency words.

But the more intriguing finding of the present study is the direction of the sequential item-frequency effect for low-frequency words: Unlike Gordon's (1983) post hoc analysis, participants in the present study were slower to respond to low-frequency words preceded by a high-frequency word than to low-frequency words preceded by a low-frequency word. This finding is consistent with the fact that sequential item frequency effects were also found in the error data, so it is not a by-product of a speed/accuracy trade-off. Furthermore, the direction of these sequential item-frequency effects is consistent with the fact that responses to low-frequency words in a lexical decision task can be faster in a pure list of low-frequency words than in a mixed list of high- and low-frequency words (e.g., Dorfman & Glanzer, 1988; Glanzer & Ehrenreich, 1979; Ratcliff, Gómez, & McKoon, 2001; Stone & Van Orden, 1993; but see Gordon, 1983). But before examining the implications of these findings, it may be important to analyse whether some of the differences between Gordon's (1983) results and the present results might have been caused by the modality of response involved in the lexical decision task. Gordon used a go/no-go procedure whereas we employed the standard yes/no procedure. (In the go/no-go task, participants are instructed to respond as quickly as they can when a word is presented, and not to respond if a nonword is presented, e.g., see Perea, Rosa, & Gómez, 2002) In a follow-up experiment with the go/no-go technique (Perea, Carreiras, Rosa, & Gómez, 2000, Experiment 3), the magnitude of the sequential item frequency effect for low-frequency words was in the same direction as that in Experiment 1 (a nonsignificant 6-ms effect), which makes it difficult to draw any firm conclusions in this respect. Nonetheless, if we look at the leading edge of the response time distributions (the .1 and .2 quantiles), we found significantly faster responses to low-frequency words when the previous trial was a high-frequency word than when the previous trial was a low-frequency word (the lower limits of the group response time distributions were 470 and 456 ms, respectively). More important, nonword-elicited activations exceeded the response criterion for a "yes" response (i.e., false-positive errors) more frequently when the previous trial was a low-frequency word (4.6%) than when the previous trial was a high-frequency word (1.6%). Taken together, these results suggest that participants seem to lower their response criteria for a "yes" response after a low-frequency word (compared to a high-frequency word) in the two varieties of the lexical decision task.

Interestingly, the MROM (Grainger & Jacobs, 1996) can predict a frequency-blocking advantage for low-frequency words (in both accuracy and latency data) by lowering the criterion based on summed lexical activation (the Σ criterion, see Grainger & Jacobs, 1996, Figure

26). One means of implementing such a mechanism would be to adjust the response criteria on a trial-by-trial basis in an attempt to reduce lexical decision times while maintaining an acceptable level of accuracy (Grainger et al., 2000). One such possibility would be to lower the Σ criterion on trial n when this same criterion has been successfully employed on trial n–1. This strategy would benefit especially low-frequency words preceded by another low-frequency word rather than low-frequency words preceded by a high-frequency word; the reason is that a response to a high-frequency word on trial n–1 would typically be made via the M criterion, and thereby it may no affect the criterion settings for the Σ criterion in the subsequent trial.[10] Thus, it is possible that by tweaking the parameters on a trial-by-trial basis, the MROM could accommodate the sequential effects for low-frequency words obtained in the present study. In this way, the small adjustments that occur on each trial in a blocked list would accumulate to generate a global blocking effect. It is worth noting that this explanation is not at odds with the lack of a first-order sequential item frequency effect for high-frequency words: high-frequency words are usually recognized via the M criterion, and this criterion is presumably less susceptible to strategic influences (Grainger & Jacobs, 1996).

The canonical random-walk (diffusion) model proposed by Stone and Van Orden (1993) might also predict a frequency-blocking advantage for low-frequency words—and presumably the observed sequential effects—under some circumstances. (Nonetheless, Stone and Van Orden acknowledged that this is a problematic finding for their model; e.g., the model could also predict the opposite effect.) If we take Ratcliff's (1978; Ratcliff et al., 2001) diffusion model as an instantiation of the Stone and Van Orden random-walk model, one possibility is to modify the starting point in the diffusion process. (For the parameter estimation of high-frequency words, low-frequency words, and nonwords, we used the values given by Ratcliff et al., 2001.) If we assume that the starting point is increased (i.e., it is closer to the "yes" barrier, e.g., from .056 to .062) after a successful response to a "difficult" word, the diffusion model can capture most of the observed sequential effects: (1) The model predicts faster response times to low-frequency words when preceded by a low-frequency word than when preceded by a high-frequency word (a 24-ms effect); (2) the model predicts that subjects would make more errors to low-frequency words when preceded by a high-frequency word than when preceded by a low-frequency word (a 3% effect); (3) the model predicts faster responses to nonwords when preceded by a high-frequency word than when preceded by a low-frequency word (a 21-ms effect). However, the model (incorrectly) predicts faster response times for high-frequency words when preceded by a low-frequency word than when preceded by a high-frequency word (a 17-ms effect). A finer adjustment in the parameter values is necessary to obtain a better fit with the data (e.g., the increase/decrease in the starting point after each trial is probably less than that used in the simulations). It is worth noting that the diffusion model can successfully predict a frequency-blocking advantage for both low- and high-frequency words (see Ratcliff et al., 2001).

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[10]Not surprisingly, the presence of an error on trial n–1 provokes longer response times on trial n, possible because the participants use more conservative response criteria after an error (e.g., see Glanzer & Ehrenreich, 1979; Rabbitt & Rodgers, 1977). For instance, the mean response time for low-frequency words preceded by an error in the previous trial was 701 ms, which was substantially larger than the mean response time for low-frequency words preceded by a correct response in the preceding trial (664 ms). (In any event, these analyses must be taken with caution, as most participants had very few or no errors on trial n–1.)

Further empirical work is necessary to elaborate these proposals in a dynamic model. In this light, it is possible that not only are the response criteria adjusted over a series of trials (Strayer & Kramer, 1994b), but also the rate of processing of the stimuli (Bodner & Masson, 2001; Kello & Plaut, 2000), or even both (Stone & Van Orden, 1993). More important, we must bear in mind that the mechanism that produces sequential effects must be flexible enough to behave in different ways for the various word identification tasks (e.g., naming task, Taylor & Lupker, 2001) and for different participants (Ratcliff, Van Zandt, & McKoon, 1999), either in the parameters of the process or by employing different processing strategies (Luce, 1995). Work examining the influence of increasingly larger sequences of preceding stimuli will be critical for testing criterion adjustment accounts of list blocking phenomena.

To conclude, the present study has shown evidence that participants can shift their response criteria in the lexical decision task on the basis of the characteristics—item-frequency and lexical status—of the immediate preceding trial. Interestingly, the pattern of data of the lexical decision responses to nonwords follows the time-criterion account proposed by Taylor and Lupker (2001) in the naming task, which is reasonable if we assume that "no" responses are made via an adjustable temporal deadline. Lexical decision times to words do not follow this tendency, however. This diversity of sequential effects can be explained in terms of the different response criteria—or different combinations of response criteria—that are used to trigger a speeded response in the different laboratory word identification tasks. Obviously, the trial-by-trial shift in the criterion settings is probably common to a wide range of cognitive tasks in which perceived task difficulty can be taken into account (e.g., verification tasks, Kiger & Glass, 1981; identification tasks, Grainger et al., 2000; naming tasks, Lupker, Taylor, & Pexman, 1997; Taylor & Lupker, 2001; visual- and memory-scanning tasks, Strayer & Kramer, 1994a, 1994b), and it may provide constraints on how speeded decisions in specific tasks are made. We believe that future models of visual word recognition should be constrained to generate more specific predictions concerning the presence of sequential effects and the necessity of accounting for erroneous responses.

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