Psychonomic Bulletin & Review
2000, 7 (2), 320-326

The interaction of meaning and sound in spoken word recognition

LORRAINE K. TYLER, J. KATE VOICE, and HELEN E. MOSS
University of Cambridge, Cambridge, England

Models of spoken word recognition vary in the ways in which they capture the relationship between speech input and meaning. Modular accounts prohibit a word's meaning from affecting the computation of its form-based representation, whereas interactive models allow activation at the semantic level to affect phonological processing. We tested these competing hypotheses by manipulating word familiarity and imageability, using lexical decision and repetition tasks. Responses to high-imageability words were significantly faster than those to low-imageability words. Repetition latencies were also analyzed as a function of cohort variables, revealing a significant imageability effect only for words that were members of large cohorts, suggesting that when the mapping from phonology to semantics is difficult, semantic information can help the discrimination process. Thus, these data support interactive models of spoken word recognition.

Models of spoken word recognition vary in the ways in which they capture the relationship between phonology and semantics. Accounts that assume a modular architecture, in which the speech input passes through a series of stages until the meaning of the word is accessed (Becker, 1980; Forster, 1979), share the view that the speech input is initially mapped onto a level of form representation. Only when this process is completed can meaning be accessed; the meaning of a word cannot affect the computation of its form-based representation. In contrast, interactive models of word recognition assume feedback between different levels of processing (McClelland & Elman, 1986). Although there is no extant interactive model that captures the entire process of word recognition, from analyzing the input to accessing meaning, we can extrapolate from existing models that capture part of the word recognition process. In TRACE, for example, the input is initially mapped onto a featural level of representation, then onto a phoneme level, and finally onto a word level (McClelland & Elman, 1986). Interaction is achieved by feedforward and feedback between levels. If we extended this model beyond the word form level to semantics and assumed the same structure, semantic information would feed back to the word form level and on to the phonemic level. Thus, this kind of model would predict that the computation of a word's form could be affected by its meaning. Similarly, the distributed model of Gaskell and Marslen-Wilson (1995, 1997) would predict an interaction between access to semantic and access to phonological knowledge. In their model, a low-level representation of the speech wave is mapped directly onto distributed representations of both the semantics and the phonology of words. In order to carry out this task, the connection weights in the network must encode information about both mappings, implying that the retrieval of the two types of knowledge will interact.

Experimental investigations of the relationship between form and meaning have often exploited imageability[1] (see Balota, Ferraro, & Connor, 1991, for a review). The imageability of a word is the degree to which its referent can be perceived through the senses; for example, *table* is a highly imageable word in that its meaning is associated with many sensory properties (size, shape, etc.), whereas *hope* is low in imageability (Paivio, 1986). The issue is whether a purely semantic variable—imageability—can affect phonological processing. If it can, we would expect high-imageability (HI) words to be recognized more easily than low-imageability (LI) words; this would be evidence that meaning variables affect word identification.

Testing this claim crucially requires a task that taps into the early stages of word recognition, a task that reflects the automatic activation of phonological and semantic information during the process of recognizing a spoken word. There are two primary candidates: word naming and lexical decision (LD; see Balota et al., 1991). LD tasks, invariably using written words and varying degree of imageability, have produced mixed results. Moreover, LD may include a postaccess decision stage (Seidenberg, Waters, Sanders, & Langer, 1984), making it less suitable for probing early word recognition processes. Naming is generally considered to tap early activation processes, but semantic effects in word naming are very elusive, with studies showing either very small (deGroot, 1989) or no effects

This research was supported by an MRC (U.K.) programme grant to L.K.T. and William D. Marslen-Wilson and by a Wellcome Trust Fellowship to H.E.M. We thank Vincent Dautry for his invaluable assistance in collecting the materials for this study, Stu McLellan for helping with the data analysis, and William Marslen-Wilson and Gareth Gaskell for their comments on an earlier draft of this paper. Correspondence concerning this article should be addressed to L. K. Tyler, Centre for Speech and Language, Department of Experimental Psychology, University of Cambridge, Downing Street, Cambridge CB2 3EB, England (e-mail:lktyler@csl.psychol.cam.ac.uk).

of imageability (Brown & Watson, 1987). Recently, however, Strain, Patterson, and Seidenberg (1995) have reported an imageability effect for low-frequency exception words with naming, arguing that when the orthographic-to-phonological mapping is slow, inefficient, or error prone, meaning plays a larger role in word naming.

The semantics/phonology interaction is perhaps most directly studied by investigating imageability effects in *spoken* word recognition, thus avoiding problems with the orthography–phonology mapping. In the experiments reported here, we asked whether imageability affects the computation of a phonological representation during the processing of a spoken word and used two tasks to address this issue: (1) auditory LD, where subjects heard a spoken item and made an LD, and (2) word repetition, where subjects rapidly repeated a spoken word. The advantage of using both tasks was that each has its associated problems that can undermine any straightforward interpretation of an imageability effect. In LD, imageability effects can, potentially, be attributed to the putative postaccess component. The repetition task, although clearly tapping into early phases of processing, has been criticized on the grounds that subjects can repeat a word quite rapidly and accurately without activating semantics (McLeod & Posner, 1984). Moreover, another potential problem with the repetition task is that it involves an articulation stage, not present in the LD task, that can potentially confound the interpretation of repetition data. However, these task-related problems are minimized if subjects show an imageability effect in both LD and repetition. The strongest claims about the relationship between phonology and semantics can be made when the same pattern of results shows up in both tasks. We can then rule out the possibility of the effects being due to either a decision stage (LD) or production phenomena (repetition).[2]

We manipulated word familiarity and imageability to see whether repetition and LD latencies were affected by either of these variables. We included familiarity as a variable, since this had been shown to affect naming, albeit in written words (Strain et al., 1995). If the meaning of a spoken word does not affect the recognition of its form, as modular accounts would predict, we would expect no effect of imageability on either repetition or LD latencies. But if there is an interaction between semantics and phonology, we should see faster latencies for HI than for LI words.

EXPERIMENT 1
Auditory Lexical Decision

Method

Subjects

The 14 subjects were recruited from the Centre for Speech and Language's subject pool and were paid for their participation.

Materials

We selected HI and LI words so that HI words had imageability and concreteness ratings above 540 and LI words had ratings below 400 (see the Appendix). These words were further grouped into two familiarity bands; high familiarity (550 or above; Coltheart, 1981) and low familiarity (less than 420). There were 44 items in the HI band and 48 items in the LI band. HI and LI words within the same familiarity bands were matched on familiarity and frequency, number of syllables, number of phonemes (see Table 1A), and phoneme onset (see Table 1B). We could not perfectly match the frequencies of the two sets of high-familiarity words, but the higher frequency of the LI words is a conservative solution to this problem, since it should increase the probability of faster responses to LI words, thus biasing against an imageability effect. The words, all of which were 1–2 syllable nouns, were pseudorandomly mixed with 60 medium-familiarity words (rated between 450 and 530), which acted as fillers. An equal number of pronounceable nonwords (e.g., *honth, thond, profif*) were included in the list, pseudorandomly interspersed between the real words. The test list was preceded by a short practice block of 8 words.

Procedure

The materials were recorded onto DAT tape in a soundproof booth. These recordings were then passed through an anti-aliasing filter and digitized at a sampling rate of 20 kHz, using a DT2821 sound-card attached to a Dell PC. The start- and endpoints of each word were marked, using the BLISS speech-editing system (Mertus, 1989). Words were played out from computer disk under the control of the DMASTR experimental package (Forster & Forster, 1990), with a 2,000-msec intertrial interval. The subjects heard each item and made a yes/no LD. LD latencies were measured from item onset. The subjects were tested individually in a sound-attenuated booth and were asked to make a yes/no LD response as quickly as possible by pressing a response key.

Results and Discussion

The subjects made an average of 3.26% LD errors, which were removed from the analyses. The raw response times (RTs) were inversely transformed (Ratcliff, 1993; Ulrich & Miller, 1994) and entered into two analyses of variance (ANOVAs) with imageability (low/high), fa-

Table 1A
Statistics of the High- and Low-Imageability Words

Imageability	Mean Conc	Mean Imag	Mean Fam	Mean Freq	No. Syll	No. Phon
Low familiarity						
Low	317	331	353	6	1.8	4.7
High	594	571	373	2	1.6	4.6
High familiarity						
Low	314	351	578	222	1.5	4.4
High	600	600	588	90	1.5	4.2

Note—conc, concreteness rating (Coltheart, 1981); imag, imageability rating (Coltheart, 1981); freq, frequency rating (LOB norms; Hofland & Johansson, 1982); syll, syllables; phon, phonemes. The familiarity rating is taken from Coltheart (1981).

Table 1B
Onsets of High and Low-Imageability Words: Number of Each Type by Familiarity Band

	Type of Onset				
Imageability	Plosive	Fricative	Nasal	Approximant	Vowel
Low familiarity					
Low	11	9	2	2	6
High	12	10	2	1	5
High familiarity					
Low	11	7	4	3	5
High	12	7	3	4	4

miliarity (high/low), and syllable number (one/two) as variables.

The mean LD RT for HI words was 37 msec faster than that for LI words [HI, 817 msec; LI, 854 msec; $F_1(1,13) = 53.19, p < .001$; $F_2(1,84) = 5.50, p < .0214$]. Highly familiar words (798 msec) were also responded to faster than unfamiliar words [877 msec; $F_1(1,13) = 77.70, p < .001$; $F_2(1,84) = 15.85, p < .001$]. Although there was a larger imageability effect for high- (60 msec) than for low- (9 msec) familiarity words, the familiarity × imageability interaction was only significant by subjects [$F_1(1,13) = 18.98, p < .001$; $F_2 < 1$]; none of the other interactions was significant. Analyses of the error data showed only a significant effect of familiarity; more errors were made to low-familiarity words (5.06%) than to high-familiarity words [1.29%; $F_1(1,13) = 5.77, p < .03$; $F_2(1,84) = 8.04, p < .005$].

EXPERIMENT 2
Repetition Naming

Method

Subjects

Sixteen subjects were tested in the study, recruited from the Centre for Speech and Language's subject pool, and were paid for their participation.

Materials

We used exactly the same speech tokens as in the LD study but did not include the nonwords. At the end of the list of real words, we included 30 pronounceable nonwords, in order to compare nonword with real-word repetition latencies. If subjects do not repeat real words faster than nonwords, it is unlikely that any lexical information (including semantic information) could influence performance (McLeod & Posner, 1984).

Procedure

The subjects were tested individually in a sound-attenuated booth, where the stimuli were played out over headphones, with stimulus onset asynchrony of 2,000 msec. They were asked to repeat each word as rapidly and accurately as possible, and their repetition latencies were measured from the onset of each item.

Results and Discussion

We initially removed all RTs under 100 msec (1.9%) from the data set and then applied an inverse transformation.[3] Repetition errors (e.g., *discourse* for *discord*, *term* for *turn*) ranged from 0% to 9%.[4] Repetition latencies were faster for HI (363 msec) than for LI words [392 msec; $F_1(1,15) = 13.869$, $p < .002$; $F_2(1,88) = 4.203$, $p < .043$]. There was also a trend for highly familiar words to produce faster repetition latencies (367 msec) than did less familiar words [387 msec; $F_1(1,15) = 6.896$, $p = .019$; $F_2(1,88) = 1.992, p = .162$]. The imageability effect was not significantly modulated by familiarity ($F_1 < 1$; $F_2 < 1$), nor were any other interactions significant. An analysis of repetition errors showed no significant effects at all.[5]

These repetition data show exactly the same pattern as that for the LD data, suggesting that, irrespective of familiarity, the imageability of a word affects the speed with which it can be repeated. However, before we can conclude that imageability had a genuine effect on naming latencies, we need to determine that the differences were not due to other confounding variables in the materials.

Word Length Effects

Word length is known to affect response times to spoken words, and for this reason, we matched items in the HI and LI groups on number of syllables. However, since number of syllables is a coarse estimate of word length, we obtained a more accurate measure of word length by measuring word duration in milliseconds for each speech token. Pearson correlations between word length in milliseconds and the transformed repetition latencies showed that, over the total 92 stimuli, length and repetition time correlated significantly ($r = .223, p = .05$), showing that as word length (measured in milliseconds of duration) increased, so too did repetition latencies.

Independent variables for regression. A subsequent regression analysis included the variables examined in the repetition experiment, plus word length and onset type, a factor that affects the time taken for the energy level in the speech signal to trigger the voice key. The word length variable was duration in milliseconds, as described above. The onset variable was defined as the initial phoneme of each word, which was coded in terms of a 10-bit binary variable (Treiman, Mullennix, Bijeljac-Babic, & Richmond-Welty, 1995). Voiced onsets were coded as 1, and voiceless as 0. There were four dummy variables for manner of articulation (vowel vs. other, nasal vs. other, fricative vs. other, liquid or glide vs. other) and five dummy variables for place of articulation (velar vs. other, alveolar or palatal vs. other, bilabial vs. other, labiodental vs. other, and interdental vs. other). The chosen onset variables, although not exhaustive, were enough to fully describe our stimulus set.

Data preparation. To ensure that our independent variables were not intercorrelated, a preliminary Pearsons correlation matrix was constructed for the variables of length, familiarity, and imageability. No significant correlations were found. Following Tabachnick and Fidell (1989), we examined the distributions of the variables and applied transformations, as necessary, to reduce skew. Repetition latencies were inversely transformed. Two-way interaction terms were constructed for all continuous variables, and continuous variables were centered before we performed regression analyses (Aitken & West, 1991).[6] The regression analysis used backward stepwise regression.

Results of regression analyses. Table 2 shows that the regression model for repetition accounted for 65% of the data (adjusted r squared = .646, $p = .001$). Familiarity had only a marginal effect. Imageability and word length both had independent significant effects, and the interaction of word length and imageability combined to form a significant interaction term, with shorter words showing larger imageability effects. This was because short words consisted of a reasonably balanced mix of HI and LI words,

Table 2
Results of Backwards Stepwise Regression to Predict Repetition: Final Model

Variable	β	t	p
Imageability	0.993	−3.574	.001
Word length (msec)	3.254	−3.104	.003
Familiarity	0.115	−1.711	.091
Length × imageability	−3.333	3.134	.002
Voicing	*0.280*	*−3.625*	*.017*
Nasal	*0.158*	*−2.263*	*.026*
Fricative	*−0.449*	*5.714*	*.000*
Liquid/glide	*−0.246*	*3.567*	*.001*
Interdental	*−0.117*	*1.699*	*.093*

Note—Total percentage of variance accounted for = 65%. Onset variables are given in italics.

whereas long words tended to be mostly LI words. The onset variables that made a significant contribution were nasal, fricative, voicing, and glide.

The regression analysis shows that a purely semantic variable, such as imageability, can affect how quickly subjects repeat a spoken word, even when the contribution of speech-relevant variables, such as length and onset, is taken into account. We now consider the nature of the relationship between semantics and phonology.

Discriminability

Strain et al. (1995) have argued that imageability only affects naming latencies for written low-frequency exception words—that is, when the orthography-to-phonology mapping is unreliable. In such situations, semantics helps to resolve the mapping problem. Within the auditory system, imageability may similarly affect the mapping of an acoustic signal onto a phonological representation when perceptual discrimination is most difficult. Auditory discrimination and mapping is most unreliable or difficult when the target word shares its onset with many other words and a large cohort of words sharing initial onset is activated (Marslen-Wilson, 1990; Marslen-Wilson & Welsh, 1978). Words from large cohorts share their onset with many other words and so are less distinct, at onset, from their cohort competitors. A word from a small cohort has fewer onset-sharing competitors. Thus, words from large cohorts that experience greater competition from other members of the cohort may show a greater effect of imageability than do words from smaller cohorts.

We examined imageability effects on repetition with respect to word discriminability by considering the cohort structure of each word, using two measures of cohort structure: (1) cohort size, the number of words sharing an onset CV or VCV with a stimulus, and (2) the word frequency of each stimulus in relation to the total word frequency of its cohort members, given Luce, Pisoni, and Goldinger's (1990) suggestion that number of competitors per se is less important than the relative competition among competitors. Luce et al. used word frequency as an index of strength of competition, as we do here.

Words from the four imageability (HI/LI) × familiarity (high/low) conditions were divided in half according to cohort structure. Stimuli were assigned to the large cohort group if there were (1) many competitors within their cohort and (2) many of the cohort members were of higher frequency than the stimulus. Table 3 shows the mean values of each condition on each of the grouping variables; items classed as large cohorts have more cohort members and account for a smaller proportion of total cohort frequency than do those from small cohorts. Large cohorts are, therefore, those with more competitors and, also, with higher frequency competitors than small cohorts.

Reanalysis of repetition data. We reanalyzed the repetition experiment by performing separate analyses on the large and small cohort sets. The inversely transformed data were entered into ANOVAs, with imageability (HI/LI), and familiarity (high/low) as the main factors. Mean repetition RTs for abstract words from small and large cohorts were 384 and 391 msec, respectively, and 369 and 344 msec for concrete words from small and large cohorts. The pattern of results was in the predicted direction, with imageability having an effect only on words that were members of large cohorts. Words from large cohorts showed a significant effect of imageability [$F_1(1,15) = 26.863, p < .001$; $F_2(1,42) = 4.96, p < .039$], with repetition latencies to LI words being, on average, 47 msec slower than those to HI words. For the large cohorts, there was no effect of familiarity ($F_1 < 1$; $F_2 < 1$) and no interaction between imageability and familiarity ($F_1 < 1$; $F_2 < 1$). In contrast, there was no effect of imageability for words in small cohorts [$F_1(1,15) = 1.102, p = .302$;

Table 3
Mean Values of Independent Variables

Familiarity	Imageability	Cohort Size	N	Familiarity	Imageability	Cohort Size	% Cohort*
High	abstract	small	11	577	302	37	32.0
		large	11	578	325	298	12.0
	concrete	small	11	589	604	14	30.0
		large	11	587	596	257	7.0
Low	abstract	small	12	353	320	41	11.0
		large	12	353	309	261	0.2
	concrete	small	12	366	589	29	14.0
		large	12	382	599	214	0.2

*Percentage of total word frequency of all cohort members accounted for by the target word (e.g., the greater the percentage, the less competition).

$F_2 < 1$]; repetition latencies for LI words were only 15 msec slower than those for HI words. There was, however, a marginally significant effect of familiarity [$F_1(1,15) = 9.052, p = .009$; $F_2(1,42) = 2.826, p < .10$]. The interaction between imageability and familiarity was not significant ($F_1 < 1$; $F_2 < 1$).

GENERAL DISCUSSION

In this paper, we investigated the relationship between semantics and phonology, using two different tasks—LD and repetition—because of the limitations that have been voiced about each as a measure of lexical processing. We found very similar results for both repetition and LD. Both were affected by a word's familiarity and by its imageability, suggesting that, at least under some circumstances, they both tap into the activation of semantic representations. The most important finding for our present purposes was the imageability effect; repetition and LD latencies were faster as a function of a word's imageability. Moreover, we also established that the imageability effect could not be attributed to other factors that affect RTs in the repetition task, such as word length. We partialed out word length in a regression analysis and still found a robust imageability effect.

An obvious objection to the repetition task is that it reflects both input and output processes; thus, the imageability effect could arise from either the input–semantics mapping or the semantics–output phonology mapping. However, there are various aspects of the data that compellingly locate the imageability effects we have observed in the input–semantics mapping. First, we obtained an imageability effect in a task in which there was no output phonology—LD. Second, we did not find an across-the-board effect of imageability in repetition, but only when the input–semantics mapping was difficult—for words that have a large number of higher frequency competitors. Cohort variables, such as number and frequency of competitors, are factors that affect the ease with which a word can be discriminated from its cohort competitors and, thus, the rate at which the input can settle into a stable semantic pattern of activation. It is unlikely that cohort variables influence the semantics–output phonology mapping. This rules out the one way in which a modular system could account for imageability effects in repetition, by locating the effect between semantics and output phonology. The fact that a semantic variable, such as imageability, has an effect on the computation of phonology cannot be accounted for within a model that assumes strict separation between phonological and semantic levels, with the output of a phonological processor feeding into a semantic processor. These models require the computation of phonological form to be independent of any semantic effects (e.g., Forster, 1979).

How does the imageability of an item affect the ease with which it is processed? One recent suggestion by Plaut and Shallice (1993) is that the semantic representations of HI and LI words differ in terms of number of semantic features, with HI words having more features than LI words. In their computational model, representing HI words as patterns of activation over a larger set of semantic features than less imageable words, the *richer* semantic representations associated with HI words generated stronger basins of attraction in the network, so that the model settled into the corresponding states more rapidly. These attractors ensure that the mapping from input (orthography) to semantics is facilitated for HI words.

However, we also found that the imageability of a word influenced the rapidity of lexical processing only for words that were members of large cohorts with many highly frequent candidates, suggesting that difficult discriminations can be facilitated by semantics. This does not mean that the system treats HI and LI words differently. We believe that there is continuous interaction between phonology and semantics for all words, irrespective of imageability, but that semantic information has a larger role to play as the discrimination process becomes more difficult.

These results support interactive models in which there is parallel activation of multiple candidates initiated by the speech input. Parallel activation is required because of the effect of cohort structure on imageability. A variety of different kinds of interactive models are compatible with our results, ranging from hierarchically structured models with multiple levels in which there is continuous feedback and feedforward throughout the system (e.g., McClelland & Elman, 1986), as well as interactive models in which there is no hierarchical structure (e.g., Gaskell & Marslen-Wilson, 1995, 1997). Such interactive systems, in which various sources of processing information combine to produce an outcome, predict that anything that makes the phonology-to-semantics mapping more difficult will increase the system's reliance on semantics. A noisy input can make the mapping more difficult, as can an inability to process the speech input appropriately. The latter can be caused by brain damage, which sometimes causes quite specific deficits, affecting particular aspects of the language system. We have recently reported an aphasic patient (Tyler & Moss, 1997) suffering from a generalized auditory-processing deficit. This patient showed normal priming for spoken HI words but no priming for LI words, even though both types of words primed robustly in the visual modality. We have argued that the lack of priming for LI words in the auditory modality reflects the lower activation of the meaning of an abstract word, resulting in an inability to adequately compensate for an impoverished speech input. The input can also be difficult to process by an undamaged system if it is noisy. Within limits, semantics should be able to compensate for noisy input, providing more help to HI words. Thus, the recognition of HI words should be less affected by a noisy input than are LI words.

In summary, the results presented support the argument that the recognition of spoken words takes place within a highly interactive system in which semantics and phonology are in constant communication with each other.

REFERENCES

Aitken, L. S., & West, S. G. (1991). *Multiple regression: Testing and interpreting interaction*. Newbury Park, CA: Sage.

Balota, D., Ferraro, R., & Connor, L. (1991). On the early influence of meaning in word recognition: A review of the literature. In P. Schwanenflugel (Ed.), *The psychology of word meanings* (pp. 187-222). Hillsdale, NJ: Erlbaum.

Becker, C. A. (1980). Semantic context effects in visual word recognition: An analysis of semantic strategies. *Memory & Cognition*, **8**, 493-512.

Brown, G. D. A., & Watson, F. L. (1987). First in, first out: Word learning age and spoken word frequency as predictors of word familiarity and word naming latency. *Memory & Cognition*, **15**, 208-216.

Coltheart, M. (1981). The MRC psycholinguistic database. *Quarterly Journal of Experimental Psychology*, **33A**, 497-505.

deGroot, A. M. B. (1989). Representational aspects of word imageability and word frequency as assessed through word associations. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **15**, 824-845.

Forster, K. I. (1979). Levels of processing and the structure of the language processor. In W. E. Cooper & E. Walker (Eds.), *Sentence processing: Psychological studies presented to Merrill Garrett*. Hillsdale, NJ: Erlbaum.

Forster, K. I., & Forster, J. C. (1990). *The DMASTR display system for mental chronometry*. Tucson: University of Arizona Press.

Gaskell, G., & Marslen-Wilson, W. D. (1995). Modelling the perception of spoken words. In J. P. Moore & F. Lehman (Eds.), *Proceedings of the Seventeenth Annual Conference of the Cognitive Science Society*. Mahwah, NJ: Erlbaum.

Gaskell, G., & Marslen-Wilson, W. D. (1997). Integrating form and meaning: A distributed model of speech perception. *Language & Cognitive Processes*, **12**, 613-656.

Hofland, K., & Johansson, S. (1982). *Word frequencies in British and American English*. Harlow, U.K.: Longman.

Luce, P., Pisoni, D., & Goldinger, S. (1990). Similarity neighborhoods of spoken words. In G. A. Altmann (Ed.), *Cognitive models of speech processing: Psycholinguistic and computational perspectives* (pp. 122-147). Cambridge, MA: MIT Press.

Marslen-Wilson, W. D. (1990). Activation, competition and frequency in lexical access. In G. A. Altmann (Ed.), *Cognitive models of speech processing: Psycholinguistic and computational perspectives* (pp. 148-172). Cambridge, MA: MIT Press.

Marslen-Wilson, W. D., & Welsh, A. (1978). Processing interactions and lexical access during word recognition in continuous speech. *Cognitive Psychology*, **10**, 29-63.

McClelland, J., & Elman, J. (1986). The Trace model of speech perception. *Cognitive Psychology*, **18**, 1-86.

McLeod, P., & Posner, M. (1984). Privileged loops from percept to act. In H. Bouma & D. G. Bouhuis (Eds.), *Attention and performance X: Control of language processes* (pp. 55-66). Hillsdale, NJ: Erlbaum.

Mertus, J. (1989). *BLISS users manual*. Providence, RI: Brown University Press.

Paivio, A. (1986). *Mental representations: A dual coding approach*. New York: Oxford University Press, Clarendon Press.

Plaut, D., & Shallice, T. (1993). Deep dyslexia: A case study of connectionist neuropsychology. *Cognitive Neuropsychology*, **10**, 377-500.

Ratcliff, R. (1993). Methods for dealing with reaction time outliers. *Psychological Bulletin*, **114**, 510-532.

Seidenberg, M. S., Waters, G. S., Sanders, M., & Langer, P. (1984). Pre- and postlexical loci of contextual effects on word recognition. *Memory & Cognition*, **12**, 315-328.

Strain, E., Patterson, K. E., & Seidenberg, M. (1995). Semantic effects in single word naming. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **21**, 1140-1154.

Tabachnick, B. G., & Fidell, L. S. (1989). *Using multivariate statistics* (2nd ed.). New York: Harper & Row.

Treiman, R., Mullennix, J., Bijeljac-Babic, R., & Richmond-Welty, E. D. (1995). The special role of rimes in the description, use and acquisition of English orthography. *Journal of Experimental Psychology: General*, **124**, 107-136.

Tyler, L. K., & Moss, H. E. (1997). Imageability and category-specific effects. *Cognitive Neuropsychology*, **14**, 293-318.

Ulrich, R., & Miller, J. (1994). Effects of truncation on reaction-time analysis. *Journal of Experimental Psychology: General*, **123**, 34-80.

NOTES

1. We use the terms *imageability* and *concreteness* interchangeably here.

2. It is possible, in principle, for both tasks to yield the same results for different reasons.

3. An initial analysis, comparing nonword and real-word RTs for each subject, showed a significant effect of word type, so that RTs to nonwords were significantly slower to all words except the low-familiarity abstract words [$F(1,4) = 6.94, p < .001$].

4. Two subjects with mean RTs of 195 and 236 msec produced substantially more errors than did the remaining subjects. Their error rates were 5% and 9%, respectively, whereas the errors for the other subjects ranged from 0% to 3.2%.

5. We calculated a mean real-word repetition latency for each subject and compared this with their mean nonword latency. Twelve out of 16 subjects showed overall faster repetition latencies for real words, suggesting that they were not initiating the naming response before semantic information started to be activated. The data from these 12 subjects were also analyzed separately. These data showed the same pattern of results as the total group of 16 subjects.

6. We thank Eamon Strain for his invaluable help with the data analyses.

(Continued on next page)

APPENDIX
Experimental Stimuli

Imageability	High Familiarity	Low Familiarity
Low	fact	creed
	guilt	realm
	length	woe
	luck	zeal
	part	accord
	sense	array
	side	carnage
	term	clamour
	thing	debut
	thought	despot
	truth	discord
	content	dogma
	effort	essence
	interest	figment
	knowledge	folly
	method	forfeit
	moment	hybrid
	purpose	malice
	reason	prelude
	system	saga
	trouble	sequel
	value	suffrage
		tally
		veto
High	blood	brook
	film	crypt
	glass	flask
	land	hive
	milk	keg
	page	ox
	street	scroll
	thumb	vine
	tooth	wren
	truck	adder
	apple	bandit
	brother	banner
	doctor	damsel
	mountain	furnace
	oven	glacier
	pocket	goblet
	river	mackerel
	shoulder	mallet
	sister	otter
	table	prairie
	vodka	saloon
	woman	sapphire
		satchel
		trapeze

(Manuscript received October 13, 1998;
revision accepted for publication August 27, 1999.)