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Activating meaning in time: The role of imageability and form-class

Lorraine K. Tyler, Helen E. Moss, Adam Galpin, and J. Kate Voice

Centre for Speech and Language, Department of Experimental Psychology, University of Cambridge, Cambridge, UK

A number of studies have shown that the meanings of spoken words are activated early in processing, well before all of the word has been heard. However, these studies have not explicitly taken into account a number of variables which are known to affect word recognition processes. Two important variables are a word's imageability and its form-class. In the experiments reported here we use a cross-modal priming task to investigate the role that these variables play on the time-course with which word meanings are activated. We present visual target words for lexical decision at different points through the duration of spoken primes. In one study the spoken primes were either abstract or concrete words, and in a second they were either nouns or verbs. We found significant priming for all types of words early in the duration of a spoken prime. We discuss these results in terms of various models of semantic activation, concluding that distributed models provide the best fit to the data.

INTRODUCTION

In the process of comprehending spoken language, listeners activate both the phonology and meaning of the words they hear. Both types of information are activated early in the recognition process, well before the entire word has been heard (Marslen-Wilson, 1987). The initial evidence

Requests for reprints should be addressed to Lorraine K. Tyler, Centre for Speech and Language, Department of Experimental Psychology, University of Cambridge, Downing Street, Cambridge CB2 3EB. Email: lktyler@csl.psychol.cam.ac.uk

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for the early activation of meaning came from shadowing studies by Marslen-Wilson (1973, 1985) and word monitoring studies by Marslen-Wilson and Tyler (1975, 1980). Marslen-Wilson and Tyler (1980) for example, found that words were recognised faster when they occurred in meaningful rather than anomalous sentences. By relating word monitoring latencies to the total duration of target words, they established that a spoken word can be recognised in context after only an average of 270 ms of the word has been heard, compared to 360 ms when the target occurred without a semantically coherent context. Assuming 50–75 ms for response execution, this implies that the meaning of the target must be activated within 200 ms of word onset in order for sentential context to influence its processing during this period. This general point was subsequently supported by gating (Tyler & Wessels, 1983, 1985) and cross-modal priming studies (Marslen-Wilson, 1987; Moss, McCormick & Tyler, 1997; Zwitserlood, 1989).

Some of the most direct evidence for the early activation of word meaning comes from the cross-modal priming studies of Marslen-Wilson (1987) and Zwitserlood (1989). In Marslen-Wilson's (1987) study, participants listened to spoken primes that were either complete words (*captain*) or fragments of words that were cut off at a point when they were compatible with at least two different cohort competitors—i.e., words sharing the same onset (e.g., /*cap* ... /: *captain, captive*). When probe words, semantically related to one or other of these competitors (e.g., *boat* or *guard*), were presented at the offset of the fragment, both were significantly primed in a lexical decision task. This suggests that the semantic representations of both competitors were activated at that point. When the same probe words were presented at the offset of the whole word (e.g., *captain*), however, only the probe related in meaning to *captain* (*boat*) was primed. This pattern suggested that early in the duration of a word, the semantic representations of multiple competitors are activated and as more of the word is heard, the meaning of those that mismatch decays rapidly. This finding was extended by Zwitserlood (1989) in a cross-modal study examining the influence of context on the processing of words. She found that multiple candidates were activated after only 130 ms of the prime word had been presented, even when the prime was heard in a sentential context that made one of the cohort competitors more plausible than the others.

The early activation of word meanings is important for two reasons. First, if semantic information is available early, then it may influence the outcome of the recognition process. The issue here revolves around the questions of whether the process of word recognition is modular in structure, with the processing of the form of a word being totally independent of its meaning. Modular accounts assume that there is an independent initial phase in which the input (speech or text) is mapped onto a level of form representation. This process must be completed before the meaning can be accessed; the meaning of a word cannot affect the computation of its form-based representation (Becker, 1980; Forster, 1979). For example, in Forster's (1979) model, the input is first analysed, then passed to a peripheral access file enabling the form of the word to be accessed from a central "master" file, and finally the word's meaning is contracted on the basis of its form representation. This model, where meaning cannot affect the computation of lexical form, predicts a delay between the activation of orthographic/phonological information and semantic information. This claim becomes less plausible to the extent that semantic information is activated early and is thus available to the system.

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, we can extrapolate from existing models, which account for part of the recognition process. In TRACE, for example, the input is initially mapped onto a featural level of representation, then a phoneme level and finally onto a word level (McClelland & Elman, 1986), with feedforward and feedback interaction between levels. Extending this model beyond the word-form level to semantics, and assuming the same structure, semantic information would feed back to the word-form and thence to the phoneme level. In this framework there is no built-in delay between the activation of form-based and semantic information, and the earlier that semantic information becomes available, the greater an influence it will be able to exert on the word recognition process via feedback to lower levels in the system.

Similarly, distributed connectionist models of word recognition, such as that of Gaskell and Marslen-Wilson (1995, 1997), also predict an interaction between semantics and phonology, and thus accommodate the early activation of semantics. In the Gaskell and Marslen-Wilson model, a low-level representation of the speech input is mapped directly onto distributed representations of both the semantics and the phonology of words. This requires the connection weights in the network to encode information about both mappings (input to phonology and input to semantics), implying that the retrieval of the two types of knowledge interact, despite the bottom-up nature of the processing (Norris, 1990). On this model, there should be no delay, in principle, between the activation of form-based and semantic information. However, in practice, the degree to which the network can rapidly settle on the representations of multiple meanings early in the duration of a word will be influenced by the number of competitor meanings consistent with the input at a given time. Because all the meanings are represented as patterns of activation over the same set of units, there is a limit to how many can be captured with any degree of accuracy within the network space.

The extent to which word meaning is activated early is also important because it provides a mechanism for the way in which words and sentences are integrated. We know that words are recognised earlier when they are in meaningful sentence contexts (Marslen-Wilson & Tyler, 1980; Stanovich & West, 1983; Tyler & Wessels, 1983, 1985; Zwitserlood, 1989). For example, both gating and word monitoring studies have shown that words in meaningful contexts can be successfully recognised approximately 100 ms earlier than when they occur in isolation. Thus, the first one or two phonemes are sufficient for accurate identification when words are heard in sentences. For context to influence word recognition in this way, activated lexical semantic information must be evaluated against the meaning of the sentence, in order to determine whether the word is contextually coherent. If word meanings are not activated early, it is difficult to account for the finding that context enables a word to be recognised after only its first one or two phonemes have been heard. Late activation of word meaning would not have the effect of changing the amount of sensory input required for correct recognition; it would only allow contextual effects to take place after the word had been identified on the basis of the sensory input (e.g., Tanenhaus & Lucas, 1987).

In spite of the theoretical significance of the early activation of word meaning, it has only been empirically established in a small number of studies and for a subset of words—namely, concrete nouns.[1] However, these are not representative of the entire set of words in the language, which includes different form-classes (e.g., nouns, verbs, adjectives) and which varies along semantic dimensions such as imageability or concreteness. Concrete nouns may be a special case, with their meanings being activated more rapidly than other kinds of words, for reasons to be discussed in the following sections. To provide a more comprehensive account of the activation of word meanings we need to determine whether the finding of early semantic activation generalises to other types of words and does not just hold for concrete nouns. In the present research, we address this issue by probing for the early activation of meaning for high and low imageability words, and for nouns and verbs.

[1] The study by Moss, McCormick, & Tyler (1997) used only concrete nouns, so that perceptually and functionally based semantic properties could be contrasted. The studies by Marslen-Wilson and Zwitserlood do not specify whether the stimuli were limited to concrete nouns, but the examples given are of this type and it is likely that this was also the case for the majority of items, at least.

Nouns and verbs

There are many reasons for assuming that the semantic representations of nouns and verbs differ. First, the acquisition profiles of verbs and nouns are different, with nouns being acquired earlier than verbs (Gentner, 1982, 1981; Gleitman, 1994; Goldin-Meadow, Geligman, & Gelman, 1976; Nelson, 1973). This effect has been accounted for in various ways. Gentner (1981) for example, has proposed that nominal categories are more natural than verbal ones, whereas Miller & Johnson-Laird (1976) argue that the semantic organisation of verbs is more complex than that of nouns. The general idea is that a more basic or simple concepts (usually nouns) will be acquired earlier than more complex concepts (usually verbs). These differences in acquisition continue to be apparent into adulthood with research generally showing poorer performance in adults for verbs than nouns on a range of measures; for example, adults find verbs harder to remember than nouns (Gentner, 1981; Horowitz & Prytulak, 1969; Reynolds & Flagg, 1976). Such memory differences may reflect variation in the semantic flexibility of verbs and nouns. Because verbs are more polysemous than nouns (Gentner, 1981; Miller & Fellbaum, 1991) they may be more difficult to integrate into a specific context, leading to less stable memory and poorer recall. Finally, verbs and nouns have been shown to dissociate following brain damage, with some patients having more problems with verbs than nouns, and others showing the reverse pattern (Caramazza & Hillis, 1991; Miceli, Silveri, Villa, & Caramazza, 1984; Zingeser & Berndt, 1990). This suggests that the content and structure of the mental representations on verbs and nouns differ in important respects, allowing them to be selectively impaired by damage to the system.

Various proposals have been put forward to account for these differences between verbs and nouns, the main focus being on differences in their organisation and structure. For example, Miller and Fellbaum (1991) have claimed that the types of relations that hold between nouns (hyponymy, merenymy) do not hold between verbs; Collins and Quillian (1969) and Keil (1979) have argued that the structure of verb and noun concepts differ, with noun concepts being hierarchically organised and verb concepts having a matrix organisation (Huttenlocher & Lui, 1979; Grasesser, Hopkinson, & Schmid, 1987).

One of the most well-developed accounts of verb/noun differences was proposed by Gentner (1981). She contrasted internal links between properties comprising a concept, with external links between the concept and the context. She argued that the representations of nouns are internally denser than those of verbs in that they have more links among properties, whereas verbs have fewer internal links and more external links than nouns. Thus, she claims that verbs have a more flexible and less invariant meaning than nouns (more polysemy) and greater potential to interact with context.

Imageability

The imageability[2] 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). Many studies have shown an advantage for concrete over abstract words, in tasks ranging from lexical decision (Bleasdale, 1987; de Groot, 1989; Rubenstein, Garfield, & Millikan, 1970; Schwanenflugel, Harnishfeger, & Stowe, 1988) to sentence verification (Belmore, Yates, Bellack, Jones, & Rosenquist, 1982; Holmes & Langford, 1976; Jorgensen & Kintsch, 1973) and sentence comprehension (Haberlandt & Graesser, 1985). A less consistent pattern has been obtained with word naming, with some studies showing a clear advantage for concrete words (Schwanenflugel & Stowe, 1989; Strain, Patterson, & Seidenberg, 1995; Tyler, Voice, & Moss, 1996, 2000), others showing only a small advantage (Bleasdale, 1987; Rubin 1980)) and still other studies finding no difference (Brown & Watson, 1987; Coltheart, Laxton, & Keating, 1988; McFalls, Schwanenflugel, & Stahl, 1996; Richardson, 1976). The distinction between abstract and concrete words is supported by neuropsychological dissociations. There are a number of patients showing a selective impairment for abstract words with concrete words remaining unimpaired (Franklin, 1989; Franklin, Hoard, & Patterson, 1994) and some (although fewer) reports of the opposite pattern (Breedin, Saffran, & Coslett, 1994; Warrington & Shallice, 1984; but see Plaut & Shallice, 1993; Tyler & Moss, 1997 for an alternate account).

Of the various attempts to account for the differences between abstract and concrete concepts, probably the best-known is Paivio's dual coding hypothesis (1971, 1986). According to this account, abstract and concrete words are differently encoded in memory, with concrete words having both a verbal and image representation and abstract words having only a verbal representation. Although each system is functionally distinct, there is some connectivity between them in that the activation of a representation in one system can activate the corresponding representation in the other. Because the two representational systems are linked together and can be co-activated, concrete words have an advantage due to the mutual activation of their dual representations.

An alternative account is that concrete words have more semantic properties, without assuming that these are necessarily represented in

[2] We use imageability and concreteness interchangeably here.

separate verbal and image-based systems. Jones (1985) demonstrated that people are able to generate significantly greater numbers of predicates for concrete than abstract words. Similarly, de Groot (1989) found that people were able to produce more associates for a concrete word in a continuous free-association task. These results indicate that there may be more information associated with concrete than abstract words in semantic memory. More recently, this assumption has been instantiated in a connectionist model designed to account for the effects of abstractness and on the reading performance of patients with deep dyslexia (Plaut & Shallice, 1993). In this model, concrete words are represented over a greater number of microfeatures than are abstract words, and the activation of those features is also more consistent over different presentations of the word. This enables concrete words to form more effective "basins of attraction" within the network, and so leads to an advantage for these words when the system is damaged (and also provides a basis for the concrete word advantage in the normal system).

Finally, a third approach emphasises the context-availability of the information associated with concrete and abstract words, rather than simply amount of information. The central claim is that contextual information is essential for the complete understanding of word meanings. If less contextual information exists for abstract words, or it is harder to retrieve for any reason, this will make them more difficult to process (Kieras, 1978; Schwanenflugel & Shoben, 1983). This account predicts that the advantage for concrete over abstract words will be diminished when additional contextual support is provided for abstract words, as has been confirmed by studies of lexical decision (Schwanenflugel et al., 1988) and sentence comprehension (Schwanenflugel & Shoben, 1983). Direct support for the context-availability account comes from studies showing that people find it more difficult to think of a context in which to use an abstract word than a concrete word. A possible basis for the lower context-availability of information about abstract words is that the latter tend to occur over a wider range of different contexts, at least according to subjects' ratings (Schwanenflugel & Shoben, 1983). In a spreading activation model of semantic memory, the greater the amount of information that is connected to a concept, the more difficult it is to retrieve any one piece of information, as a result of the "fan effect" (Anderson, 1983; Schwanenflugel & Shoben, 1983). Schwanenflugel and Shoben propose that abstract words contain a large number of context-dependent properties, whole concrete words have more context-independent properties (cf. Barsalou, 1982). This context-independent information is easy to access even when the word occurs in isolation and means that concrete words have more consistent, stable core meanings (see also Saffran, Boyo, Schwartz, & Martin, 1980).

Word class, imageability and the time course of semantic activation

Although none of the models developed to account for imageability and word class effects explicitly assess the implications for the time-course of activation of word meanings, we can consider how they could be interpreted with respect to this issue. At the most general level, all of the models imbue nouns with a processing advantage over verbs, and concrete words with a processing advantage over abstract words. If this is the case, it is possible that the evidence for the earliness of semantic activation, and therefore the potential for semantic information to influence word recognition and contextual integration, has been overestimated, because earlier studies have focused largely on concrete nouns. The activation of semantic representations for words with more abstract meanings and from different form classes may take considerably longer. We consider the details of these assumptions within different activation models in the General Discussion.

The current research

In this paper we report a set of behavioural studies designed to probe the time-course of semantic activation of concrete and abstract words, and nouns and verbs. We used a cross-modal priming paradigm in which a visual target is presented for lexical decision at three different time points after the onset of a spoken prime. The first was the isolation point (IP) of the prime. The IP is the earliest point at which a word starts to be reliably recognised (Marslen-Wilson, 1987). It can be operationally defined by means of the gating task (Grosjean, 1980; Tyler & Wessels, 1983, 1985), in which participants are presented with ever-increasing durations of a spoken word (e.g., */ka/*, */kap/*, */kapt/*, */kapti/*) and asked to indicate what word they think they are hearing after each fragment. The IP is taken as the point at which they start to reliably recognise the word and do not subsequently change their minds.[3] The second point at which

[3] In some studies the Isolation Point (IP) of a word has been distinguished operationally from its Recognition Point (RP). The RP in a gating task is similar to the IP, except that in addition to correctly identifying the word without subsequent incorrect responses, participants must also indicate that they are confident of their response, with mean confidence ratings exceeding some pre-set criterion (usually 8/10). We have used the IP rather than RP in this experiment because it corresponds to a point slightly earlier in the word recognition process, at which participants have identified the word, but not necessarily with a high degree of certainty, because in some cases there may still be one or two other candidates consistent with the sensory input. Since we are interested in tracking the early activation of semantic information during word recognition, the earlier reference point is the more appropriate of the two.

visual targets were presented was at the offset of the spoken prime, thereby allowing on average 280 ms longer to process the primes compared to the IP probe point. The third point at which visual targets were presented was after a 250 ms delay after the offset of the spoken prime.

Two independent sets of studies were run to investigate the effects of imageability and form-class on the time-course of semantic activation. It was necessary to investigate form-class and imageability separately due to the difficulty of finding a single set of stimuli which could be matched on all the relevant variables, yet leaving sufficient number of items in each of the categories. The fact that some words have more than one meaning belonging to both noun and verb form-classes (i.e., *a walk/to walk*) placed considerable constraints on stimuli selection. Thus we decided to conduct two separate sets of studies, one set in which we manipulated imageability, contrasting high and low imageability words and controlling for form-class, and a second set investigating form-class, by contrasting unambiguous nouns and unambiguous verbs while controlling for imageability.

For each of the two sets of studies, three experiments were run to investigate semantic activation at each of the three different times of target presentation; at the isolation point of the spoken prime (IP), at the offset of the spoken prime, and after a 250 ms delay from the onset of the spoken prime. In each set of studies exactly the same materials and design were used, only the presentation point of the visual probe varied.

EXPERIMENT 1: IMAGEABILITY

The aim of this study was to determine when the semantic representations of abstract and concrete words are activated in the processing of a spoken word.

Method

Materials and design. We initially selected abstract and concrete prime-target pairs according to the following constraints: concrete words had a concreteness rating greater than 420, and abstract words had a concreteness rating less than 390 on a scale of 100 (most abstract) to 700 (most concrete; Coltheart, 1981). These word-pairs were also selected to be high in semantic relatedness, low in forward and backward association (Moss & Older, 1996), orthographically regular, morphologically simple or very opaque,[4] and if they were homophones then they were the higher frequency meaning of homophonic possibilities.

Semantic relatedness pre-test. To ensure that the word-pairs were highly semantically related we subjected them to a pre-test to empirically establish degree of semantic relatedness. The pre-test consisted of 252 test pairs as well as filler items, which were made up of 50 semantically related category coordinate pairs (e.g., *cup-saucer*) and 150 semantically unrelated word-pairs. These 452 pairs were randomly ordered and split into two separate booklets each containing 226 pairs. Seventeen participants from the Centre for Speech and Language (CSL) participant pool rated each potential pair on a scale of 1 (not related) to 9 (very strongly related). The mean rating value for each pair constituted its semantic relatedness score. We rejected any pair with a semantic relatedness score of less than 5.

We then selected 80 semantically related word pairs—40 concrete word pairs, and 40 abstract word pairs—in which both prime and target were matched for familiarity (as given in the MRC database or determined by rating studies carried out at the CSL),[5] word length (in number of letters) and number of syllables (see Table 1). The mean semantic relatedness ratings for the final set of items is also given in Table 1. *T*-tests carried out to see if there were any statistical differences in the semantic relatedness for the concrete and abstract words found no significant differences, $t(\mathrm{df} = 78) = 0.572, p > .1$.

To control for form-class there were an equal number of noun and verb pairs in each imageability condition. Thus, within both the concrete and abstract word conditions there were 20 noun pairs and 20 verb pairs. As some words contain a meaning that can fall into both noun class and verb class (e.g., a dream/ to dream), the most frequent use of the word (taken from the CELEX database; Baayen, Pipenbrook, & Guilikers, 1995) as used to assign them to either form class. The noun and verb sets within each imageability condition were matched on prime and target familiarity, number of letters, and number of syllables.

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[4] By morphologically opaque we mean that the meaning of the whole word cannot straightforwardly be derived from the meanings of the components (e.g., delight). We chose morphologically simple or opaque words because we can assume that there is a semantic representation corresponding to the whole word in these cases. For morphologically transparent words, it is possible that the meaning is represented separately for stems and affixes (e.g., re+build) and that this will interact with the time course of activation of the component semantic elements (Marslen-Wilson, Tyler, Waksler, & Older, 1994).

[5] We used familiarity rather than frequency because this has been claimed to be a more robust estimate of how well-known a word is (Gernsbacher, 1984).

TABLE 1
Experiment 1: Statistics for the abstract and concrete word stimuli

	Imageability			
	Concrete		*Abstract*	
	Prime Mean/SD	*Target Mean/SD*	*Prime Mean/SD*	*Target Mean/SD*
Semantic relatedness		7.1/0.7		6.9/0.7
Concreteness	531/65	544/70	294/53	295/58
Imageability	553/44	545/48	346/70	363/54
Familiarity	505/52	510/56	532/70	536/43
Number of letters	4.9/1.1	5/1.3	5.1/1.2	5.1/1.3
Number of syllables	1.3/0.5	1.3/0.5	1.6/0.6	1.5/0.5

	Imageability			
	Concrete primes		*Abstract primes*	
	Mean	*SD*	*Mean*	*SD*
Word duration (ms)	647	98	639	101
Duration to IP (ms)	400	104	373	97
Duration post IP (ms)	247	80	265	97

We also ensured that the word pairs were not strongly associated in either forward or backward direction. This was to ensure that any facilitation from prime to target was based on the semantic relation between them and not a possible separate mechanism of associative priming based on frequent co-occurrence of words (Moss, Day, Hare, & Tyler, 1994; Moss, Ostrin, Tyler, & Marslen-Wilson, 1995). Association strength was measured according to free association norms (Moss & Older, 1996) and was .028 (forwards) and .047 (backwards) for the concrete word-pairs and .052 (forwards) and .054 (backwards) for the abstract word-pairs.

Every test prime was assigned a semantically unrelated control prime to act as a lexical decision baseline against which to measure priming. Control primes were obtained by pseudo-randomly rotating the test primes around the targets, thus the related primes in one version served as control primes in the second version. This method ensures that the control primes were matched to test primes in terms of concreteness, imageability, familiarity, syllable number, and letter length. We also ensured that the control words were semantically and phonologically unrelated to the target words. We ran a second semantic relatedness test to ensure that the control prime-target pairs were equally unrelated in both abstract and concrete conditions. The test consisted of all 80 unrelated word-pairs together with an equal number of related word-pairs. Fifteen participants rated each word-pair on a scale of 1 (not related) to 9 (very strongly related). The mean semantic relatedness scores for the control prime-target abstract words was 2.1 (SD = 0.6), and 1.3 (SD = 0.6) for the concrete pairs. Thus, the test confirmed that the unrelated pairs were indeed semantically unrelated.

Gating pre-test to determine IPs. The 80 primes were included in a gating study in order to establish their isolation points. This set of words was split into 4 shorter sets, each of 20 words, in order to reduce the gating study to a manageable size for participants. Each of these sets contained 5 concrete nouns, 5 abstract nouns, 5 concrete verbs and 5 abstract verbs. Since gating responses to a word may be influenced by the previously gated word, we generated two different randomisations of each 20-item set. Paid participants from the Centre of Speech and Language participant pool attended two hour-long sessions and completed two sets of 20 items. Every word was contemplated by at least 10 participants.

The spoken prime words were recorded as complete words, and for each one we played out the first 100 ms of the word, increasing word duration by 50 ms on each subsequent trial until the complete word had been heard. On each trial, participants were given 5 seconds to write down what they thought the word was. The Isolation Point was defined as the average gate duration at which a word was first correctly identified. A word was deemed to have been correctly identified when a participant had written the correct word and had not deviated from that response on subsequent trials. The mean Isolation Points of the primes, measured in milliseconds from word onset, were 400 ms (SD = 104 ms) for the concrete words and 373 ms (SD = 97 ms) for the abstract words.

To reduce the proportion of related word pairs within each experiment, thus minimising the opportunity for participants to notice the semantic relations between primes and targets and adopt response strategies on the basis of post-lexical semantic matching (Neely, 1991), we included 38 semantically unrelated and non-associated word–word filler pairs and 118 word–non-word filler pairs. This also meant that 50% of trials had word targets and 50% had non-word targets, ensuring that there should be an equal number of yes and no responses in the lexical decision task. Half of the filler pairs had noun primes and half had verb primes. Fillers were selected to have a concreteness rating in the mid-range (filler nouns = 426; filler verbs = 352). The same filler pairs were used in the two versions of the experiment. Within each version, 17% of the trials involved related word-pairs.

Thirty practice pairs were constructed. Half the practice pairs were word–word pairs and half were word–non-word pairs. Of the word–word pairs 26% (4/15) were semantically related.

Since each target was paired with both a test prime and a control prime, we constructed two versions of the experiment to avoid the repetition of target items within the same testing session. The test items in each condition were divided equally between the two versions such that half the targets of any condition appeared in version A with their related test prime and in version B with their unrelated control prime, while the other half appeared with the control prime in version A and the test prime in version B. This division of conditions ensured that the two versions were matched in terms of mean semantic relatedness, association strength, target word familiarity, target concreteness and target word length (number of letters and syllables). Filler and practice item pairs were exactly the same for both versions.

Randomisation of each version was performed on 9 blocks of 24 items and 1 block of 20 items. This blocking of item pairs before randomisation ensured that all conditions of the experiment were evenly spread throughout the filler items.

Procedure. All materials were recorded in a sound-attenuated booth by a female British English speaker. The speech was digitised onto computer hard disc at a sampling rate of 22 kHz. The experiment was run using DMASTER/VMASTER (Forster & Forster, 1990) software, which played out the speech tokens directly from their stored wave forms, and recorded participants' responses.

Participants in each of the studies were tested in groups of up to four at a time, seated in individual carrels. On each trial participants were first presented with a spoken word over headphones and then a visual target word appeared on the screen in front of them. In one study, the target appeared for 200 ms immediately at the offset of the fragment corresponding to the duration of the spoken word up to its Isolation Point.[6] In the second study, the visual target appeared at the acoustic offset of the prime. In the third study, the visual target appeared after a 250 ms delay after the offset of the spoken prime. Participants made a lexical decision response to the target. Responses were timed from the onset of the visual target and had to be made within 2 s before the computer timed out and moved on to the next trial.

Participants. Twenty-five participants were tested in the first study (IP), 33[7] in the second study (Offset), and 33 in the third study (Delay). All subjects were taken from the Centre for Speech and Language's

[6] Primes were cut off at the IP rather than continuing so that participants could not take in any additional information after presentation of the target.

[7] We initially tested 45 subjects in this study. In order to make the numbers comparable in each study, we randomly omitted 12 subjects from the analysis. All of the reported analyses were carried out with these 12 subjects removed. However, we also analysed the data including these 12 subjects, and the pattern was consistent across analyses.

participant pool and were paid for their efforts. No subject participated in more than one study, and none had participated in the gating pre-test.

Results and discussion

Six subjects were removed because they incurred a large number of errors ($> 18\%$). This resulted in the removal of three subjects from the offset experiment, and three subjects from the delay experiment. No subjects needed to be removed from the IP experiment. The data were entered into a 4-way by-items and by-participants analysis of variance (ANOVA). The variables were presentation point (IP, Offset, Delay), imageability (concrete, abstract), version (A, B), and prime type (test, control).

A significant overall priming effect was found in both the by-subjects analysis, $F_1(1, 79) = 45.524$, MSe $= 601.013, p < .001$, and the by-items analysis, $F_2(1, 76) = 31.127$, MSe $= 1437.250, p < .001$, with faster RTs to targets following related (508 ms) compared to unrelated (527 ms) primes. There was also a significant interaction between priming and imageability, $F_1(1, 79) = 9.446$, MSe $= 539.217$, $p = .003$; $F_2(1, 76) = 4.833$, MSe $= 1437.250, p < .031$, due to more priming for concrete (27 ms) compared to abstract (12 ms) words, and no interaction with presentation point (presentation point $\times$ priming $\times$ imageability: F_1 and $F_2 < 1$). There was no effect of version.

Separate analyses carried out on the concrete words showed significant priming, $F_1(1, 79) = 44.695$, MSe $= 627.198, p < .001$; $F_2(1, 38) = 31.725$, MSe $= 1216.811, p < .001$ which did not vary across presentation points, $F_1(2, 79) = 0.949$, MSe $= 627.198, p > .05$; $F_2(2, 76) = 1.139$, MSe $= 886.115$,

TABLE 2
Experiment 1: Reaction times (ms) and error rates (%) at the three presentation points

		Word type					
		Concrete			*Abstract*		
Presentation point		*Test*	*Control*	*Difference*	*Test*	*Control*	*Difference*
IP	RT mean	527	546	19	521	534	14
	RT SD	52	58		49	59	
	Error %	3.60%	9.00%	5.40%	4.00%	7.40%	3.40%
Offset	RT mean	489	519	30	501	512	10
	RT SD	46	44		35	55	
	Error %	2.50%	8.00%	5.50%	5.50%	6.83%	1.33%
Delay	RT mean	505	537	32	504	515	11
	RT SD	38	61		39	58	
	Error %	3.67%	5.00%	1.33%	5.00%	5.17%	0.17%

$p > .05$. Similar analyses carried out on the abstract words also showed significant priming, $F_1(1,79) = 8.619$, MSe $= 513.032, p = .004$; $F_2(1,38) = 4.995$, MSe $= 1657.689, p = .032$, which did not vary across presentation points (F_1 and $F_2 < 1$). Finally, we carried out an analysis to determine whether priming was affected by the duration of the prime word up to IP, since the mean duration of the prime to IP was slightly shorter for the abstract words compared to the concrete words (see Table 2). We found no significant correlations between fragment duration to IP and priming at the IP ($r = -.188, p > .05$), offset ($r = .071, p > .05$), or at the delay position ($r = .007, p = .05$). Furthermore, when the analysis of variance was repeated for each presentation point with duration of prime word up to IP added as a covariate (ANCOVA), we found no effect of the covariate.[8]

Lexical decision error rates were calculated for each item and analysed, after arcsine transformation (Winer, 1971), with ANOVA in the same way as the reaction time by-items data. There was a significant main effect of priming on error rates, $F_2(1,76) = 19.028$, MSe $= 0.005229, p < .001$ due to larger numbers of LD errors to targets in the control conditions (6.8%) compared to test conditions (4.06%) and no interaction of concreteness and priming, $F_2(1,76) = 3.436$, MSe $= 0.0052296, p < .05$. There was a significant priming × presentation point interaction, $F_2(2,152) = 3.831$, MSe $= 0.003717, p < .024$, reflecting the fact that there was a significant "priming effect" (i.e., a larger number of errors in the control compared to test conditions) at IP, $F_2(1,76) = 15.290$, MSe $= 0.005101, p < .001$ and offset, $F_2(1,76) = 11.041$, MSe $= 0.004310, p < .01$, but not at the delay presentation point ($F_2 < 1$).

We carried out three additional analyses to determine whether priming was affected by (a) variations in association strength between items within

[8] As mentioned earlier, 12 subjects were removed from the offset analysis in order to make the number of subjects comparable across the three presentation points. We carried out an analysis including these 12 subjects to see whether their inclusion affected the results, and found exactly the same pattern as for the analysis in which they were excluded. We obtained significant priming in both the by-subjects analysis, $F_1(1,91) = 54.517$, MSe $= 636.753, p < .001$ and the by-items analysis, $F_2(1,76) = 36.671$, MSe $= 1296.438, p < .001$ with faster RTs to targets following related (508 ms) compared to unrelated (528 ms) primes. A significant interaction was found between priming and imageability, $F_1(1,91) = 12.753$, MSe $= 539.575$, $p = .001$; $F_2(1,76) = 5.819$, MSe $= 1296.438, p = .018$, but there was no interaction between priming and presentation point (F_1 and $F_2 < 1$). Further, secondary analyses of the concrete words in isolation again found significant priming, $F_1(1,91) = 56.726$, MSe $= 639.086$, $p < .001$; $F_2(1,38) = 39.279$, MSe $= 1183.364, p < .001$, and no interaction with presentation point, $F_1(2,91) = 1.303$, MSe $= 639.086, p > .1$; $F_2 < 1$. The same pattern of results was obtained for the abstract words, with a significant priming effect, $F_2(1,91) = 9.943$, MSe $= 537.241, p = .002$; $F_2(1,38) = 6.104$, MSe $= 1409.511, p = .018$ that did not interact with presentation point (F_1 and $F_2 < 1$).

a word-pair, and (b) mediated association effects, or (c) strategic effects. An analysis to determine whether the association strength of each word-pair correlated with the amount of priming, showed no significant relation between forwards or backwards association strength and amount of priming at any of the three presentation points (all $p > .05$).[9] An analysis to investigate any potential effects of mediated association (McNamara, 1988) also showed no significant effects (all $p > .05$).[10] Finally, we carried out a correlational analysis to determine whether subjects were using strategies to develop expectations about the relationship between primes and targets. If this were the case, we would expect priming effects to increase through the duration of the test list as strategies are increasingly developed and employed. However, there was no correlation between the position of each word-pair in the experimental list, and the size of priming effects.[11]

These results show priming effects for both abstract and concrete words at all three presentation points. The amount of priming did not vary significantly across presentation point. Even when listeners only heard a fragment of the spoken prime, up to the Isolation Point, this was enough information for the meaning of a word to be sufficiently activated to produce semantic priming, irrespective of its imageability. Giving participants the additional speech input and processing time from IP until the offset of the prime, or even later in the delay condition, appeared to have very little effect on the pattern of priming. These results suggest that the meanings of abstract and concrete words become available very early in the processing of the speech input, although concrete words generate significantly more priming than abstract words at all presentation points. We will consider the implications of these findings in the General Discussion.

EXPERIMENT 2: NOUNS AND VERBS

The purpose of this second set of experiments was to examine the time-course with which the meanings of nouns and verbs are activated in the processing of a spoken word.

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[9] Forward association: IP: $r = -.100, p = .379$, offset: $r = -.044, p = .697$; delay: $r = -.219$, $p = .051$; backwards association: IP: $r = -.014, p = .900$; offset: $r = -.014, p = .904$; delay: $r = .199, p = .077$.

[10] For this analysis, we obtained the mediated strength values for each word-pair from the Florida database (Nelson, McEvoy, & Schrieber, 1998). IP: $r = .016$, $p = .652$, offset: $r = -.059, p = .661$; delay: $r = -.104, p = .441$.

[11] Degree of priming by item position: IP: $r = .039, p = .730$; offset: $r = -.048, p = .670$; delay: $r = -.004, p = .974$.

Method

Materials and design. We selected a large number of possible noun–noun and verb–verb prime-target pairs, using the same constraints as in Experiment 1. In this study, since the focus was on the contrast between nouns and verbs, we tried as much as possible to select pairs where the prime word was either a noun or a verb. Where this was not possible, we selected primes where the lemma frequency was considerably (10 times) higher in one form class than the other. These pairs were then entered into a pre-test to determine the degree to which they were semantically related, similar to that described in Experiment 1. Many primes were tested with multiple targets to see which yielded the strongest semantic relatedness. This resulted in 205 test pairs. A further 139 filler pairs were added, 29 of which were related and 110 unrelated. Nineteen participants provided ratings on a scale of 1 to 9, with 1 being very unrelated, and 9 being strongly related. The mean rating value for each pair constituted its semantic relatedness score. We rejected any pair with a score of less than 5. The mean semantic relatedness ratings are given in Table 3. A *t*-test to

TABLE 3
Experiment 2: Statistics of the noun and verb stimuli

	Word type			
	Nouns		*Verbs*	
	Prime Mean/SD	*Target Mean/SD*	*Prime Mean/SD*	*Target Mean/SD*
Semantic relatedness		7.0/0.7		6.9/0.7
Imageability	424/86	449/111	442/86	424/89
Familiarity	514/40	525/56	472/74	499/78
Number of letters	5.6/1.4	5.5/1.1	5.2/1.2	5.1/1.5
Number of syllables	1.8/0.7	1.6/0.7	1.5/0.5	1.4/0.5
	Nouns		*Verbs*	
	Noun	Verb	Verb	Noun
Prime frequency	60.8/80	0.2/0.7	59.4/91.6	0.3/0.9
Target frequency	93/175.6	7.3/23.5	101/225.7	12.0/24

	Word type			
	Noun primes		*Verb primes*	
	Mean	*SD*	*Mean*	*SD*
Word duration (ms)	700	113	711	113
Duration to IP (ms)	377	106	432	113
Duration post IP (ms)	324	120	280	113

determine whether there were statistical differences in the semantic relatedness between nouns and verbs found no significant effects, $t(\text{df} = 78) = 0.572, p > .1$. We also ensured that the word pairs were not strongly associated with either forward or backward direction. The mean association strength of the nouns was .082 (forwards) and .090 (backwards), and for the verbs it was .080 (forwards) and .075 (backwards).

We obtained familiarity and imageability ratings for the primes and targets, either from the MRC database (Coltheart, 1981) or our own norms. We then selected sets of 40 noun–noun pairs and 40 verb–verb pairs, where the primes and targets were matched on familiarity, imageability, degree of semantic relatedness, number of letters, and number of syllables. The statistics of the word-pairs are given in Table 3.

We obtained unrelated pairs by pseudo-randomly rotating the primes around the targets, as in Experiment 1, such that the related primes in one version served as control primes in the second version. The control primes thus match the test primes in terms of concreteness, imageability, familiarity, syllable number, and letter length. We then carried out a second semantic relatedness test to check that the control-target pairs were equally semantically unrelated in the noun and verb sets. The test included the 80 unrelated words and an equal number of related pairs. Fifteen participants rated each word-pair on a scale of 1 (not related) to 9 (very strongly related). The mean semantic relatedness of the noun pairs was 1.83 (SD = 0.56) and 1.77 (SD = 0.49) for the verb pairs.

Gating pre-test to determine IPs. The 80 primes were included in a gating study in order to establish their isolation points. The procedure was exactly the same as that described for Experiment 1. Paid participants from the Centre of Speech and Language participant pool completed two sets of 20 items. Every word was completed by at lest 10 participants. The mean Isolation Points, measured in milliseconds from word onset, of the noun primes was 377 ms (SD = 105 ms) and 431 ms (SD = 113) for the verb primes (see Table 3).

Two versions of the materials were constructed, such that the same target occurred only once per version, and so that primes served as test primes in one version and control primes in the other. The test pairs were pseudo-randomly interspersed with filler pairs. The details of test and filler pairs was exactly the same as that in Experiment 1. There were 80 test pairs, 38 unrelated real-word filler pairs and 118 word–non-word pairs, making the relatedness proportion 17%, and ensuring an equal number of word and non-word targets. We also constructed 30 practice pairs, half being word–word pairs and half being word–non-word pairs. Of the word–word pairs 26% (4/15) were semantically related. The two versions were matched in terms of mean semantic relatedness, association strength, target word familiarity, target concreteness and target word length (number of letters and syllables). Filler and practice item pairs were exactly the same for both versions.

Procedure. The materials were recorded in a sound-attenuated booth by a female British English speaker. The speech was digitised onto computer hard disc at a sampling rate of 22 kHz. The experiment was run using DMASTER/VMASTER software, which played out the speech tokens directly from their stored wave forms, and recorded participants' responses. The procedural details replicated those in Experiment 1. In all studies, the visual target was presented for 200 ms and participants responded by making a lexical decision response. In one study, it was presented at the IP, in a second at the offset of the prime and in a third 250 ms after the offset of the prime. Responses were timed from the onset of the visual target.

Participants. Twenty-seven participants were tested in the first study (IP), 28 in the second study (Offset), and 27 in the third study (Delay). All subjects were taken from the Centre for Speech and Language's participant pool and were paid for their efforts. No subject participated in more than one study, and none had participated in either the gating pre-tests or Experiment 1.

Results and discussion

Two subjects were removed from the analysis because their error rate was over 20%. The data were entered into a 4-way by-items and by-participants analysis of variance (ANOVA). The variables were experiment (IP, Offset, Delay), form-class (noun, verb) version (A, B), and prime type (test, control). The mean RTs in each condition are shown in Table 4.

A significant overall priming effect was found in both the by-subjects analysis, $F_1(1,74) = 66.097$, MSe $= 627.113, p < .001$ and the by-items analysis, $F_2(1,76) = 36.543$, MSe $= 2314.754, p < .001$ with faster RTs to targets followed by related (513 ms) compared to unrelated (540 ms) primes. There was no interaction between priming and form-class ($F_1 < 1$, $F_2 < 1$), between priming and presentation point (F_1 and F_2 $p > .1$) or between priming, presentation point and form-class (F_1 and F_2 $p > .1$). We also carried out analyses to determine whether priming was modulated by the duration of the prime up to the IP, since the duration of the nouns was slightly shorter than that of the verbs (see Table 4). However, there were no significant correlations with duration either at IP ($r = .198, p > .05$), offset ($r = -.015, p > .05$) or delay ($r = .208, p > .05$). Furthermore, when

TABLE 4
Experiment 2: Reaction times (ms) and error rates (%) at the three presentatiaon points

		Word type					
		Noun			*Verb*		
Presentation point		*Test*	*Control*	*Difference*	*Test*	*Control*	*Difference*
IP	RT mean	500	514	14	502	533	31
	RT SD	47	49		57	97	
	Error %	2.68%	3.46%	0.78%	4.29%	6.73%	2.44%
Offset	RT mean	527	564	37	553	581	29
	RT SD	37	55		56	72	
	Error %	1.54%	5.58%	4.04%	3.27%	5.96%	2.69%
Delay	RT mean	494	514	20	504	533	28
	RT SD	32	41		44	69	
	Error %	2.50%	5.20%	2.70%	3.93%	5.77%	1.84%

the analysis of covariance was repeated for each presentation point with duration of prime word up to IP added as a covariate (ANCOVA) we found no effect of the covariate.

Analyses were also carried out to ascertain whether the priming effects at each presentation point were mediated by the imageability of the items. No significant correlations were found between the imageability of the target and the amount of priming at IP ($r = .022, p > .05$) or offset ($r = .018, p > .05$), or delay ($r = .131, p > .05$). Furthermore, imageability or test primes did not correlate with amount of priming at IP ($r = -.12, p > .05$), or offset ($r = .088, p > .05$), although a significant correlation was found between the imageability of the primes and the amount of priming at the delay presentation point ($r = .244$, $p = .029$). However, when the analysis of variance was repeated for each presentation point with imageability of the test prime included as a covariate (ANCOVA), we found no effect of the covariate.

Lexical decision error rates were calculated for each item and analysed, after arcsine transformation (Winer, 1971), with ANOVA in the same way as the reaction time by-items data. There was a significant main effect of priming on error rates, $F_2(1,76) = 9.573$, MSE $= 0.006089, p = .003$) due to larger numbers of LD errors to targets in the control conditions (5.31%) compared to test conditions (3.13%), and no interactions with either form-class ($F_2 < 1$) or presentation point ($F_2 < 1$).

As in Experiment 1, we also carried out an analysis to determine whether association strength correlated with priming at each presentation point and found no significant correlation between either forwards (all *p*s

$> .05$) or backwards (IP and delay $p < .05$) association strength and amount of priming,[12] except for a weak backwards priming effect at offset ($r = .225, p = .047$). We also examined the effect of mediated associations on priming and found no significant effects (all $p > .05$).[13] Finally, we carried out a correlational analysis to determine whether subjects were using strategies to develop expectations about the relationship between primes and targets. To do this, we correlated amount of priming with the position of each word-pair in the experimental list, but found no significant effects.[14]

These results show that both nouns and verbs prime at all three presentation points, including the IP. Just as we saw for abstract and concrete words, nouns and verbs activate sufficient semantic information to generate significant priming well before all of the prime word has been heard. When a prime word is heard up to the Isolation Point, sufficient semantic information is activated to generate a significant priming effect. In this respect the pattern of results for verbs and nouns is very similar to that obtained for abstract and concrete words. Moreover, the amount of priming did not vary significantly as a function of form-class. We will consider the implications of these findings in the General Discussion.

GENERAL DISCUSSION

The purpose of the experiments reported here was to track the time-course of the activation of the meanings of abstract and concrete words and nouns and verbs. We found that the semantic representations of all these different types of words are activated early in the processing of a word. Moreover, the data suggest that these priming effects are due to the automatic activation of word-meanings and cannot be attributed to strategic effects. Although previous studies have rarely directly addressed the time-course of semantic activation of different word types, there are a few findings which are broadly consistent with the present data.

Bleasdale (1987), for example, conducted experiments to determine whether there were different lexicons for abstract and concrete words and found significant priming for each when prime and target were both either concrete or abstract. In this study, primes were presented until subjects had

[12] Forward association: IP: $r = .112, p = .324$, offset: $r = .184, p = .102$; delay: $r = .080, p = .479$; backwards association: IP: $r = -.064, p = .575$; offset: $r = .225, p = .047$; delay: $r = .212, p = .062$.

[13] For this analysis, we obtained mediated strength values for each word-pair from the Florida database (Nelson, McEvoy, & Schrieber, 1998). IP: $r = .068, p = .620$, offset: $r = .040, p = .769$; delay: $r = .106, p = .442$.

[14] Degree of priming by item position: IP: $r = .139, p = .220$; offset: $r = -.132, p = .245$; delay: $r = .009, p = .934$.

named them, thus making prime presentation duration variable. The SOA appears to have been approximately 900–1000 ms, making this study most similar to our delay condition, and in both cases abstract and concrete words primed significantly. Bushell and Martin (1997) recently reported a study in which they contrasted priming for abstract and concrete words at 2 SOAs—250 ms and 750 ms. They found that concrete nouns primed significantly at the short but not the long SOA, although in fact the size of the priming effects at the short (15 ms) and long SOAs (13 ms) did not differ significantly. Motion verbs (which they assumed were concrete, although they were not rated along this dimension) also primed significantly at the short SOA but not at the long SOA. Abstract words did not prime at either SOA. The absence of abstract word priming in the Bushell and Martin experiment contrasts with the significant abstract word priming we report in the present paper, but there are many differences between the studies which may have generated different effects.

As we outlined in the introduction, various models have been developed to account for imageability and form class effects, all of which make the general prediction of a processing advantage for concrete over abstract words and for nouns over verbs. While our results generally support the first prediction in that concrete words primed more strongly than abstract words, the second prediction was not confirmed. We found no significant difference in the extent to which nouns and verbs primed; they both primed from the earliest presentation point and throughout the time-course of the presentation of the prime. Thus, our experiments replicate previous findings in showing the early activation of semantic information for concrete nouns (Marslen-Wilson, 1987; Moss, McCormick, & Tyler, 1997; Zwitserlood, 1989; Zwitserlood & Schriefers, 1995), and extend these results by showing that the meanings of both abstract and concrete words and nouns and verbs are also activated early.

Time-course effects

We now turn to a discussion of the time-course of activation of semantic information as revealed by the pattern of priming effects across the experiments. We found significant priming for all types of words when we probed at the IP, the point at which a spoken word starts to emerge from its competitors and becomes uniquely identifiable (Marslen-Wilson & Welsh, 1978; Tyler & Wessels, 1983). At this early probe point, sufficient activation had accrued to produce significant facilitation of responses to a related target. The form-class results suggest that both nouns and verbs prime at IP, irrespective of the degree to which they are imageable, and continue to prime robustly as more of the prime word is heard.

What are the implications of these results for the various models developed to account for imageability and word-class effects that were outlined in the introduction? Given that our index of semantic activation was priming for semantically related target words in a lexical decision task, we need to consider accounts of imageability and form-class in the context of a specific model of semantic activation and priming, in order to generate specific predictions. Although the aim of this paper was not to distinguish between different models of priming, we suggest that only a subset of possible permutations of imageability and word-class accounts and activation mechanisms are consistent with the current data.

The most popular framework for interpreting semantic priming data is that of spreading activation within a network of nodes, each corresponding to a concept in semantic memory (Anderson, 1983; Collins & Loftus, 1975; McNamara, 1992). This approach has been adopted by the majority of researchers in explaining imageability effects (de Groot, 1989; Paivio, 1986; Schwanenflugel & Shoben, 1983). Within this framework, the time course of semantic activation for a given word is a function of the speed with which activation spreads from its concept node to the related nodes in the network that constitute its meaning. Activation of these related nodes also provides the basis for the semantic priming effect for related words. An important determinant of retrieval time within a spreading activation model is the number of links radiating from the source node. The more connections there are, the less activation available for each of the related nodes (Anderson, 1983). This fan effect could be the basis of differential priming effects for abstract and concrete words within a spreading activation model, although it would generate different predictions depending on claims about the differences in the semantic representation of abstract and concrete words. If abstract words have fewer properties than concrete words (Jones, 1985; Plaut & Shallice, 1993), the model would predict more and earlier priming for abstract words. If, on the other hand, abstract words have *more* information in the form of weakly related context-dependent properties (Schwanenflugel and Shoben, 1983), the model would predict slower activation for abstract words. We did not observe either of these patterns. Abstract and concrete words both produced rapid and early priming effects.

Nor are our results completely compatible with predictions generated by Paivio's (1986, 1991) dual coding model, which also incorporates many of the basic processing assumptions of a spreading activation network, although in this case there is activation among related nodes both within and across the verbal and image-based systems. In this model, concrete words are more likely than abstract words to activate images as well as related lexical nodes within the verbal system. Paivio (1986) makes explicit that, although associative processing (within the verbal system) and referential processing (between the verbal and image systems) are theoretically different, they do not necessarily differ in any quantitative way, as might be reflected in the reaction times for associative and referential processing (p. 69). Paivio also states that there is no basis in his model for a difference in the connections between related words within the verbal system for abstract and concrete words (p. 129). Taken together, these properties of the model predict that the immediate priming effects for concrete and abstract words should be similar, because they are based on direct spread of activation within the verbal system. Only later, when two-stage referential activation starts to feed back from the image system, would we expect to see an additional priming effect for concrete words. This is not consistent with our finding of greater priming for concrete words right from the earliest presentation point.

Recently, an alternative account of semantic activation and priming has been proposed within the framework of distributed connectionist models of semantic memory (Masson, 1991, 1995; McRae, De Sa, & Seidenberg, 1997; Sharkey, 1989). Although these models differ in their details, their central claim is that the meanings of words are represented as patterns of activation distribution over many units that correspond loosely to semantic properties. Words with similar meanings have a large degree of overlap in these activation patterns. The time course of activation of word meanings in such models can be captured in the speed with which the network settles into a stable pattern of activation. The priming of related words is a result of the network having to make only minor changes from the state of the prime meaning to that for the target meaning when they overlap on many properties (the trajectory through semantic space is shorter) than when they are very dissimilar in meaning.

The difference between concrete and abstract words has been modelled within such a distributed system (Plaut & Shallice, 1993), on the assumption that concrete words have "richer" semantic representations made up of more properties that are more consistently co-activated than is the case for abstract words. This leads to more stable patterns of activation, which can also be described as larger basins of attraction within semantic space. This difference has been shown to provide a basis for the better performance on concrete than abstract words when the input to the system is noisy (Plaut & Shallice, 1993). However, this model does not explicitly include parameters which model the time-course with which semantic representations are activated; it just makes the general prediction that concrete words should settle more rapidly than abstract words. What we can't tell from this model is how setting time maps onto priming. A number of studies have shown that semantic priming effects can be obtained when targets are presented well before the IP and when cohort competitors are clearly still active (Marslen-Wilson, 1987; Zwitserlood, 1989). Similarly, in the present studies, we find significant activation at the IP, even though lexical processing is not complete at that point since the whole word has not yet been heard. Would the Plaut & Shallice model predict, for example, that the semantic representations of words could be sufficiently activated so as to generate significant priming effects before the network has settled into a stale pattern of activation? It is not clear how a model like that of Plaut & Shallice can accommodate the finding of early priming effects.

One distributed connectionist model of semantic memory that makes explicit claims about the time course of semantic activation is that of McRae et al. (1997). In this model, the degree of intercorrelation among properties within a representation, as well as its total number of properties, are important factors in determining how rapidly the network can converge into the correct pattern for the meaning of concrete noun concepts. McRae et al.'s analysis of the structure of concepts was based on property norms generated for a large set of concrete nouns. Can these variables predict the priming differences over time for different word-types that we observe in the current set of experiments? We have recently obtained property norm data for a large number of different types of words, including abstract and concrete nouns and verbs. These property norms show that people generate an average of 7 properties per concept to abstract words and verbs, compared to a mean of 11 per concept for a familiarity-matched set of concrete words.[15] Moreover, we know from an earlier property norm study that the number of properties generated for a concept tends to be correlated with the number of correlations between pairs of properties; as the number of properties in a concept increases the number of correlated property pairs (CPPs) also increases. In this study property norms were obtained for a set of 93 concepts from the categories of animals, fruits, tools, and vehicles. Animals elicited a mean of 19 properties/concept which generated 121 correlated property pairs (CPPs), fruits 16 properties/concept generating 104 CPPs, tools 9 properties/concept and 28 CPPs, and vehicles 24 properties/concept and 64 CPPs (Moss & Greer, submitted).

However, the present results do not support the claim that number of properties and degree of intercorrelation affect the earliness with which the meaning of a concept becomes available since we found that the meanings of all word-types were significantly activated by the IP. Instead, the priming results suggest that the structural properties of an individual concept may affect the overall amount of activation of its meaning, and therefore the degree to which it primes. The fact that the magnitude of

[15] These differences between abstract and concrete nouns, and between verbs and concrete nouns were statistically reliable.

priming for all word types does not change over time[16] suggests that their semantic representations are already maximally activated at IP, at least when they occur in word lists. When words appear in a normal sentential context, it remains to be seen whether the degree to which the meaning of a word is activated can be affected by the context. In future studies we hope to investigate whether magnitude of priming over time is modulated by the degree to which a word's meaning is constrained by the sentence context in which it occurs.

CONCLUSIONS

In this paper we have reported a set of studies designed to track the time course with which the meanings of different types of spoken words become activated. We found that the meanings of abstract and concrete words, as well as nouns and verbs, start to become activated very early, well before all of the word has been heard. Activation of word meanings at early stages of word recognition, when the candidate word is only starting to emerge from its competitors, has implications for theories of word recognition and for the wider processes of language comprehension. To the extent that word meanings are activated early in processing a spoken word, this reduces the plausibility of those models which assume the complete independence of the processing of form and meaning. As discussed in the Introduction, a number of studies have shown that concrete nouns can be identified earlier when they occur in sentential contexts compared to in isolation (e.g. Marslen-Wilson & Tyler, 1980). This finding argues for the early activation of the meanings of spoken words, making them available for contextual evaluation. The present data confirm this and extend it to abstract words and verbs, suggesting that their meanings become similarly rapidly available for contextual integration and evaluation. This is consistent with the important role of verbs in an utterance, as relational elements combining concepts by virtue of their syntactic and semantic properties. These findings provide constraints on the development of accounts of the representations of the meanings of different types of words, the processes by which the meanings of words are activated over time, and the availability of semantic information for processes of word recognition and contextual integration.

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[16] To test this issue on a larger data-set, we combined the data from the two experiments in an ANOVA. We found an overall effect of prime type, $F_1(1, 159) = 90.697$, MSe $= 366.722$, $p < .001$; $F_2(1, 158) = 62.817$, MSe $= 2008.685$, $p < .001$ which did not interact with presentation point (F_1 and $F_2 < 1$) or experiment (F_1 and $F_2 > 1$).

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APPENDIX 1

(a) List of primes and targets used in Experiment 1/ Imageability study

Concrete words		*Abstract words*	
Primes	*Targets*	*Primes*	*Targets*
kipper	herring	oath	pledge
basket	hamper	total	result
alley	lane	clue	hint
trunk	chest	reason	cause
brush	broom	temper	mood
arrow	dart	law	rule
crow	raven	blunder	error
chief	boss	mercy	pity
whisky	scotch	clamour	din
drug	pill	envy	greed
hurricane	tornado	gain	profit
coast	shore	bane	curse
tart	pie	motive	purpose
card	paper	custom	habit
swamp	bog	skill	talent
falcon	hawk	creed	faith
sofa	couch	fault	blame
tusk	horn	theme	topic
rake	fork	system	method
storm	blizzard	force	power
jump	bounce	dare	challenge
giggle	chuckle	ignore	neglect
roar	growl	agree	consent
cling	grip	keep	save
rub	stroke	hope	wish
weep	sob	get	fetch
cut	chop	declare	claim
fidget	twitch	believe	trust
hiss	spit	offer	bid
shiver	tremble	astonish	amaze
shine	glow	assist	help
crush	squeeze	admire	respect
carve	slice	dodge	evade
slap	smack	divide	share
shake	quiver	stay	wait
sniff	snort	attach	connect
pounce	leap	cope	manage
thump	punch	say	tell
scream	cry	rid	ban
soak	drench	insist	urge

(b) List of primes and targets used in Experiment 2/ Form-class study

Nouns		*Verbs*	
Primes	*Targets*	*Primes*	*Targets*
crisis	emergency	soak	drench
trunk	chest	cling	grip
extreme	limit	greet	welcome
attitude	opinion	hover	fly
luck	fate	strangle	throttle
moment	minute	attach	link
theme	topic	annoy	bother
coast	shore	forbid	ban
ambition	desire	grope	fumble
prestige	honour	bake	cook
custom	habit	warn	advise
welfare	benefit	shine	glow
core	centre	choke	suffocate
rice	grain	sprinkle	scatter
thief	crook	stun	hit
cloth	fabric	appear	look
justice	judge	chew	bite
virtue	merit	cater	provide
empire	land	cope	manage
poetry	verse	speak	utter
skill	talent	pant	gasp
duty	chore	arise	emerge
origin	source	ignore	snub
art	craft	accuse	blame
drug	pill	flatter	praise
guilt	shame	dangle	suspend
berry	fruit	lose	fail
soul	spirit	divide	share
gravity	force	sniff	snort
idea	notion	sing	chant
nonsense	rubbish	stir	mix
evidence	proof	clench	squeeze
youth	child	crumble	decay
pint	gallon	stay	wait
mercy	pity	attract	pull
armour	shield	arrive	enter
cult	religion	fasten	secure
circuit	loop	weep	sob
incident	event	preach	talk
card	paper	rob	burgle