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Open Wide and Say ''Blah!'' Attentional Dynamics of Delayed Naming

Stephen D. Goldinger, Tamiko Azuma, Marianne Abramson, and Pushpam Jain

Arizona State University

In a well-known study, Balota and Chumbley (1985) used a *delayed naming* task to assess post-perceptual word frequency effects. They observed frequency effects after considerable delays, suggesting that frequency sensitivity characterizes not only the perceptual stage, but also post-access stages. The present investigation examined delayed naming in a dual-task. Using delays after perception and a constant response (''blah'') for all catch trials, we attained relatively pure indices of the mental workloads incurred by low- and high-frequency words. Across experiments, reliable frequency effects occurred in both word-naming and catch trials. The frequency effects can be modified by altering omnibus task difficulty, or by adding phonologically confusable memory loads. The results suggest that frequency effects in delayed naming (and their occasional absence in prior studies) partly reflect attentional differences. We describe a resonance framework in which word perception, rehearsal, and production all rely on stable feedback loops among knowledge structures. Attention is required both to create and to maintain feedback loops; each word's level of attention demand is predicted by its frequency of previous occurrence. © 1997 Academic Press

The mind cannot fix long on one invariable idea.
John Locke (1690/1894, p. 244)

The classic frequency effect in word perception is strangely paradoxical. On one hand, it is remarkably robust; word frequency predicts performance in all perceptual tasks, such as lexical decision (Rubenstein, Garfield, & Millikan, 1970; Stone & Van Orden, 1993; Whaley, 1978), naming (Forster & Chambers, 1973; Waters & Seidenberg, 1985), and perceptual identification (Manelis, 1977). Words that commonly occur in print are recognized faster and more accurately than their lower-frequency counterparts. Indeed, the frequency effect is an empirical cornerstone in word perception that all theories must explain. However, despite the stability and ubiquity of frequency effects, nobody seems to agree about their basis. Theoretical disagreements about frequency effects are of two general types. The first concerns the proper mechanisms to model the effect. Modelers have suggested frequency-sensitive logogens (Morton, 1969; Selfridge & Neisser, 1960), connection weights (Seidenberg & McClelland, 1989), or search orders (Forster, 1976; Paap, Newsome, MacDonald, & Schvaneveldt, 1982). Critical experiments for testing these mechanisms have produced a wealth of data (Andrews, 1989; Becker & Killion, 1977; Glanzer & Ehrenreich, 1979; Grainger & Segui, 1990; Paap & Johansen, 1994), but no clear winner.

The second disagreement concerns the *locus* of frequency effects in the flow of cognitive processes required by various tasks. The question is whether frequency uniquely affects word perception/lexical access, or whether it also affects post-access processes. For example, early demonstrations of frequency effects in tachistoscopic word identification (Broadbent & Broadbent, 1975; Howes & Solomon,

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Address reprint requests and correspondence to S. D. Goldinger, Department of Psychology, Box 871104, Arizona State University, Tempe, AZ 85287-1104. E-mail: goldinger@asu.edu.

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1951; Solomon & Postman, 1952) were followed by demonstrations of frequency-based response strategies (Catlin, 1969, 1973; Snodgrass & Mintzer, 1993). Goldiamond and Hawkins (1958) even observed ''word frequency'' effects in tachistoscopic identification of meaningless smudges. Such results led researchers to question the role of word frequency in lexical access and to favor response time (RT) methods, primarily lexical decision and naming.

The frequency effect in lexical decision is extremely robust, reaching statistical reliability in virtually all experiments despite variations in participants, methods, or stimuli (Whaley, 1978). Moreover, frequency interacts with other variables in lexical decision, such as visual clarity (Becker & Killion, 1977), semantic priming (Becker, 1979; Norris, 1984), word repetition (Scarborough, Cortese, & Scarborough, 1977), spelling–sound consistency (Coltheart, Davelaar, Jonasson, & Besner, 1977; Jared, McRae, & Seidenberg, 1990; Waters & Seidenberg, 1985), and neighborhood characteristics (Andrews, 1989; Grainger & Segui, 1990). This combination of robust effects and principled interactions makes lexical decision a popular investigative tool.

However, the interactions of word frequency with miscellaneous variables are not limited to perceptual factors. For example, frequency effects vary in magnitude across tasks. Forster and Chambers (1973; also Balota & Chumbley, 1984; Frederiksen & Kroll, 1976) found that frequency effects were about three times larger in lexical decision than in naming. Overall RT differences across these tasks are not surprising; lexical decision requires an extra decision stage. However, as noted by Balota and Chumbley (1984), a frequency × task *interaction* suggests that the decision stage is also frequency-sensitive. Thus, we cannot measure the frequency effect in ''pure'' lexical access via lexical decision (although see Monsell, Doyle, & Haggard, 1989).

Although lexical decision entails word recognition, it is also a signal-detection task (Balota & Chumbley, 1984), and is thus affected by variations in signal sensitivity and decision criteria. Ideally, word frequency would affect only sensitivity, but various interactions imply that it also affects criterion placement. For example, the frequency effect is increased when nonword foils more closely resemble words (Lewellen, Goldinger, Pisoni, & Greene, 1993; Stone & Van Orden, 1993) and is decreased when unequal proportions of low-frequency (henceforth LF) and high-frequency (HF) words are presented in a block of trials (Glanzer & Ehrenreich, 1979; Gordon, 1983). Given this difficulty with lexical decision, it is often assumed that naming, which involves no decision stage, provides ''cleaner'' estimates of lexical access. Fortunately, most effects in lexical decision are also observed in naming, albeit to attenuated degrees (Andrews, 1989; Forster & Chambers, 1973; Frederiksen & Kroll, 1976).

THE DELAYED NAMING PROCEDURE

The logic in comparing lexical decision to naming is clear: If an effect in lexical decision is due to the decision stage, it should vanish in naming. Conversely, if an effect in lexical decision is due to the perception stage, it should remain in naming. It was from similar logic that *delayed naming* was created, originally as a control condition. Forster and Chambers (1973) observed a frequency effect in naming. To ensure that this was not due to production differences across items, they ran a test in which participants saw words for 2 s before a response cue. As expected, no frequency effect occurred. Delayed naming has since been used by other researchers in this precautionary manner (Andrews, 1989; Jescheniak & Levelt, 1994). However, in one study, Balota and Chumbley (1985) had volunteers view LF and HF words and then wait for a cue to begin speaking. In several experiments, they observed reliable frequency effects in delayed naming, well after lexical access should have been complete (delays of 650 ms or greater). They concluded that frequency effects in naming are not purely perceptual; they are exaggerated by differences in post-access processes. Balota and Chumbley did not *deny* that word frequency affects perception, but warned that ‘‘one must be very cautious in unequivocally attributing the frequency effect found in [the naming] task to lexical access’’ (p. 104).

Since the Balota and Chumbley (1985) article was published, it has received empirical and theoretical scrutiny. Their results have been extended, indicating generality (Connine, Mullennix, Shernoff, & Yelen, 1990) but have also proven fragile, vanishing in some procedures (McRae, Jared, & Seidenberg, 1990; Monsell et al., 1989; Savage, Bradley, & Forster, 1990). Monsell et al. (1989) suggested that the Balota and Chumbley participants were not adequately prepared to speak before the response cues. As such, participants may have ‘‘re-accessed’’ words upon receiving the cue, effectively conducting the perception stage anew. To rectify this, Monsell et al. conducted a delayed naming test, using procedures designed to ensure full preparation. They used a constant, long (2500 ms) delay interval, with ‘‘countdown’’ signals presented 1500 and 1000 ms before the response cue. Also, they had participants pronounce each word on three consecutive trials. Perhaps not surprisingly, when Monsell et al. examined the second and third responses to each word, they observed no frequency effects.

Unfortunately, null effects are hard to interpret, and the null frequency effect reported by Monsell et al. (1989) may only reflect their procedures: When participants first named each word, a small but reliable frequency effect was observed. This effect vanished in later presentations, but interactions of word repetition and frequency are well-known. If LF and HF words are presented multiple times in a perceptual task, the frequency effect is steadily reduced (Norris, 1984; Scarborough et al., 1977). If perceptual frequency effects are attenuated by repetition, post-access frequency effects would likely follow suit. By analyzing only latter repetitions of each word, Monsell et al. may have guaranteed the null result (Balota & Chumbley, 1990). Nevertheless, their data suggest a central role of *preparation* in delayed naming, indirectly anticipating the present investigation.

Other investigations of delayed naming were reported by Savage et al. (1990) and McRae et al. (1990). Using the Balota and Chumbley stimulus materials, but a restricted range of delays (800–1200 ms), Savage et al. failed to replicate the frequency effect. With new stimuli covering a smaller frequency range, they observed significant frequency effects at a few delays, but not consistently. McRae et al. (1990) reported similar findings in delayed naming of homophones and rhyming words. Collectively, these data suggest that frequency effects in delayed naming are fragile. However, we should note that the methods used in these investigations may have minimized the effect. For example, by using a restricted range of word frequency, Savage et al. (and McRae et al.) considerably reduced the frequency effect in standard naming, which would also reduce the effect in delayed naming. Moreover, both studies used restricted ranges of delay intervals, which may help participants anticipate the response cues (Balota & Chumbley, 1990).

FREQUENCY EFFECTS IN AND OUT OF WORD RECOGNITION

Taken together, the data on word frequency create a mixed picture. On one hand, despite arguments (e.g., McCann & Besner, 1987; McCann, Besner, & Davelaar, 1988; Paap & Johansen, 1994), word frequency truly appears to affect perception. Beyond standard experimental tasks, frequency effects emerge in tasks with few demand characteristics. For example, word frequency predicts saccadic gaze durations (Rayner & Duffy, 1986; Inhoff & Rayner, 1986) and event-related potentials in reading (Rugg, 1990; Rugg & Doyle, 1992; Van Petten & Kutas, 1990).

On the other hand, considerable evidence suggests that frequency affects behavior *beyond* perception. Variations in word frequency are reflected in the speed of typing keystrokes (Gentner, LaRochelle, & Grudin, 1988; Inhoff, 1991; West & Sabban, 1982), simple manual tapping (Brown & Carr, 1989), and the physical force of lexical decision and naming responses (Abrams & Balota, 1991; Balota & Abrams, 1995). Word frequency also affects rehearsal in working memory (Goldinger, Pisoni, & Logan, 1990; Sumby, 1963; Watkins & Watkins, 1977), and accuracy of recognition memory (Glanzer & Adams, 1990; Glanzer & Bowles, 1976). Frequency also affects non-lexical behaviors, such as practice effects in motor skill (Bernstein, 1967; Keele, 1986; Schmidt, 1982), the development of automaticity (Logan, 1988; Shiffrin & Schneider, 1977), formation of category prototypes (Homa, Sterling, & Trepel, 1981), and almost all forms of learning. Thus, beyond lexical processes (even broadly construed), sensitivity to frequency may be a basic principle of cognitive/behavioral systems.

THE PRESENT INVESTIGATION

In the present investigation, we re-examined delayed naming. First, we replicated the conditions that yield a reliable effect (Balota & Chumbley, 1985), then systematically examined those conditions. In particular, we used a modified procedure to wait out perception and to equate production, leaving the *intervening processes* as our focus. We sought to assess the frequency sensitivity of assembly and rehearsal processes that presumably occur between word perception and production (see Savage et al., 1990). Toward this end, we examined delayed naming in a *dual-task/change* procedure: Most trials entailed ''standard delayed naming,'' in which the participant saw a word, waited for a response cue, and then quickly pronounced the word. However, catch trials presented a different response cue, requiring the participant to say ''blah!'' as quickly as possible. Word frequency effects were examined in all trials.

Our approach has been anticipated in previous research. The idea in delayed naming is to equate perception across words, leaving production differences free to vary. Theios and Muise (1977) took the converse approach, leaving perceptual differences across words free to vary, but equating their productions. They examined naming times to homophonic word pairs, in which one word (e.g., *heir*) was LF, and the other (e.g., *air*) was HF. They observed a small (11 ms) but reliable frequency effect. This is suggestive in two ways: The reliable frequency effect implicates perception as a true locus. However, the diminished effect, relative to most published results, suggests that a portion of the standard frequency effect is due to assembly or production differences. Indeed, Balota and Chumbley (1985; Experiment 3) had participants silently rehearse the alphabet during the delay between reading and speaking. The frequency effect lasted over considerable delays, which seems to confirm frequency sensitivity of the speech production stage.

The study by McRae et al. (1990) more directly anticipated the present study. Like Theios and Muise (1977), they examined naming of LF and HF homophones, but they included delayed naming conditions. Using moderate delays (baseline naming times + 200 ms) calibrated for individual participants, McRae et al. observed residual frequency effects, although both perception and production were presumably equated. At longer delays (baseline + 400 ms), the frequency effect vanished. Nevertheless, the persistent frequency effect at moderate delays suggests that processes between perception and production (assembly, rehearsal, cue detection, response initiation, etc.) are frequency-sensitive and that further investigation of delayed naming may be fruitful.

EXPERIMENT 1

Experiment 1 was conducted for methodological and comparative purposes: We sought to replicate the frequency effect Balota and Chumbley (1985) observed in delayed naming, using our stimuli, apparatus, and procedures. We also sought to establish a baseline frequency effect to serve as a comparison standard for the later dual-task experiments. Experiment 1 included a standard (zero-delay) naming condition, and a delayed naming condition, with methods modeled after the second experiment of Balota and Chumbley: Six delay periods were used, randomly intermixed

TABLE 1

SUMMARY STATISTICS FOR WORDS USED IN EXPERIMENTS 1–3

	Low-frequency words	High-frequency words
Mean frequency[a]	3.84 (3.44)	141.14 (195.56)
Mean familiarity[b]	6.04 (1.11)	6.94 (0.13)
Mean orthographic *N*[c]	1.63 (2.54)	2.26 (3.22)
Mean neighbor frequency	11.04 (36.19)	29.09 (51.28)
Mean phonologic *N*[d]	3.40 (5.63)	4.06 (6.11)
Mean phonologic NF	19.15 (48.07)	41.93 (60.42)
Mean length (letters)	5.67 (0.63)	5.62 (0.40)
Mean length (phonemes)	4.84 (0.97)	4.54 (0.92)
Number of		
Monosyllables	32	33
Bisyllables	106 (sw,[e] 77; ws,[f] 29)	105 (sw, 84; ws, 21)
Trisyllables	2 (sww, 2)	2 (sww, 2)
Initial phonemes		
Stops	82	76
Vowels/Glottal stops	20	21
Nasals	11	13
Fricatives	17	15
Affricates	3	6
Liquids/glides	7	9

[a] Kuçera and Francis (1967).
[b] Nusbaum et al. (1984).
[c] Coltheart et al. (1977).
[d] Luce (1986).
[e] Strong–weak stress pattern.
[f] Weak–strong stress pattern.

across trials. Participants in standard naming spoke immediately upon viewing each word; participants in delayed naming saw the same words, but did not speak until signaled by a 400-Hz tone.

Method

Participants. Sixty Arizona State University students participated in Experiment 1 for course credit. Twenty-four students participated in standard naming; 36 participated in delayed naming. All volunteers were native English speakers with normal or corrected vision.

Stimulus materials. For the experimental trials, 120 LF and 120 HF words were selected from published experiments that showed reliable frequency effects (Balota & Chumbley, 1985; Connine et al., 1990; Monsell et al., 1989). The words had been selected by previous researchers using the Kuçera and Francis (1967) frequency norms and subjective familiarity ratings. We selected word sets to maintain frequency differences, but to match as closely as possible for length (in letters, phonemes, and syllables), stress loci, and initial phonemes. Table 1 provides key summary statistics. For practice trials, another 24 words were randomly selected. All words used in Experiments 1–3 are shown in Appendix A.

Procedure. Students participated individually in a quiet room, seated in front of a Gateway 2000 computer at a comfortable viewing distance (approximately 50 cm). The computer was equipped with a VGA display; words were shown in a standard font, white on black, in lowercase letters. To collect naming RTs, participants wore a headset-mounted microphone connected to a voice key. Both the computer and the experimenter provided instructions, and participants were encouraged to ask questions during a break after the practice trials. The experimenter monitored the procedure on a separate computer screen, noting any mispronunciations or other errors.

In standard naming, each trial began with a ready signal (###) centered on the screen for a total of 400 ms. A response timer was initiated after 250 ms, and a stimulus word replaced the pound signs 150 ms later. The word remained visible until a response triggered the voice key. If a participant responded before the word was presented, or after 2000 ms elapsed (recorded from word onset), an error was recorded. After each response, the computer waited 1 s and then began the next trial.

In delayed naming, each trial began with the ready signal, shown for 400 ms. A stimulus word then replaced the pound signs and remained visible throughout a randomly selected delay period, lasting either 150, 400, 650, 900, 1150, or 1400 ms. Across participants, all words appeared equally often at all delay intervals. A response timer was initiated 150 ms before the end of the delay period, which was indicated by a 400-Hz tone. (In both standard and delayed naming, the 150-ms ''lead time'' was subtracted from RTs prior to analysis.) Upon presentation of tones, words were immediately replaced by a pattern mask to prevent a ''resampling'' strategy, in which participants could wait for the tone and then re-read the word if necessary (Savage et al., 1990). As in standard naming, participants pronounced the words as quickly as possible, with early or late responses recorded as errors. In both standard and delayed naming, the experiment lasted approximately 20 min.

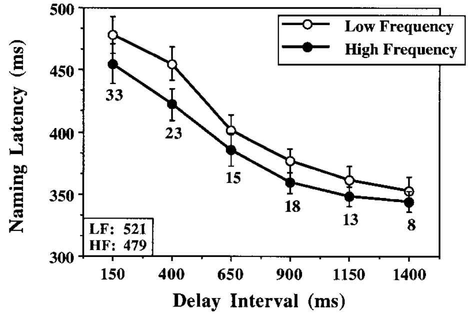

FIG. 1. Standard and delayed-naming times: Experiment 1. Standard naming times for LF and HF words are shown in the inset box; delayed-naming times are shown by lines. Frequency effect (in ms) is shown at each delay interval.

Results and Discussion

In addition to trials automatically counted as errors (for early or late responding), data files were edited by the experimenter after each session. Trials in which the speaker made an error (an incorrect response or extraneous noise) were noted in the data files. (Given this aspect of this procedure, only naive experimenters were used.) Error rates in both standard and delayed naming were below 3% and showed no statistically reliable trends or evidence of speed–accuracy tradeoff.

Figure 1 displays all latency data: Mean naming RTs for LF and HF words in standard naming are shown in a box in the lower left-hand corner. The remainder of the figure shows mean delayed naming RTs. For comparison purposes, differences (in ms) between LF and HF words are shown at each delay. The data from each condition were analyzed via separate, repeated-measures ANOVAs, examining subject and item means. In standard naming, a reliable Frequency effect was observed [$F_1(1,23) = 27.40$, $MS_e = 158.61$; $F_2(1,238) = 29.09$, $MS_e = 311.54$]. (Throughout this article, all tests assume a $p < .05$ criterion.) This 42-ms frequency effect is comparable to other published naming data.

In delayed naming, reliable main effects were observed for Frequency [$F_1(1,35) = 17.64$, $MS_e = 612.04$; $F_2(1,238) = 15.88$, $MS_e = 807.01$] and Delay [$F_1(1,35) = 138.72$, $MS_e = 881.31$; $F_2(5,1190) = 205.56$, $MS_e = 1016.75$]. On average, HF words were named 18 ms faster than LF words, and all RTs decreased at longer delays. A Frequency × Delay interaction [$F_1(5,175) = 6.21$, $MS_e = 901.40$; $F_2(5,1190) = 4.16$, $MS_e = 1023.15$] reflected the smaller frequency effect at longer delays. Planned comparisons at each interval revealed reliable frequency effects at the 150-ms delay [$t_1(35) = 4.02$; $t_2(238) = 3.79$] and the 400-ms delay [$t_1(35) = 3.55$; $t_2(238) = 2.49$]. A marginal frequency effect was observed at the 900-ms delay [$t_1(35) = 2.19$; $t_2(238) = 1.19$, ns], but no other differences were reliable.

The results of Experiment 1 were relatively straightforward. Reliable frequency effects were observed in standard naming, and at the shorter intervals in delayed naming. Experiment 1 was conducted primarily to replicate the second experiment of Balota and Chumbley's (1985). The replication was generally successful, although our frequency effects at early delays were slightly smaller. The frequency effects in delayed naming were used as baselines for later comparison to the dual-task experiments.

EXPERIMENT 2

Experiment 1 showed a reliable frequency effect in delayed naming, with our materials and procedures. Presumably, at delays beyond 150 ms, word perception is complete. The residual frequency effect may therefore suggest that frequency affects word production. However, beyond articulatory fluency, at least two possible sources of the residual frequency effect were unexplored in Experiment 1—acoustic and attentional factors. With respect to acoustic factors, we minimized differences between LF and HF words by balancing initial phonemes, syllabic length, stress loci, etc. Nevertheless, by definition, some acoustic differences must remain across words, and they may affect the data considerably (see Treiman, Mullennix, Bijeljac-Babic, & Richmond-Welty, 1995). In this regard, the McRae et al. (1990) comparison of homophones may be an ideal frequency manipulation, as no acoustic or articulatory confounds could obscure the effect. Unfortunately, such tight procedures do not generalize to most published naming studies (except Theios & Muise, 1977). Moreover, if participants quickly translate letter strings into phonologic representations (as they should) in naming, it is doubtful that HF and LF homophones maintain their *printed* frequency distinctions in the articulatory loop (Baddeley, 1990). Thus, the vanishing frequency effect in delayed homophone naming may be artifactual. For these reasons, we are compelled to examine truly distinctive sets of words. Pragmatically speaking, we can do little more than exercise the precautions already mentioned and hope that remaining variance due to acoustic vagaries is normally distributed across stimulus categories.[1]

With respect to attentional factors in delayed naming, no previous studies have assessed potential differences across LF and HF words (although Monsell et al. *controlled* such differences by fully preparing participants to speak). This is not surprising: Given a prevalent view that lexical access is automatic (Forster, 1979; LaBerge & Samuels, 1974), it is natural to assume that word production requires little or no attention. However, delayed naming is not merely a perception stage added to a production stage. In the interim, participants must assemble and perhaps rehearse words, and such rehearsal may be frequency-sensitive. Indeed, with respect to delayed naming, Savage et al. (1990) noted the possibility of variable attentional requirements:

> In the translation from immediate to delayed pronunciation, some consideration needs to be given to the load imposed by the secondary task of monitoring for a response cue. We assume only that the unknown elevation of reaction time is uniform across frequency classes. (p. 207, footnote 1)

Savage et al. were likely correct—the load imposed by an impending response cue is probably constant across trials. However, LF and HF words may create different *a priori* demands on attention, potentially leading to differences in later processes. Consider initial word perception: Despite assumptions of automaticity, evidence suggests that word perception (and even letter perception; Paap & Og-

[1] Indeed, further analysis of Experiment 1 confirmed that naming RTs varied reliably across classes of initial phonemes (beyond frequency, other factors were not reliable predictors). However, LF and HF words were equally affected by phonetic variation.

den, 1981) is attention-demanding, and at least one model (Becker, 1976; Paap et al., 1982) incorporates capacity limitations. For example, expectancies created by semantic priming improve the speed and accuracy of recognition (Neely, 1991). Other evidence comes from dual-task studies: Becker (1976) examined lexical decision by participants who simultaneously performed either a simple or complex tone classification task (cf. Karlin & Kestenbaum, 1968). Becker found that word perception demands attention in a *frequency-sensitive* manner: More attention (indexed by RT differences between the simple and complex secondary tasks) was required for LF words.

Becker's observation has been replicated and extended. Paap and Noel (1991) examined naming by participants under memory loads, finding that both frequency and spelling–sound consistency (Seidenberg, Waters, Barnes, & Tanenhaus, 1984) predict the attention demands of word processing. Herdman (1992; Herdman & Dobbs, 1989) modified Becker's procedure, finding that word perception requires attention in the earliest stages of processing, again to frequency-sensitive degrees (see also Daneman & Carpenter, 1980; Humphreys, 1985; Kellas, Ferraro, & Simpson, 1988; Mullin & Egeth, 1989). Naturally, delayed naming requires word perception, but may also require rehearsal. As in perception, the efficiency of working memory rehearsal is affected by word frequency (Goldinger et al., 1990; Sumby, 1963; Watkins & Watkins, 1977), among other factors (see Baddeley, 1990; Burgess & Hitch, 1992). Together, the data on frequency-based attention demands make a new prediction: Frequency effects in delayed naming should extend beyond perception and production; they should also be evident in the hidden, intermediate processes. This prediction was tested in Experiment 2.

Experiment 2 was a modified delayed naming task, employing a dual-task/change paradigm (Herdman, 1992; Logan & Burkell, 1986). Participants were given a primary task (delayed word naming), but were occasionally required to quickly abandon that task and perform another. In 80% of trials, participants saw a word until a high-pitched (900-Hz) tone was played, instructing them to quickly say the word (as in Experiment 1). However, in 20% of trials, a low-pitched (400-Hz) tone was played, instructing participants to abandon the prepared word and to say ''blah'' as quickly as possible. The words from Experiment 1 were used, allowing two contrasts: First, we compared the magnitudes of frequency effects in the single- and dual-task situations. Second, we compared ''blah'' RTs when participants were prepared to speak either LF or HF words. As a bonus, the ''blah'' trials completely equate the acoustics of responses to LF and HF words, removing potential confounds. Sixty-two students participated in the dual-task. Another 12 students performed a ''modified standard'' naming task, in which they saw stimulus words, but immediately said ''blah'' in response to each.

Method

Participants. Seventy-four students participated in Experiment 2 for course credit. Twelve participated in the ''modified standard'' naming condition; 62 participated in the dual-task, delayed naming condition. All were native English speakers with normal or corrected vision.

Stimulus materials. The words from Experiment 1 were used in Experiment 2.

Procedure. The ''modified standard'' naming procedure was identical to the standard naming condition of Experiment 1, except that participants always said ''blah,'' rather than words. Participants were, however, encouraged to identify the words before responding. In delayed naming, the procedures were identical to Experiment 1, except a second tone and a corresponding response were added. In 80% of trials, participants saw a word until a high-pitched (900-Hz) tone instructed them to quickly say it. In 20% of trials, a low-pitched (400-Hz) tone instructed them to abandon the stimulus word and quickly say ''blah.'' Word and ''blah'' trials were randomly intermixed. Across participants, all words appeared equally across delays, and all were used equally in ''blah'' trials.

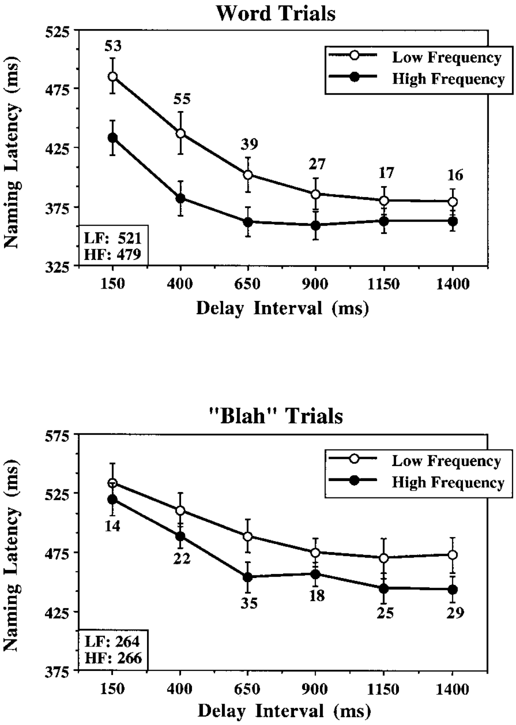

FIG. 2. Experiment 2. (Top) Inset shows standard naming times from Experiment 1; delayed word-naming times are shown by lines. (Bottom) Inset box shows ''modified standard'' naming times from Experiment 2; delayed-naming times for ''blah'' trials are shown by lines. Frequency effect (in ms) is shown at each delay interval.

Results and Discussion

As before, errors were removed from data files automatically (for early or late responses) or by the experimenter after each session. Data from two dual-task participants were discarded, due to their apparent difficulty learning the task (>20% errors). For the remaining 60 participants, error rates were below 4%, and the only reliable trend was an exaggerated error rate on ''blah'' trials. (Speakers often initiated their prepared words and then switched to ''blah.'') Thirty-two percent of all errors occurred on ''blah'' trials, significantly higher than chance (defined as 20%; $\chi^2(1) = 11.19$). There were virtually no errors in the modified standard naming task.

Figure 2 displays all latency data: The top panel shows word-naming trials; the bottom panel shows ''blah'' trials. In one corner of the upper panel, mean standard naming RTs from Experiment 1 are shown. In the bottom panel, immediate ''blah'' RTs to LF and HF words are shown in a similar inset box. The remainders of each panel show mean RTs at all delays, with differences (in ms) between LF and HF words indicated at each interval.

Word-Naming Trials. The data from delayed word-naming trials were analyzed in repeated-measures ANOVAs, followed by planned comparisons. (Recall that the standard naming data in the inset box were from Experiment 1.) Reliable main effects were observed for Frequency [$F_1(1,59) = 291.92$, $MS_e = 812.11$; $F_2(1,238) = 301.15$, $MS_e = 1013.55$], and Delay [$F_1(1,59) = 114.39$, $Ms_e = 801.50$; $F_2(5,1190) = 195.03$, $MS_e = 997.41$]. On average, HF words were named 34.5 ms faster than LF words, and all RTs decreased at longer delays. The Frequency $\times$ Delay interaction was also reliable [$F_1(5,295) = 28.66$, $MS_e = 1115.82$; $F_2(5,1190) = 27.09$, $Ms_e = 1138.27$], reflecting the smaller frequency effects at longer delays. Planned comparisons showed reliable frequency effects at every delay: 150-ms [$t_1(59) = 19.75$, $t_2(238) = 16.82$], 400-ms [$t_1(59) = 18.93$; $t_2(238) = 16.13$], 650-ms [$t_1(59) = 12.73$; $t_2(238) = 12.15$], 900-ms [$t_1(59) = 7.14$; $t_2(238) = 6.22$], 1150-ms [$t_1(59) = 2.66$; $t_2(238) = 2.39$], 1400-ms [$t_1(59) = 1.81$; $t_2(238) = 1.68$].

To compare the magnitude of frequency effects in the word-naming trials of Experiment 2 to those in Experiment 1, two mixed-model ANOVAs were conducted, with Experiment as a between-subjects variable. The main effect of Experiment was reliable [$F_1(1,94) = 120.40$, $MS_e = 1183.05$; $F_2(1,238) = 98.36$, $MS_e = 1254.12$], reflecting generally slower RTs in Experiment 2. The Experiment $\times$ Frequency interaction was also reliable [$F_1(1,94) = 21.07$, $MS_e = 1183.05$; $F_2(1,238) = 17.65$, $MS_e = 1254.12$], reflecting the larger frequency effects in Experiment 2. Apparently, adding the secondary task increased participants' sensitivity to word frequency. No other interactions involving the Experiment factor were reliable.[2]

''Blah'' trials. The data from ''blah'' trials were analyzed in a manner similar to that used in word-naming trials. In the ''modified standard'' naming task (inset box in bottom panel of Fig. 2), no frequency effect was found. This was predictable, given the shallow nature of the task. (Despite instructions, participants apparently responded without truly reading the words.) The delayed naming results were more surprising: A reliable main effect of Frequency was observed [$F_1(1,59) = 88.01$, $MS_e = 2721.11$; $F_2(1,238) = 51.26$, $MS_e = 3020.94$]. Although participants said only ''blah,'' the frequency of the abandoned word mattered: On average, ''blah'' responses were 24 ms faster to HF words than to LF words.

A main effect of Delay was observed [$F_1(1,59) = 14.18$, $MS_e = 2002.19$; $F_2(5,1190) = 8.27$, $MS_e = 2114.47$], reflecting faster RTs at longer delays. The Frequency × Delay interaction was reliable by participants [$F_1(5,295) = 2.86$, $MS_e = 2011.72$], but not by items [$F_2(5,1190) = 1.61$, $MS_e = 2205.19$, ns], reflecting the slightly larger frequency effects at longer delays. Although the differences were impressive in magnitude, each participant received only eight ''blah'' trials at each delay, decreasing statistical power. Planned comparisons revealed reliable frequency effects only at the 650-ms [$t_1(59) = 2.02$; $t_2(238) = 1.77$] and 1400-ms delays [$t_1(59) = 1.94$; $t_2(238) = 1.79$].

Combined data. The data were also analyzed with all trials included in 2 × 2 × 6 ANOVAs examining Response Type, Frequency, and Delay. A main effect of Response Type [$F_1(1,59) = 100.66$, $MS_e = 802.49$; $F_2(1,238) = 95.04$, $MS_e = 816.07$] reflected faster RTs in word-naming trials. A Response Type × Delay interaction [$F_1(5,295) = 4.18$, $MS_e = 611.05$; $F_2(5,1190) = 4.51$, $MS_e = 800.29$] reflected a stronger Delay effect in word-naming trials. The three-way Response Type × Frequency × Delay interaction was also reliable [$F_1(5,295) = 3.70$, $MS_e = 702.17$; $F_2(5,1190) = 3.33$, $MS_e = 814.40$], reflecting opposite Frequency × Delay interactions across Response Types.

The results of Experiment 2 underscore the importance of attention in delayed naming, and the role of word frequency in its allocation. This was shown by two aspects of the data: First, when delayed naming was performed in the dual-task, the frequency effect in word-naming trials was enhanced, relative to Experiment 1. (This was primarily due to slower responses to LF words. HF words were actually named about 5 ms faster in Experiment 2 than in Experiment 1; we have no explanation for this asymmetry.) This implies that frequency effects in delayed naming are partly due to processing demands imposed by LF and HF words. When participants operated under the heightened cognitive load of Experiment 2, sensitivity to word frequency increased.

The second, more important finding involved the ''blah'' trials. Because word naming was required in 80% of trials, an optimal participant would prepare to say the presented word on every trial, switching to ''blah'' only when necessary. With this in mind, the point raised by Savage et al. (1990) may be reconsidered: It is likely true that the attention required to identify tones and initiate responses is relatively constant, at least within classes of trials (word vs ''blah''). However, if the intrinsic cognitive load varies across words, the efficiency of other task-specific processes will also vary (Posner & Boies, 1971). Such inequalities of processing load are often hidden in primary task performance (in this case, word naming), but are revealed in secondary task performance (Kahneman, 1973; Kellas et al., 1988).

Given that LF and HF words demand unequal attention, in both perception and rehearsal, a natural prediction for ''blah'' trials arises: While preparing to speak LF words, participants should experience greater diffi-

[2] Naturally, the previously reliable main effects and interaction of Frequency and Delay were again reliable in the combined analyses. For brevity and clarity, we avoid reporting such redundant results, focusing on new comparisons involving the Experiment factor.

culty with all other task demands (tone identification, response selection, etc.), relative to the same situation with HF words. Therefore, despite the superficial constancy of ‘‘blah’’ trials, participants should be slower to abandon the speech plan and say ‘‘blah’’ when the original stimulus is a LF word. This prediction was confirmed in Experiment 2. A related observation was the tendency for frequency effects in ‘‘blah’’ trials to increase at longer delays, contrary to the pattern in word-naming trials. It is known that, within limits, attentional effects build over time (McLean & Shulman, 1978; Posner & Snyder, 1975), which predicts this trend.[3]

EXPERIMENT 3

Experiment 2 suggested that varying attentional demands of word perception and rehearsal may enhance the frequency effect in delayed naming. This is a direct application of classic dual-task logic (Kahneman, 1973; Posner & Boies, 1971): We suggest that participants dedicate greater attention to LF words, thus increasing the perceived difficulty of other task demands. Over the delay period, participants approach equal performance levels for LF and HF word-naming (primary task), but this entails a symmetric cost in the ‘‘blah’’ trials (secondary task). In Fig. 2, the converging word-naming functions over delays are matched to diverging functions in ‘‘blah’’ trials. Such cost–benefit tradeoffs commonly occur in tasks with attentional components, such as priming (Goldinger, Luce, Pisoni, & Marcario, 1992; Posner & Snyder, 1975).[4]

In a dual-task, attention demands are typically indexed by secondary task performance (Posner & Boies, 1971). Therefore, we may refer to the bottom panel of Fig. 2 to characterize the attention required to rehearse LF and HF words over time. As delays increase, attention demands decrease monotonically (i.e., participants become more prepared to speak). However, this occurs at frequency-sensitive rates; the demands of LF and HF words grow more disparate over time. An implicit assumption in dual-task research is that participants strive to optimize primary-task performance. Thus, these unequal degrees of attention are presumably geared to produce equal naming times for LF and HF words, as is occasionally reported in delayed naming (Savage et al., 1990). This depiction of attention predicts both the frequency-based convergence in word-naming trials, and the divergence in ‘‘blah’’ trials, across delays.

Experiment 3 further tested this account by replicating Experiment 2, but making the task a bit harder. Toward that end, we increased the difficulty of tone discrimination. In Experiment 2, tones signaling ‘‘blah’’ and word-naming trials were 400 and 900 Hz, respectively. In Experiment 3, these were changed to 550 and 750 Hz. By our account, this manipulation of task difficulty should exacerbate the frequency effects in both word-naming and ‘‘blah’’ trials.

Method

Participants. Sixty-four students participated in Experiment 3 for partial course credit. All were native English speakers with normal or corrected vision.

[3] Note that an alternative account could be formulated in an opposite manner. We assume that ‘‘blah’’ responses to LF words are slow because they require extra attention in rehearsal/preparation. However, we could assume that ‘‘true’’ frequency effects for ‘‘blah’’ trials should be *larger* than we observed because attention is more easily switched away from less-prepared LF words. Clearly, we cannot discount this idea (nor are we certain it is testable), but it is not consistent with other published data showing that LF words demand greater attention.

[4] One aspect of the present data that do not directly follow the dual-task logic is the general trend for all responses to speed up over delays. Given the logic just described, we would expect ‘‘blah’’ RTs to increase as word-naming RTs decrease. Clearly, this did not occur, although the Delay effect was reliably stronger in word-naming than in ‘‘blah’’ trials. Posner and Boies (1971) also noted this ‘‘aging foreperiod’’ effect, which seems to reflect arousal and preparation that build as participants await a ‘‘go’’ signal. Of the three attentional components Posner and Boies identified (preparation, selectivity, and processing capacity), most dual-tasks examine only the latter two, using pretrial warnings to alert participants.

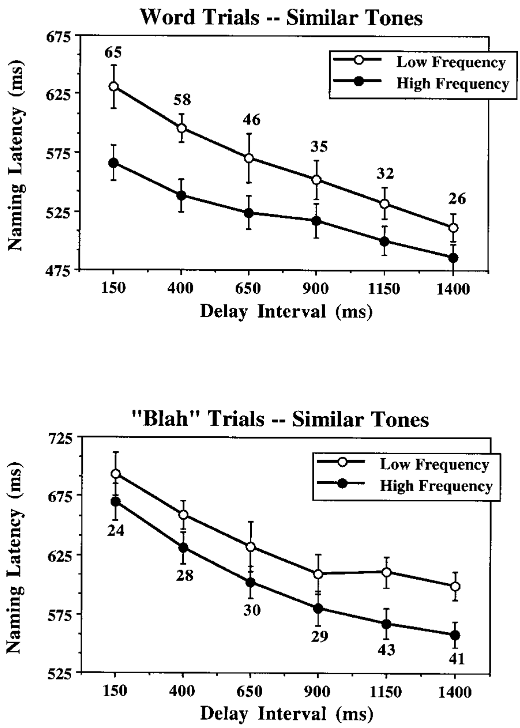

FIG. 3. Delayed-naming times: Experiment 3. (Top) Word-naming trials; (bottom) ''blah'' trials. Frequency effect (in ms) is shown at each interval.

Stimulus materials. The words from Experiment 1 were used again in Experiment 3.

Procedure. The procedures were identical to the delayed-naming condition of Experiment 2, except that 550- and 750-Hz tones were used as response signals, instead of 400- and 900-Hz tones.

Results and Discussion

As before, errors were removed from data files both automatically (for early or late responses) and by the experimenter after each session. Data from 4 participants were discarded, due to their apparent difficulty with the task (>20% errors). For the remaining 60 participants, error rates were below 4.5%. Most errors consisted of extraneous noises before speaking; the only reliable trend was a small Frequency effect, wherein LF words led to more errors than HF words (2.65% vs. 1.80%; $F_1(1,59) = 5.91$, $MS_e = 1.06$; $F_2(1,238) = 5.20$, $MS_e = 1.13$]. Figure 3 displays all RT data: The top panel shows word-naming trials; the bottom panel shows ''blah'' trials. The data resemble those of Experiment 2, but the frequency effects were more robust.

Word-naming trials. The word-naming RTs were analyzed in repeated-measures ANOVAs, followed by planned comparisons. Reliable main effects were observed for Frequency [$F_1(1,59) = 313.48$, $MS_e = 905.07$; $F_2(1,238) = 334.00$, $MS_e = 939.18$] and Delay [$F_1(1,59) = 81.22$, $MS_e = 911.46$; F_2 $(5,1190) = 95.57$, $MS_e = 977.12$]. On average, HF words were named 43.7 ms faster than LF words, and RTs decreased across delays. A reliable Frequency × Delay interaction [F_1 $(5,295) = 12.41$, $MS_e = 1230.25$; $F_2(5,1190) = 7.71$, $MS_e = 1281.66$] reflected the smaller frequency effect at longer delays. Planned comparisons revealed reliable frequency effects at all intervals: 150-ms [$t_1(59) = 25.14$; $t_2(238) = 22.01$]; 400-ms [$t_1(59) = 17.05$; $t_2(238) = 16.91$], 650-ms [$t_1(59) = 13.99$; $t_2(238) = 12.86$], 900-ms [$t_1(59) = 8.10$; $t_2(238) = 7.58$], 1150-ms [$t_1(59) = 4.16$; $t_2(238) = 3.80$]; 1400-ms [$t_1(59) = 2.21$ $t_2(238) = 1.88$].

To compare the word-naming frequency effects across Experiments 2 and 3, mixed-model ANOVAs were conducted, with Experiment as a between-subjects variable. A reliable main effect of Experiment [$F_1(1,94) = 121.40$, $MS_e = 1470.09$; $F_2(1,238) = 114.55$, $MS_e = 1602.15$] reflected the slower RTs in Experiment 3. The Experiment × Frequency interaction was also reliable [$F_1(1,94) = 66.81$, $MS_e = 1443.92$; $F_2(1,238) = 57.14$, $MS_e = 1650.03$], reflecting the larger frequency effect in Experiment 3. The three-way Experiment × Frequency × Delay interaction was not reliable.

''Blah'' trials. The RTs from ''blah'' trials were analyzed in a manner similar to that used word-naming trials. A reliable main effect of Frequency was observed [$F_1(1,59) = 100.12$, $MS_e = 1951.82$; $F_2(1,238) = 88.39$, $MS_e = 2117.41$]; ''blah'' responses were 33.5 ms faster to HF words than to LF words. A main effect of Delay [$F_1(1,59) = 23.60$, $MS_e = 1982.80$; $F_2(5,1190) = 20.40$, $MS_e = 2054.00$]

reflected faster responses at longer delays, and a Frequency × Delay interaction [$F_1(5,295) = 9.51$, $MS_e = 2211.35$; $F_2(5,1190) = 5.04$, $MS_e = 2319.56$] reflected the larger frequency effects at longer delays. Planned comparisons revealed reliable frequency effects at most delays: 400-ms delay [$t_1(59) = 4.15$; $t_2(238) = 3.94$], 650-ms delay [$t_1(59) = 3.18$; $t_2(238) = 2.56$], 1150-ms delay [$t_1(59) = 4.66$; $t_2(238) = 4.01$], 1400-ms delay [$t_1(59) = 4.39$; $t_2(238) = 3.70$]. Frequency effects were not reliable at the 150- or 900-ms delays.

To compare the ''blah'' frequency effects across Experiments 2 and 3, mixed-model ANOVAs were conducted, with Experiment as a between-subjects variable. A reliable main effect of Experiment [$F_1(1,94) = 96.48$, $MS_e = 1707.30$; $F_2(1,238) = 90.65$, $MS_e = 1729.08$] reflected the slower RTs in Experiment 3. The Experiment × Frequency interaction was also reliable [$F_1(1,94) = 39.18$, $MS_e = 1723.55$; $F_2(1,238) = 31.86$, $MS_e = 1732.01$], reflecting the larger frequency effect in Experiment 3. The three-way Experiment × Frequency × Delay interaction was not reliable.

Combined data. The data from Experiment 3 were also analyzed in 2 × 2 × 6 ANOVAs examining Response Type, Frequency, and Delay. A main effect of Response Type [$F_1(1,59) = 117.09$, $MS_e = 1201.65$; $F_2(1,238) = 103.27$, $MS_e = 1411.81$] reflected faster RTs in word-naming trials. A Response Type × Delay interaction [$F_1(5,295) = 16.87$, $MS_e = 1231.44$; $F_2(5,1190) = 12.90$, $MS_e = 1301.55$] reflected a stronger Delay effect in the word-naming trials. The three-way Response Type × Frequency × Delay interaction was also reliable [$F_1(5,295) = 9.53$, $Ms_e = 1241.62$; $F_2(5,1190) = 7.80$, $MS_e = 1310.19$], reflecting opposite Frequency × Delay interactions across Response Types.

The results of Experiment 3 seem to bolster the account offered thus far. We have suggested that participants dedicate unequal attention to LF and HF words, particularly during response preparation/rehearsal (Baddeley & Hitch, 1974; Watkins & Watkins, 1977). The attention dedicated to rehearsal is usurped from other task demands, such as tone identification and response selection. This frequency-sensitive siphoning of attention would be especially evident in ''blah'' trials, which require a change from the prepared response (Becker, 1976; Posner & Boies, 1971).

Word Frequency in a Resonance Framework

Although dual-task logic adequately predicts the results of Experiments 2 and 3 (and their comparison to Experiment 1), it is not wholly satisfying. Specifically, by attributing frequency-based RT differences to frequency-based attention differences, we have merely re-named the data. We have not addressed *why* LF and HF words demand attention to unequal degrees. To make the account substantial, some mechanism for the *allocation* of attention is required. As noted earlier, Becker's (1976) verification model (also Paap et al., 1982) assumes that word perception entails an attention-demanding, frequency-ordered search process. LF words require longer searches and hence more attention.

Although Becker's model has support (e.g., Herdman, 1992), we find utility in a ''resonance'' account of our data. This account is not original; it borrows heavily from published models of word perception, production, and memory (Burgess & Hitch, 1992; Dell, 1986; MacKay, 1987; McClelland & Rumelhart, 1981; Seidenberg & McClelland, 1989). Van Orden and Goldinger (1994) described a resonance framework for printed word perception, in which processing is characterized by initially diffuse activation that quickly becomes refined (see also Grossberg, 1980; Grossberg & Stone, 1986; Stone & Van Orden, 1994). Upon presentation of a letter string, a diffuse wave of activation spreads from visual feature nodes to all associated letter, phoneme, and word nodes. The strength of activation passed between nodes is a function of their frequency of previous association, usually operationalized via connection weights in trainable networks (Seidenberg, Plaut, Petersen, McClelland, & McRae, 1994). Once activated, the higher-level nodes return activation in feedback, which is then returned again, etc. Early in processing, many possible combinations of units are ''hypothesized'' as tentative feedback loops, but they are quickly overtaken by dynamics supporting the correct combinations (see Carpenter & Grossberg, 1987, for computer simulation). Eventually, if the feedforward and feedback patterns adequately match, the separate knowledge sources coalesce into a coherent, dynamic whole—a *resonance.* We assume that such resonances occur in word perception, rehearsal, and production. Indeed, all these behaviors have been successfully modeled in connectionist simulations (perception: Plaut, McClelland, Seidenberg, & Patterson, 1996; Seidenberg & McClelland, 1989; rehearsal: Burgess & Hitch, 1992; production: Dell, 1986).

To relate the resonance framework to attention and delayed naming, we must consider processing time. The events in normal lexical processing are continuous and turbulent: Words must be quickly perceived and integrated into discourse, as new words and ideas will follow. Thus, resonances are typically transient states that contribute to cognition and then quickly dissipate. Delayed naming, however, does not allow graceful dissolution of established resonances. Instead, words must be recognized, prepared for speech, and held in a vigilant state of readiness, often characterized as an *articulatory loop* (Baddeley, 1990; Gupta & MacWhinney, 1995). We view it as a state of maintained resonance, which is not incompatible (see Burgess & Hitch, 1992; Hartley & Houghton, 1996).

Because resonances dissolve quickly after stabilizing, maintaining their integrity (reversing their natural tendency) requires focused attention. This has been simulated in connectionist models as *temperature* (Smolensky, 1986), *vigilance* (Carpenter & Grossberg, 1987), and *resonance* (Schneider, 1993; Shedden & Schneider, 1990; Zipser, 1991). This may help explain frequency effects in delayed naming: Resonances for HF words (''strong attractors'') are easily established and maintained, relative to LF words (Grossberg & Stone, 1986; Van Orden & Goldinger, 1994). This is a simple function of internal connection weights; stronger connections are more resistant to degradation. By our hypothesis, the *inverse* of such resistance is the level of attention words demand in rehearsal. Thus, the attention required to rehearse a word in delayed naming should be inversely proportional to its frequency.

Although the resonance/attention account of Experiments 1–3 accommodates the data reported thus far, an adequate account should also predict new results. To this point, we have considered word frequency only as a resonance-enhancing factor. However, other factors are important, especially in consideration of the ''disintegrating resonance'' hypothesis. A particularly germane factor is *competition* among alternatives for resonance, which was the focus of Experiment 4.

EXPERIMENT 4

For better or worse, contemporary research in word perception is characterized by a growing collection of variables that affect simple reading tasks. Beyond the classics (e.g., word frequency, context, visual clarity), many subtle factors (e.g., concreteness, word shape, polysemy) correlate with performance. One such factor is the nature of words' *similarity neighborhoods.* Although some early models of word perception assumed independent lexical units (Morton, 1969; Forster, 1976), later models incorporated cooperative and competitive forces among words (Goldinger et al., 1989; Grainger & Segui, 1990; McClelland & Rumelhart, 1981; Seidenberg & McClelland, 1989). Neighborhood effects show that processing of any given word is affected by similar words, broadly construed. For example, both auditory and visual word perception are affected by neighborhood size (Andrews, 1989; Coltheart et al., 1977; Goldinger et al., 1989; Snodgrass & Mintzer, 1993) and by the relative frequencies of a presented word and its neighbors (Grainger, O'Regan, Jacobs, & Segui, 1989; Luce, 1986). An extension is the *consistency effect,* in which perception of a printed word is affected by the spelling–sound patterns of similar words (Glushko, 1979; Taraban & McClelland, 1987).

Consistency effects have a natural basis in a resonance system. As noted, frequency of association between nodes helps determine their time to achieve resonance. Another basic determinant is *crosstalk* (Van Orden & Goldinger, 1994). Resonance occurs when nodes share activation in a relatively exclusive feedback loop. However, if many similar resonances (those sharing subsets of common units) are learned by the system, it becomes more difficult for the correct resonance to coalesce. For example, words with bodies that support multiple pronunciations (e.g., _EAD, as in BEAD and HEAD) take longer to recognize than words with bodies that support unique pronunciations (e.g., _EAP, as in LEAP). In connectionist simulations (Kawamoto & Zemblidge, 1992; Seidenberg & McClelland, 1989), the basis of the effect is clear: Inconsistent words incur multiple ‘‘hypotheses’’—previously learned resonances that share elements with the target resonance. If there are many competitors, or if some competitors are strong attractors (HF words), time to correct resonance will increase. This predicts the commonly observed frequency X consistency interaction; LF words are more susceptible to competition, both in immediate naming (Jared et al., 1990; Waters & Seidenberg, 1985) and in delayed naming (Inhoff & Topolski, 1994).

Ideally, we hope to describe delayed naming without assuming different principles for word perception, rehearsal, and production. Indeed, very similar models have been applied to word perception (Grossberg & Stone, 1986; Seidenberg & McClelland, 1989), rehearsal (Burgess & Hitch, 1992), and production (Dell, 1986; MacKay, 1987). Thus, we assume the dynamics involved in establishing resonance (perception) are also involved in maintaining resonance (rehearsal). As such, we should observe interactions of frequency and competition in rehearsal, as others have noted in perception. Experiment 4 tested this hypothesis, examining delayed naming under various conditions of *memory load*. Participants memorized nonsense syllables, then performed blocks of 20 delayed naming trials (80% word-naming, 20% ‘‘blah’’), followed by syllable recall tests. There were four between-subjects conditions: In the *Crosstalk* condition, the nonsense syllables were phonologically similar to the subsequent naming stimuli. In the *No-Crosstalk* condition, the syllables were relatively dissimilar to the naming stimuli. In the *No Load* (control) conditions, participants memorized syllables (of either type) and then completed the recall test *before* the naming trials.

Predictions for Experiment 4 were relatively straightforward: Both No-Load conditions were expected to produce similar performance and to resemble the earlier data. The No-Crosstalk memory load was expected to increase task difficulty and to slightly exacerbate the frequency effect. The Crosstalk memory load was also expected to increase task difficulty and to greatly exacerbate the frequency effect (because the memory load should primarily affect rehearsal of LF words). As before, these attention-based effects should be most evident in the ‘‘blah’’ trials.

Method

Participants. One hundred seven students participated in Experiment 4 for course credit. All were native English speakers with normal or corrected vision.

Stimulus Materials. Experiment 4 used a subset of words from Experiments 1–3. These were grouped into 10 blocks of 20 words (10 LF and 10 HF), based on phonological similarity. For each block, two sets of 6 nonsense syllables were generated. Syllables in Crosstalk memory sets shared many phonemes with the naming stimuli (an average of 163.7 overlapping phonemes per block); No-Crosstalk memory sets were relatively dissimilar to the naming stimuli (22.9 overlapping phonemes per block). A practice block of 6 nonsense syllables and 20 words was used in all conditions. All stimuli for Experiment 4 are shown, as organized into blocks, in Appendix B.

Procedure. All volunteers participated in a

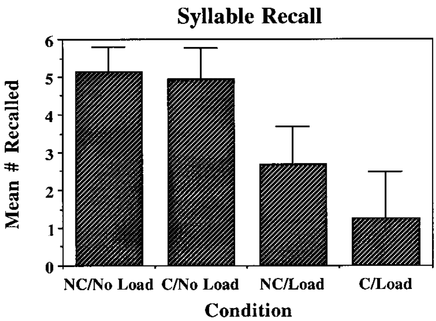

FIG. 4. Mean syllable recall rates: Experiment 4. ''NC'' and ''C'' indicate ''no-crosstalk'' and ''crosstalk,'' respectively.

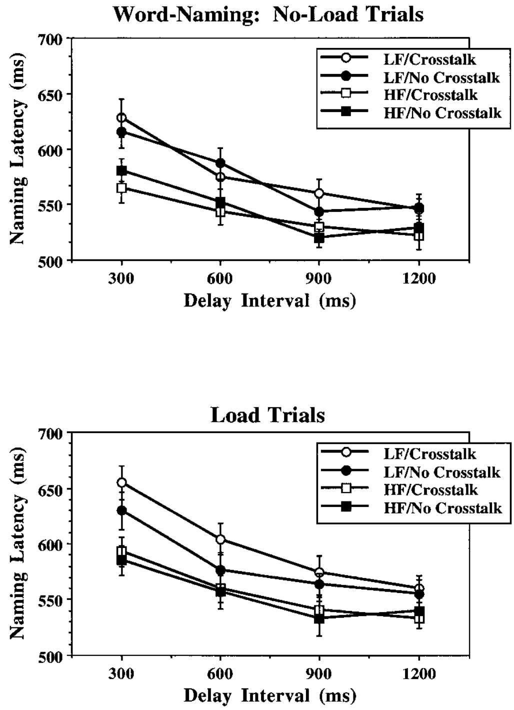

FIG. 5. Delayed word-naming times: Experiment 4. (Top) No-load trials; (bottom) load trials. All data are shown as a function of word frequency and crosstalk.

delayed naming dual-task, using the method described for Experiment 3, including the 550- and 750-Hz tones. Before each block of naming trials, they saw a vertical row of six nonsense syllables, which remained visible for as long as required for memorization. Once prepared, they pressed the space bar (and confirmed with another keystroke) to continue. In the No-Load (control) conditions, a recall test immediately followed the memorization phase. Participants were shown six blank spaces, also arranged vertically. They typed all remembered syllables in the spaces, in any order, and could edit their responses until satisfied. Once participants had recalled all possible syllables, they pressed ''enter'' and an extra keystroke to continue. Immediately afterward, a block of 20 delayed naming trials began. Procedures were identical to those of Experiment 3, but only four delay values were used: 300, 600, 900, and 1200 ms.

In the Load conditions (Crosstalk and No-Crosstalk), all procedures were the same, except participants performed the delayed naming trials *before* syllable recall. The order of recall and naming phases, and the confusability of memory loads with naming words, were manipulated between-subjects, with 25 students per condition. In all conditions, block order was randomized across individuals, although all began with a common practice block.

Results and Discussion

As before, naming errors were removed from data files before analysis. Data from 7 participants were discarded, due to their apparent difficulty with the task (>25% naming errors or consistent failure to recall >1 sylla-

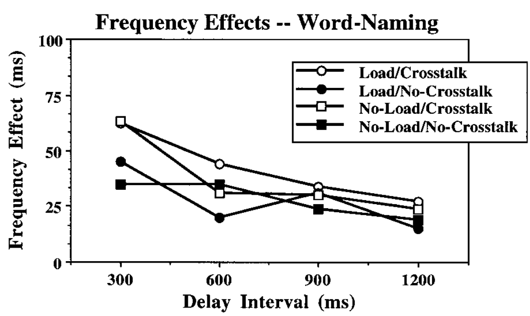

FIG. 6. Frequency effects from word-naming trials: Experiment 4. Data are shown as a function of memory load and crosstalk.

ble). For the remaining 100 participants, error rates were below 5.5%. No statistically reliable error patterns emerged, despite a trend toward higher errors at shorter delays.

Syllable recall. Figure 4 displays mean syllable recall rates (number out of six per block) from each condition. A liberal scoring criterion was used, counting any sound-alike syllables as correct responses (about 75% of all recall errors were blank spaces). In a 2 × 2 (Load × Crosstalk) between-groups ANOVA, a reliable main effect of Load was observed [$F(1,99) = 43.19$, $MS_e = 2.24$], reflecting superior recall in the No-Load conditions. The main effect of Crosstalk was null, but a significant Load × Crosstalk interaction [$F(1,99) = 6.51$, $MS_e = 2.81$] reflected the stronger Crosstalk effect in the Load conditions. A planned comparison confirmed that recall was better in the No-Crosstalk/Load condition than in the Crosstalk/Load condition [$t(49) = 4.55$],

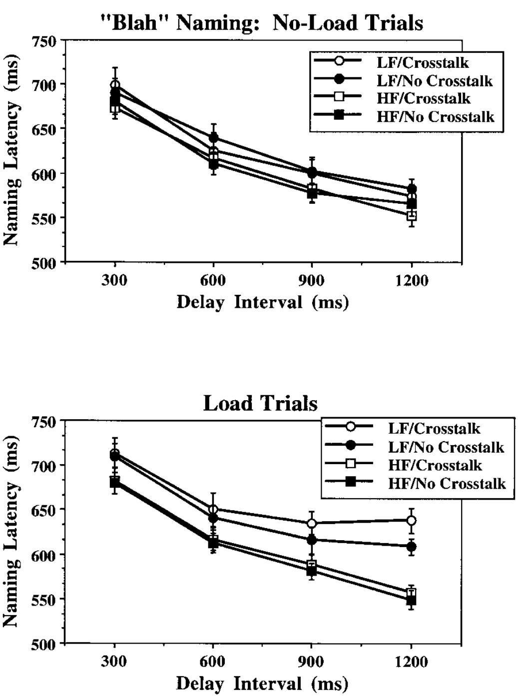

FIG. 7. Delayed ''blah''-naming times: Experiment 4. (Top) No-load trials; (bottom) load trials. All data are shown as a function of word frequency and crosstalk.

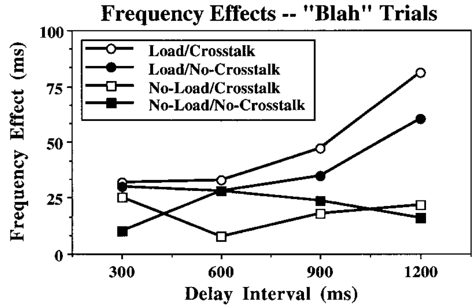

FIG. 8. Frequency effects from ''blah'' trials: Experiment 4. Data are shown as a function of memory load and crosstalk.

suggesting that Crosstalk loads engendered greater interference with the naming trials.

Word-Naming trials. Figure 5 presents all word-naming RTs, and Fig. 6 shows the associated frequency effects. The omnibus data from word-naming trials were first analyzed in separate 2 × 2 × 4 (Frequency × Load × Delay) ANOVAs. Reliable main effects were observed for Frequency [$F_1(1,99) = 119.16$, $MS_e = 1059.11$; $F_2(1,198) = 84.22$, $MS_e = 1449.90$] and Delay [$F_1(1,99) = 50.61$, $MS_e = 1091.02$; $F_2(3,594) = 41.79$, $MS_e = 1313.88$]. On average, HF words were named 33.7 ms faster than LF words, and RTs decreased at longer delays. The Frequency × Delay interaction was also reliable [$F_1(3,297) = 70.19$, $MS_e = 1118.43$; $F_2(3,594) = 61.48$, $MS_e = 1301.45$], reflecting the smaller frequency effect at longer delays. The main effect of Load was unreliable, although responses were 13.4 ms longer for participants under memory load. Contrary to expectations, the Load × Frequency interaction did not approach significance. The Load × Delay and the Frequency × Load × Delay interactions were also unreliable.

Data from the Load conditions were next analyzed in separate 2 × 2 × 4 (Frequency × Crosstalk × Delay) ANOVAs. The main effects of Frequency [$F_1(1,49) = 92.05$, $MS_e = 913.82$; $F_2(1,198) = 80.17$, $MS_e = 1025.09$] and Delay [$F_1(1,49) = 63.04$, $MS_e = 941.15$; $F_2(3,594) = 50.08$, $MS_e = 1074.30$] were again significant, as was their interaction

[F_1(3,147) = 62.56, MS_e = 938.06; F_2 (3,594) = 49.12, MS_e = 1061.87]. Neither the 10-ms main effect of Crosstalk nor the Frequency × Crosstalk interaction were reliable (although crosstalk effects were 14 ms larger for LF words than for HF words). Despite a trend, the Crosstalk × Delay interaction was also unreliable. However, the three-way Frequency × Crosstalk × Delay interaction was reliable [F_1 (3,147) = 22.46, MS_e = 1061.58; F_2(3,594) = 15.16, MS_e = 1130.76], indicating that crosstalk did exacerbate the frequency effect, primarily at shorter delays.

''Blah'' trials. Figure 7 presents RT data from ''blah'' trials, and Fig. 8 shows the associated frequency effects. The RT data were first analyzed in separate 2 × 2 × 4 (Frequency × Load × Delay) ANOVAs. Reliable main effects were observed for Frequency [F_1(1,99) = 59.30, MS_e = 1206.29; F_2(1,198) = 37.15, MS_e = 1413.62] and Delay [F_1(1,99) = 122.04, MS_e = 1251.83; F_2(3,594) = 91.15, MS_e = 1427.18]. On average, ''blah'' responses were 31.1 ms faster to HF words than to LF words, and RTs decreased at longer delays. The Frequency × Delay interaction was also reliable [F_1(3,297) = 11.40, MS_e = 1338.17; F_2(3,594) = 8.28, MS_e = 1409.50], reflecting the larger frequency effect at longer delays. The main effect of Load was unreliable, although responses were 12.9 ms slower for participants under memory load. The Frequency × Load interaction was reliable [F_1(1,99) = 32.80, MS_e = 1206.29; F_2(1,198) = 26.05, MS_e = 1413.62]; the frequency effect was 24.4 ms larger for participants under memory load. Neither the Load × Delay interaction nor the Frequency × Load × Delay interaction were reliable.

Next, data from the Load conditions were analyzed in separate 2 × 2 × 4 (Frequency × Crosstalk × Delay) ANOVAs. The main effects of Frequency [F_1(1,49) = 47.12, MS_e = 1270.58; F_2(1,198) = 31.84, MS_e = 1465.36] and Delay [F_1(1,49) = 83.66, MS_e = 1321.03; F_2(3,594) = 66.39, MS_e = 1513.84] were again reliable. On average, ''blah'' responses were 43.3 ms faster to HF words than to LF words, and RTs decreased at longer delays. The Frequency × Delay interaction was reliable [F_1(3,147) = 25.07, MS_e = 1258.34; F_2(3,594) = 18.52, MS_e = 1490.81], reflecting the larger frequency effects at longer delays. The main effect of Crosstalk was not reliable, nor were the Frequency × Crosstalk or Crosstalk × Delay interactions. However, the 3-way Frequency × Crosstalk × Delay interaction was reliable [F_1(3,147) = 15.28, MS_e = 1315.02; F_2(3,594) = 8.16, MS_e = 1562.93], showing that crosstalk exacerbated the frequency effect, primarily at long delays.

Combined data. As before, the combined data were analyzed in separate 2 × 2 × 2 × 2 × 4 ANOVAs examining Response Type, Frequency, Load, Crosstalk, and Delay. A main effect of Response Type [F_1(1,99) = 202.31, MS_e = 1421.01; F_2(1,198) = 186.83, MS_e = 1780.62] reflected faster responses to word-naming trials. The Response Type × Delay interaction was null, but the three-way Response Type × Frequency × Delay interaction was reliable [F_1(3,147) = 13.25, Ms_e = 1421.01; F_2(3,594) = 8.38, MS_e = 1780.62], reflecting the opposite Frequency × Delay interactions across Response Types. No four- or five-way interactions were reliable.

The results of Experiment 4 resemble those of perceptual experiments examining word frequency and consistency. As before, in both word-naming and ''blah'' trials, responses were faster to HF words. Moreover, although there were no main effects of Crosstalk or Load, a predicted interaction emerged: The frequency effects were magnified by the added crosstalk (primarily at short delays in word-naming, and long delays in ''blah'' trials). This parallels previously observed frequency × consistency interactions in immediate naming (Jared et al., 1990; Waters & Seidenberg, 1985) and delayed naming (Inhoff & Topolski, 1994), and is easily predicted by models incorporating mechanisms of frequency and crosstalk (Seidenberg & McClelland, 1989; Van Orden & Goldinger, 1994).

GENERAL DISCUSSION

The findings of the present investigation are easily summarized: The frequency effect in delayed naming (Balota & Chumbley, 1985) was replicated in Experiment 1. In Experiments 2–4, a dual-task was used, allowing secondary-task assessment of the relative attention demands of LF and HF words. All experiments showed reliable frequency effects in both word-naming and ‘‘blah’’ trials. The frequency effects could be modified by altering task difficulty, or by adding phonologically confusable memory loads. Taken together, the data suggest that frequency effects in delayed naming partly reflect attentional differences in processing LF and HF words.

By extension, the data also support the earlier suggestion by Monsell et al. (1989) that frequency effects arise in delayed naming when participants are not truly prepared to speak before the response signal. Our claim is that word frequency influences the efficiency of processes *during* preparation. By definition, one is ‘‘prepared’’ to respond only when such word-specific differences have been ironed out. Thus, the vanishing frequency effect reported by Monsell et al. (1989) may represent the end-state of a frequency-sensitive preparation process. If so, the residual frequency effects reported here (and by Balota & Chumbley, 1985) may reflect a cascade (McClelland, 1979) in which frequency affects first perception and then rehearsal and later response assembly. Thus, at this level, our results are consistent with earlier reports by Monsell et al. (1989) and Savage et al. (1990), along with the Balota and Chumbley (1985) original demonstration of frequency effects in delayed naming.

Regarding the study by McRae et al. (1990), a caveat is necessary. As mentioned earlier, the McRae et al. comparison of homophones may be an ideal frequency manipulation, as it avoids all acoustic or articulatory confounds. We did not maintain this level of control, for reasons reviewed earlier (we must generalize to prior studies, and homophones may not maintain printed frequency distinctions in the articulatory loop). Given such pragmatic choices, we must acknowledge that our ‘‘frequency effects’’ could reflect other stimulus dimensions, such as differences in words’ relative ease of articulation (assuming rehearsal entails inner speech). It is known that LF and HF words differ in phonetic structure (Landauer & Streeter, 1973), so frequency and ease of articulation are potentially confounded. Naturally, we minimized such differences in stimulus selection, but the possibility remains. Such natural confounds impart a ‘‘chicken-and-egg’’ paradox: Are HF words easier to speak (or rehearse by inner speech) due to their increased practice, or have articulatory constraints naturally selected frequency differences? Either source of the ‘‘frequency’’ effect would predict the present data.

Our results are almost all accommodated by classic dual-task logic (Kahneman, 1973; Posner & Boies, 1971). However, a missing ingredient is some linkage of word frequency to attention demands. Whereas Becker (1976) applied a verification model, we have suggested a resonance framework. Attention is required when resonance is first established, as shown by previous research (Herdman, 1992; Herdman & Dobbs, 1989), and is also required when resonance is maintained in working memory, but not uniformly across words. Because HF words are stronger attractors, they require less attention to maintain integrity over time. Experiment 4 examined a secondary prediction of the resonance account—the relative sensitivity of different word rehearsal states to crosstalk, operationalized via memory loads. The results were consistent with the account, showing frequency-sensitive crosstalk effects.

In implemented models (e.g., Plaut et al., 1996), word frequency effects reflect a general principle: Frequently established system states (such as the association of HF spellings to pronunciations) are more easily established in perception, more robust to various types of noise, and more easily maintained over time. Taken together, frequency and crosstalk predict the performance of connectionist models and human observers (McClelland & Rumelhart, 1986; Van Orden & Goldinger, 1994). We have not simulated our delayed naming data, and nonlinear simulation processes could yield unexpected results. However, our account is based on well-explored principles such as attractor strength, competitive dynamics, and entropy (Grossberg, 1980; Smolensky, 1986). Thus, although our account is metaphorical, it is constrained by implemented models (which are also metaphorical; see Forster, 1994; Lewandowski, 1993; Stone & Van Orden, 1994).

Resonance and Vigilance

Although the present investigation focused on delayed naming, the hypotheses are quite general: (1) Word perception, rehearsal, and production require stable feedback loops (resonances) among relevant knowledge structures. (2) Establishing resonance requires some attention. (3) In typical language perception or production, resonances are quickly established and dissolved, replaced by later words in the discourse. If a resonance is needed for an exaggerated period, as in delayed naming, extra attention is required to maintain its integrity. (4) The amount of required attention is predicted by word frequency and the strength of competing words.[5] As a resonance degrades, other potential resonances (neighboring words) may usurp activation that escapes the original feedback loop.

The transient nature of resonant states, and their potential replacement by competing states, is reminiscent of other lexical processes. It is unclear whether resonances degrade due to node saturation (MacKay, Wulf, Yin, & Abrams, 1993) or because new ideas impinge upon the active mind. In either case, the present data seem related to a broad set of ''saturation'' phenomena, such as the *verbal transformation effect* (VTE; Lackner, 1974; MacKay, 1969; Warren, 1961; 1968). When a word is played repeatedly (as in a tape loop) to a listener, an illusion is experienced—the word seems to successively change to other words. MacKay et al. (1993) noted the example *face*, which perceptually transforms to words like *space*, *paste*, *base*, and *taste* over repetitions. This is similar to the *semantic satiation effect,* in which a repeated word loses its meaning to a speaker (e.g., Balota & Black, 1997).[6]

The VTE seems to share key properties with delayed naming, as both involve vigilance of coherent system states. We have suggested that resonances degrade and require attention over time. Similarly, in VTE experiments, the rate of perceptual changes and the variety of interlopers typically increase over time (Warren, 1968). In delayed naming, resonance integrity appears to be frequency-dependent. Natsoulas (1965) compared VTEs to words (e.g., *parrot*) and nonwords (e.g., *tarrop*), finding that nonwords generate more (and more varied) perceptual transformations. Although comparing words to nonwords is an extreme frequency difference, this finding suggests that resonances degrade faster for less familiar stimuli.

The finding that VTEs for nonwords involve a wider variety of interlopers also supports the hypothesized nature of crosstalk. In perception, words with HF ''enemies'' are more slowly recognized (Jared et al., 1990); nonwords should experience such competition from all similar words. In rehearsal, as a resonance deteriorates, its activation should be drawn into neighboring attractors, especially strong (HF) attractors (Van Orden & Goldinger, 1994). Indeed, Yin and MacKay (1992) reported that VTEs are more frequent

[5] We demonstrated this property in Experiment 4 with memory loads that were phonologically similar to the naming stimuli. An alternative method would compare words from different similarity neighborhoods; to examine crosstalk intrinsic to the lexicon (cf. Inhoff & Topolski, 1994), rather than adding extrinsic crosstalk. Post-hoc analyses of our data show a trend for ''weak'' LF words to require more attention than ''strong'' LF words, with ''strength'' determined by presence of HF neighbors. This dimension was not manipulated, however, and the trend was unreliable.

[6] Another similar effect occurs when a static image is continuously projected to a fixed area of the retina (Riggs, Ratliff, Cornsweet, & Cornsweet, 1953). Using this technique, Pritchard (1961) found that words (e.g., BEER) do not merely fade from view over time; participants actually perceive a series of other words sharing subsets of features (e.g., PEER, PEEP, BEEP, etc.). We view this as a deteriorating resonance, its escaping activation usurped by opportunistic neighboring attractors.

and varied for words from larger phonetic neighborhoods. In ‘‘tip-of-the-tongue’’ (TOT) studies, LF words elicit more TOT states, and phonetically similar interlopers persistently occur to the suffering observer (Burke, MacKay, Worthley, & Wade, 1991). Finally, natural and laboratory-induced speech errors are more common among LF words (MacKay, 1970; Stemberger & MacWhinney, 1986), and the errors tend to form real words (Dell, 1986).

These findings share a common thread[7]—activation from a deteriorating resonance is seemingly usurped by neighboring attractors. Such crosstalk effects are usually examined in the earliest moments of perception, when competitors are most viable (Jared et al., 1990). In the present investigation, we observed similar effects in the aftermath of perception. Lexical processes do not pass from organized, perceptual states directly to entropy states. Instead, as resonance decays, nearby words again compete for the escaping activation. Thus, frequency × crosstalk interactions are observed in mental rehearsal, as in perception (Burgess & Hitch, 1992).

Conclusion

The word frequency effect in delayed naming, and its absence in several studies, has invigorated a debate on the locus of frequency effects in lexical processing. Although some null effects suggest that word frequency is mainly a perceptual variable (Monsell et al., 1989; Savage et al., 1990), the present investigation underscores the role of attention. Previous research has shown frequency-sensitive allocation of attention during word perception (Becker, 1976; Herdman, 1992). The present data suggest that attention is allocated in a frequency-sensitive manner, even beyond the perceptual stage. Indeed, all ‘‘stages’’ of delayed naming may reflect a common system, in which word frequency is a basic control parameter.

If various forms of lexical processing truly reflect a common system, our experimental repertoire should include tasks beyond lexical decision, naming, and others dedicated only to the perceptual stage. Theories of lexical access may benefit from studies of speech production, serial recall, writing, etc. We suggest that ‘‘saturation phenomena,’’ which already have a rich empirical history, offer an important line of future investigation. This article began with a quote from John Locke regarding the difficulty of maintaining a single mental state. His observation is confirmed by VTEs and semantic satiation effects. Reports of repetition blindness and deafness (Kanwisher, 1987; Miller & MacKay, 1994) provide variations on saturation techniques, allowing real-time investigation of resonance formation and deterioration. In all such paradigms, tracking attentional demands may provide a window on underlying lexical dynamics.

[7] We are not the first to notice this common thread. MacKay (1987) has developed a resonance model of language production by researching speech errors, VTEs, TOT states, mental rehearsal processes, and repetition deafness. MacKay has uniformly explained such phenomena in terms of saturated nodes or feedback loops.

APPENDIX A: STIMULI USED IN EXPERIMENTS 1–3

Practice Words

church, triangle, foliage, prime, drain, glimpse, radio, folder, adventure, mouse, ladder, buffalo, sauce, brace, yearn, switch, cloudy, penguin, garage, cedar, frosty, decade, somber, dismay, circuit, canoe, anchor, waist

High-Frequency Words

dog, key, man, apple, deny, door, fire, item, town, unit, adult, alive, apply, avoid, basic, begin, bill, blood, bone, bread, cover, dozen, enter, event, exist, floor, glass, grass, horse, hotel, image, index, minor, money, motor, mouth, novel, paper, party, raise, right, royal, seed, seven, shoe, story, taken, visit, vital, accept, attend, battle, become, bottle, buckle, cattle, coffee, corner, cotton, county, cousin, credit, dinner, divide, doctor, effect, engine, extend, follow, forget, garden, happen, island, income, letter, marine, market, mother, number, office, palace, police, proper, square, window, captain, college, current, growth, kitchen, machine, picture, trouble, teacher, village, contact, distance, merchant, student, president, science, later, car, order, snack, topic, tired, valley, long, color, dollar, across, balance, between, beauty, brother, perfect, private, practical, product, purpose, travel, traffic, content, couple, plenty, person, daughter, pressure, plant, plate, pattern, shirt, spoon, green, wall, news, time, phone, pain

Low-Frequency Words

pan, arid, crux, dune, emit, icon, malt, omit, adobe, annoy, antic, argon, banal, banjo, bonus, broom, cadet, crate, dogma, decor, dregs, elfin, felon, pluto, plight, flute, inane, inept, melon, modal, knave, nylon, tug, bilk, bluff, exhume, gloss, hovel, abduct, ruse, wretch, pagan, polka, relic, shawl, superb, tunic, vista, vigil, anthem, astute, barrow, beaker, befall, bodice, canine, carat, castle, cavern, climax, coward, cradle, devoid, dismal, donkey, eclair, enzyme, facade, gander, grocer, hangar, hearse, inlaid, invent, seep, forage, larder, magnet, malign, mayhem, mildew, option, palate, parole, propel, quartz, skate, strewn, wicket, buffoon, cadence, cossack, crevice, dissect, prowess, sputter, terrace, conquest, nostril, surcease, parachute, tumbler, vintage, baron, boulder, brutal, barber, chronic, confine, digress, deluge, dormant, drastic, pardon, parish, pastry, patron, perfume, pigment, pollen, prophet, tangle, trifle, tremble, peasant, picket, piston, potent, lurid, capsule, shank, spool, grail, whale, noose, tomb, font, pate, creed, twinge

APPENDIX B: STIMULI USED IN EXPERIMENT 4

Practice Block

Memory Load: wilk, norp, slib, trafe, bloin, grum

Naming Stimuli: church, triangle, foliage, prime, drain, glimpse, radio, folder, adventure, mouse, ladder, buffalo, sauce, brace, yearn, switch, cloudy, penguin, garage, cedar

Block 1

Crosstalk Load (22 phonemes, 116 overlapping): grob, drune, darb, nord, brug, gand

Non-Crosstalk Load (22 phonemes, 22 overlapping): pice, wush, jimp, steek, clate, voost

Naming Stimuli: dog, adult, begin, bread, divide, growth, blood, garden, green, dinner, dune, argon, dogma, dregs, adobe, banal, broom, grail, gander, bodice

Block 2

Crosstalk Load (21 phonemes, 152 overlapping): moke, troon, krit, vike, keet, croot

Non-Crosstalk Load (21 phonemes, 24 overlapping): blide, doose, jod, slafe, grode, houb

Naming Stimuli: cover, key, motor, item, cotton, cattle, event, visit, vital, market, confine, crate, cavern, climax, tunic, tomb, emit, vintage, cadet, tumbler

Block 3

Crosstalk Load (25 phonemes, 204 overlapping): slig, grice, sprim, gursp, ploss, sporn

Non-Crosstalk Load (24 phonemes, 49 overlapping): fint, thonk, widge, truft, breen, yaft

Naming Stimuli: grass, palace, police, proper, square, president, glass, forget, person, spoon, gloss, pagan, capsule, spool, grocer, pigment, propel, prowess, pastry, sputter

Block 4

Crosstalk Load (23 phonemes, 152 overlapping): krob, munt, berm, bount, croot, mank

Non-Crosstalk Load (22 phonemes, 30 overlapping): glip, ziff, worve, gloop, prass, flerge

Naming Stimuli: become, bottle, buckle, county, battle, captain, man, money, number, time, banjo, tremble, malt, icon, bilk, beaker, canine, malign, wicket, chronic

Block 5

Crosstalk Load (24 phonemes, 193 overlapping): snood, tonks, dake, sterk, nost, koust

Non-Crosstalk Load (24 phonemes, 25 overlapping): grelp, freep, yulf, lorge, grosh, fludge

Naming Stimuli: seed, student, snack, seven, distance, science, town, story, daughter, doctor, decor, astute, donkey, pan, crux, devoid, dusk, cadence, dissect, nostril

Block 6

Crosstalk Load (24 phonemes, 167 overlapping): blick, slock, scoob, cleeb, bolks, snib

Non-Crosstalk Load (23 phonemes, 32 overlapping): grash, tomp, wurgs, chuff, greep, prosh

Naming Stimuli: basic, bill, long, color, dollar, balance, across, trouble, below, block, bluff, befall, boulder, brutal, abduct, castle, cradle, dismal, cossack, crevice

Block 7

Crosstalk Load (25 phonemes, 189 overlapping): sprat, hurps, rimp, triss, preet, hasp

Non-Crosstalk Load (24 phonemes, 30 overlapping): mook, yold, chonk, clume, blant, dant

Naming Stimuli: horse, house, paper, practical, purpose, accept, happen, raise, sport, press, ruse, superb, hearse, seep, parole, strewn, surcease, parachute, parish, piston

Block 8

Crosstalk Load (20 phonemes, 151 overlapping): noom, leem, nall, smeen, marn, melk

Non-Crosstalk Load (22 phonemes, 22 overlapping): froop, prack, grood, doast, dorge, hiff

Naming Stimuli: minor, mouth, novel, income, marine, mother, window, machine, news, merchant, inane, inept, melon, modal, knave, nylon, anthem, enzyme, mayhem, dormant

Block 9

Crosstalk Load (22 phonemes, 150 overlapping): ploot, lant, nipe, clune, nork, plark

Non-Crosstalk Load (24 phonemes, 32 overlapping): silge, joss, grelz, gilch, freem, drame

Naming Stimuli: college, current, kitchen, couple, plate, picture, constant, party, corner, credit, antic, twinge, patron, pluto, palate, polka, exhume, conquest, potent, shank

Block 10

Crosstalk Load (23 phonemes, 163 overlapping): bint, prant, norp, treep, brune, bort

Non-Crosstalk Load (23 phonemes, 28 overlapping): karf, gleek, drong, gliss, chask, hink

Naming Stimuli: between, teacher, beauty, pattern, plenty, topic, perfect, private, pain, product, pollen, barber, digress, drastic, pardon, prophet, pate, peasant, baron, buffoon

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