5. Cross-modal priming experiments with embedded words

Cross-modal priming of lexical decision is a well-established method for probing the activation of competing interpretations of lexically-ambiguous spoken sequences (Zwitserlood, 1989; Gow & Gordon, 1995; Tabossi, Burani & Scott, 1995; Gaskell & Marslen-Wilson, 1996). In constructing materials for use in priming tasks, a variety of different relations between prime and target have been utilised. Target words that are both semantically and associatively related to the prime are commonly used. For example, the pair *cat* and DOG[1] not only have a similar meaning, but are also associatively related since a majority of participants in a free-association task produce the word DOG for the cue word *cat* (Moss & Older, 1996).

However, since associated pairs can produce priming in the absence of any semantic relationship between prime and target (such as between the pair *pillar* and SOCIETY Moss, Hare, Day & Tyler, 1994) associative priming may reflect form-based associations between words that frequently co-occur. Thus associative priming need not require access to meaning in the same way as pure semantic priming appears to (see Moss et al., 1994 and Plaut, 1995, for networks that model the separate contribution of associative and semantic relationships). Recent research addressing issues in semantic representation and processing (e.g. Moss, Ostrin, Tyler & Marslen-Wilson, 1995; McRae, de Sa, & Seidenberg, 1997) has therefore used pure semantic priming without any associative relation between prime and target.

Cross-modal semantic (non-associative) priming may, however, be too weak to be used to assess the activation of competing interpretations of sentences (though see Moss & Marslen-Wilson, 1993). Since the goal of the experiments reported here is to assess the activation of competing interpretations of embedded words, the constraint of having to find pairs of words which both have strong associates would restrict the number of items

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[1] Throughout this thesis I will follow the convention of listing prime stimuli in *italics* and target stimuli in CAPITALS.

that could be used. Consequently the priming experiments reported in this chapter all used repetition priming – where the visual target is identical to the auditory prime.

Questions have been raised about the susceptibility of repetition priming to form-based effects. However, these effects may be minimised by including non-word foils where an equivalent degree of phonological overlap is paired with a non-word target (e.g. *stumble*–STUMB). With appropriately constructed filler items, priming is not observed between phonologically related pairs such as *pillow*–PILL in cross-modal repetition priming with single word primes, though priming is observed for pairs that are morphologically and semantically related like *darkness*–DARK (Marslen-Wilson, Tyler, Waksler & Older, 1994). These results are interpreted as evidence that repetition priming is sensitive to lexical-level effects and thus may be used to assess the lexical activation of competing interpretations of ambiguous sequences. A further advantage of the use of repetition priming is that it removes a potential source of variance produced by differences in the strength of the semantic or associative relationships between primes and targets in different conditions.

By varying the point in the prime sentence at which the visual target is presented and by cutting off the spoken prime at the probe position, cross-modal priming allows the time course of lexical activation to be measured at different points during an utterance while controlling how much speech the listeners have heard (Gaskell & Marslen-Wilson, 1996; Zwitserlood, 1989). By using the same stimuli and cut-off points as in Experiment 1, results can be compared to those obtained in gating. However, since cross-modal priming produces an on-line measure of the lexical activation of competing interpretations, the results should be less affected by the response biases that were evident in the gating data.

A series of cross-modal priming experiments was therefore carried out, each investigating the activation of competing lexical hypotheses at one point in the speech stream. The initial experiment used stimuli cut-off at the offset of the first syllable of the critical words – alignment point 1 (AP_1) in Experiment 1.

5.1. Experiment 2a – AP_1

Results obtained in the gating task indicate that listeners were strongly biased towards short word interpretations of stimuli presented up to AP_1. On this basis, strong and significant priming of short words would be expected at this probe position, while priming of long words may be weaker or non-significant. The results of this experiment also suggest that acoustic differences between segments and syllables in short and long words can be used by listeners to assist in discriminating monosyllabic words from the onset of longer words in which they are embedded.

However, the off-line response task used in gating may be susceptible to systematic biases that could distort the data in unforeseen ways. Consequently, follow-up experiments using cross-modal repetition priming will provide converging evidence on the time course of identification of onset embedded words and longer competitors. This data will provide valuable evidence regarding the ambiguity of syllables in short and long words.

5.1.1. Method

Participants

Seventy four paid participants from the Birkbeck Centre for Speech and Language subject pool were tested on this experiment. None of the participants had taken part in Experiment 1.

Design and materials

The same 40 pairs of test sentences were used as in Experiment 1. In all cases, these were presented up to the marker placed at the offset of the initial syllable of the test words (AP_1 – see Section 4.2.2 for further details). To provide a baseline measure, lexical decision response times following an unrelated control prime were compared to responses following the test sentences. The control prime sentences were identical to the test sentences in all but the word at the probe position which was replaced with a contextually appropriate but unrelated prime; either a monosyllabic word matched in frequency to the short test word, or a bisyllable matched to the long word target (see Table 5.1).

Prime Type	Prime Stimulus	Short Target	Long Target
Short Test	*The soldier saluted the flag with his* ***cap***[a] *tucked under his arm.*	CAP	CAPTAIN
Long Test	*The soldier saluted the flag with his* ***cap***[a]***tain*** *looking on.*	CAP	CAPTAIN
Short Control	*The soldier saluted the flag with his* ***palm***[a] *facing forwards.*	CAP	CAPTAIN
Long Control	*The soldier saluted the flag with his* ***rif***[a]***le*** *by his side.*	CAP	CAPTAIN

Table 5.1: Prime and target stimuli for experiment 2a. a = probe position for Experiment 2a.

This produced an experimental design with four prime types (two test prime and two control prime conditions). The additional two sets of 40 control prime sentences were recorded at the same time as the original test items from the gating experiment to minimise possible differences in voice quality or prosodic structure across the four sentences for each item. The four test and control primes were paired with either of the two targets, producing a 40 item, eight condition experiment as shown for an example set of four sentences in Table 5.1. The 320 test trials were rotated into eight experimental versions, such that each subject heard only one version of each sentence. Test version was included as a variable in subsequent analyses to reduce estimates of random error. In the analysis of participant means this referred to the test version to which each participant was assigned. In the items analysis this referred to the number of the item group sharing the same assignment of conditions to test versions.

In addition to the 40 test items in each experimental version 80 filler sentences were interspersed with the test items. Of these fillers, 20 were followed by a word target that was phonologically and semantically unrelated to the prime sentence. A further 20 filler sentences were followed by a non-word target that was phonologically similar to the word at the probe position in the prime sentences – these were added to discourage participants from associating phonological overlap between prime and target with a ‘yes’ response. The remaining 40 fillers were followed by non-word targets that were unrelated to the prime stimulus.

Also included in the experiment were 20 practice items and 10 lead-in items to allow participants to settle into each experimental block. This produced 150 sentences in each version (50% followed by word targets and 50% by non-words). Of the 150 sentences in the experiment, 20 were test sentences where a phonologically related word target followed the auditory prime. This produced a relatedness proportion of 13% over the entire test set for a given participant. To encourage participants to attend to the auditory prime sentences a recognition test on some of the filler sentences was given at the end of the experimental sessions.

Procedure

Participants were tested on one of the eight experimental versions in groups of one to four seated in booths in a quiet room. They were warned that they would be given a memory test on the auditory stimuli after the main experiment, but also informed that they should not attempt to rehearse or memorise the sentences. Each version of the experiment was split into four sessions, first a block of 20 practice sentences, after which subjects were given feedback on their lexical decision reaction times and errors. This was followed by two test blocks, each starting with five lead-in items for which no data was recorded, followed by 60 sentences, with a short interval between blocks. A pencil and paper recognition test was given after the end of the second test block.

Each trial started with a sentence fragment being played over headphones. At the first alignment point (or an equivalent position in the control sentences and at a range of positions in the filler sentences) the speech was cut off and a word presented for 200ms on the monitor in front of each participant. Participants were required to press the ‘yes’ button with their dominant hand if the target was a real English word or the ‘no’ button if it was not. Reaction times were measured from the onset of the target word (corresponding to the offset of the prime stimulus) with a 3 second time out. Following the presentation of each target (and the participant’s response), there was a short pause before the start of the next trial when the procedure was repeated. Each test session, including practice items, lasted approximately 25 minutes.

At the end of the lexical decision experiment, participants were given a sheet listing 25 sentences, 12 of which were filler sentences from the experiment. Participants were instructed to circle any sentences which seemed familiar, even if they had not heard all of the sentence. There was no time limit on this task, though most completed it within 5 minutes.

5.1.2. Results

Of the 74 participants, 9 were excluded for slow or error-prone lexical decision responses (excluding those participants whose mean test and control RT was greater than 750ms and/or produced more than 12.5% errors). One test target (BRAN) produced a large number of errors (over 30%) and consistently slow reaction times (over 750ms) and was therefore removed from the analysis, along with the matched bisyllable (BRANDY). Also excluded were 4 outlying responses over 1200ms each coming from a different participant in response to a different item. These discarded response times and response times from trials in which participants responded incorrectly were treated as missing data points and played no part in the following analyses. Following these exclusions, mean reaction times and error rates in each condition were as shown in Table 5.2.

		Short Target (CAP)		Long Target (CAPTAIN)	
Prime Type	Prime Word	RT (ms)	Error (%)	RT (ms)	Error (%)
Short Test	*cap*	485	3.2	539	4.8
Long Test	*captain*	501	2.8	528	6.4
Short Control	*palm*	512	3.8	561	4.3
Long Control	*rifle*	512	2.8	557	6.0

Table 5.2: Experiment 2a. Mean response times and error rates by prime and target type.

A three-way repeated measures ANOVA was carried out to investigate effects of the length of the word from which the prime syllable was taken (short/long), prime type (test/control) and length of the target word (short/long). An additional between-groups factor of version or item group (in the participants and items analysis respectively) was included to reduce estimates of random variation, though effects involving this factor will not be reported. ANOVA on response times showed a main effect of prime type (test/control) ($F_1[1,57]=33.34$, $p<.001$; $F_2[1,31]=26.33$, $p<.001$) indicating significantly faster responses following related test primes. There was also a significant main effect of the length of the target word ($F_1[1,57]=80.98$, $p<.001$; $F_2[1,31]=30.48$, $p<.001$), with significantly faster lexical decision responses to shorter target words. There were no main effects involving the number of syllables in the primes.

Even though prime sentences were cut off at the offset of a single syllable such as [kæp], there was no difference in the amount of priming for words that exactly matched the prime (*cap*) compared to longer items in which the prime was embedded (*captain*) (see Figure 5.1). There was no interaction between prime type and target length ($F_1[1,57]=1.09$, $p>.1$; $F_2[1,31]=1.48$, $p>.1$). This is a very different pattern to that observed in the gating experiment. At AP_1 in Experiment 1 subjects produced many more short word than long word responses. The lack of an equivalent effect here shows that cross-modal priming may be less susceptible to the single word bias that was observed in Experiment 1, suggesting that these results provide a purer measure of lexical activation than those obtained in gating.

Perhaps the most crucial result in this experiment is the significant interaction between the number of syllables in the prime and the number of syllables in the target ($F_1[1,57]=7.89$, $p<.01$; $F_2[1,31]=5.55$, $p<.05$). Lexical decision responses were faster when the number of syllables in the target matched the number of syllables in the prime. Inspection of the condition means shown in Table 5.2 suggests that this effect is only to be found for the test prime condition. The three-way interaction between prime type, prime syllables and target syllables was significant by items but not by participants ($F_1[1,57]=2.15$,$p>.1$; $F_2[1,31]=5.03$, $p<.05$).

The critical interaction between prime length and target length was examined by carrying out pairwise comparisons between response times following test and control primes. To simplify these contrasts, data was collapsed over the two control prime conditions since these had been found not to differ. Following the guidelines provided by Toothaker (1991), pairwise comparisons were carried out using one-way repeated-measures ANOVAs including the non-repeated factors of version and item group in the participants and items analysis, respectively. Since only four comparisons are required for this experiment (comparing responses to each target following test and control primes) no correction is required to control family-wise error. The magnitude of these differences and the significance of these pairwise comparisons is plotted in Figure 5.1.

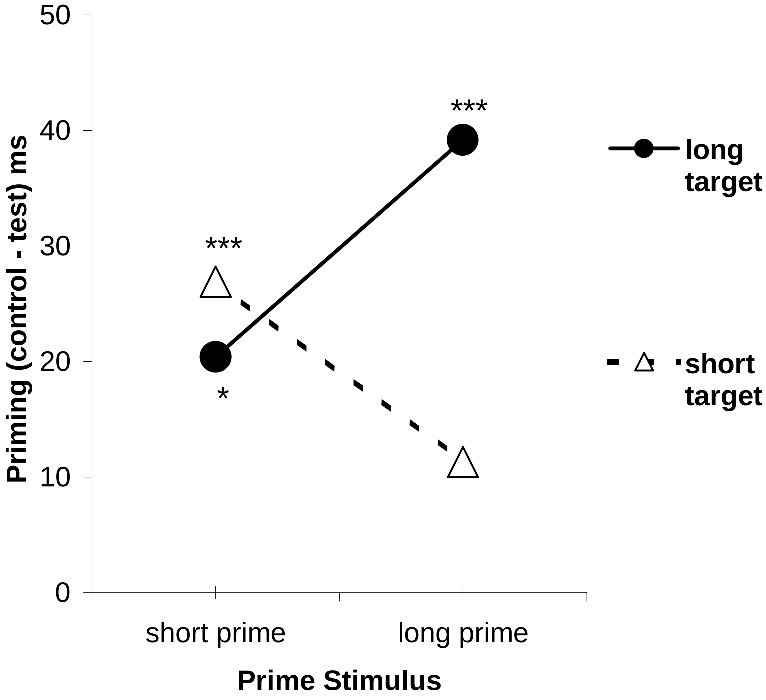

Figure 5.1: Experiment 2a – Magnitude and significance of repetition priming by prime and target type. * priming p<.001, * priming p<.05**

Strongest priming in this experiment was observed where the prime syllable comes from the same word as the target. The initial syllable of a long word significantly speeded responses to a long word target ($\underline{F}_1[1,57]=20.09$, $p<.001$; $\underline{F}_2[1,31]=24.30$, $p<.001$) but not to a short word target ($\underline{F}_1[1,57]=2.61$, $p>.1$; $\underline{F}_2[1,31]=2.33$, $p>.1$). Short word primes significantly facilitate responses to a short word target ($\underline{F}_1[1,57]=15.13$, $p<.001$; $\underline{F}_2[1,31]=23.23$, $p<.001$) with numerically weaker, though still significant, priming of responses to long words ($\underline{F}_1[1,57]=6.57$, $p<.05$; $\underline{F}_2[1,31]=4.31$, $p<.05$).

The interaction between prime and target length is confirmed by an analysis using the difference between response times following test and control primes as the dependent variable with the length of the prime word and the length of the target word as independent variables. This confirmed that there was no overall difference in priming of short or long targets ($\underline{F}_1$<1; $\underline{F}_2$[1,31]=1.71, p>.1) or from short or long primes ($\underline{F}_1$<1; $\underline{F}_2$<1). There was however a significant crossover interaction between the factors of target length and prime length ($\underline{F}_1$[1,57]=9.14, p<.01; $\underline{F}_2$[1,31]=8.76, p<.01).

Error rates were arcsine transformed to stabilise variances (Winer, 1971) and then entered into the same three-way ANOVA as the response time data. There was a marginal main effect of target length ($\underline{F}_1$[1,57]=7.2, p<.01; $\underline{F}_2$[1,31]=3.99, p<.1) reflecting fewer lexical decision errors for short targets and a trend towards a two way interaction between prime length and target length ($\underline{F}_1$[1,57]=3.17, p<.1; $\underline{F}_2$[1,31]=2.48, p>.1). No other effects approached significance in this analysis.

5.1.3. Discussion

The first important result that emerges from these analyses is that cross-modal repetition priming suggests that the lexical activation of competing hypotheses is less biased towards short words than was suggested by the results of Experiment 1. In the gating study the majority of responses to stimuli presented up to AP_1 matched the short word. However, no such preference for short word interpretations is shown in the priming data. This result presents problems for lexical competition models such as TRACE, which predict an initial bias towards short word interpretations during the identification of onset-embedded words.

The second important point, confirming the pattern of results in gating, is that these results provide evidence that the perceptual system is sensitive to acoustic differences between syllables from short and long words. The cross-over interaction shown in Figure 5.1 demonstrates that significantly greater priming is found where the prime syllable comes from the same word as the target. Recall that this difference is observed for prime stimuli cut off at AP_1 – where participants can only hear the first syllable of the test words.

In previous discussions of lexical accounts of word segmentation (McQueen, Cutler, Briscoe & Norris, 1995) it has been argued that the presence of large numbers of onset embedded words places an important constraint on the structure of the spoken word recognition system. This argument, based on an assumption that word recognition proceeds from a phonemic or syllabic representation of the speech input, is that since onset-embedded words are ambiguous at their offset, following context must be used for their identification. This necessitates models of spoken word recognition that incorporate lexical-level competition. The experimental results reported so far suggest that the perceptual system is able to use sub-phonemic cues to distinguish onset-embedded words from the start of longer words in which they are embedded. To the extent that this is generally the case, processes such as delayed recognition and mechanisms of lexical competition may play a less important role in spoken word recognition than would be argued in accounts based on a purely phonemic analysis of the speech stream.

In the light of this finding another result from the gating study can now be re-examined – namely the evidence for competition between short and long words after AP_1 (the offset of the first syllable). Given the absence of biases towards short word interpretations in the cross-modal priming results at AP_1, it might be expected that effects of competition at later probe positions – which could also be attributed to response biases in gating - would be reduced in cross-modal priming. In three further experiments the cross-modal priming task was used to examine the lexical activation of potentially competing short and long target words at three further probe positions.

5.2. Experiment 2b-d

These subsequent experiments were set up in a similar fashion to Experiment 2a except that the probe position was advanced through the stimuli across the three experiments. In this way it is possible to track the activation of competing interpretations as increasing amounts of speech is presented to participants. One further difference between these experiments and Experiment 2a is that, since there were no significant differences between the two control primes used in Experiment 2a, only one control prime condition was used for each target type. This reduces the number of experimental versions required to test the lexical activation of each target word at a given probe position.

The probe positions used in these experiments were set up to facilitate comparisons with the gating study. Experiment 2b and c tested responses at the two later alignment points (AP_2 and AP_3 respectively) used in Experiment 1. The probe position in Experiment 2b (AP_2) marks the point at which the continuation of the embedded word becomes available to listeners (for example, the /t/ in *captain* and *cap tucked*). In the gating experiment this information produces a marked increase in the proportion of long word responses to both short and long word stimuli. Consequently, it might be predicted that there would be an increase in the amount of priming observed for long word stimuli in Experiment 2b. Given the results obtained at AP_2 in Experiment 1, this increase may be observed for both short and long word prime stimuli. However, given the potential for acoustic cues that mark word onsets (Gow & Gordon, 1995; Nakatani & Dukes, 1977) the magnitude of this effect may depend on whether these segments occur at the onset of a word or not.

The third alignment point (AP_3), tested in Experiment 2c, is placed in the vowel of the second syllable. AP_3 marks the point where the stimuli used in these experiments diverge phonemically. In Experiment 1 there is a corresponding divergence in the responses made at this point in the stimuli. For long word stimuli listeners continue to produce more long word responses, whereas for the short word stimuli, short word responses increase between AP_2 and AP_3. Consequently, less ambiguity would be predicted in the priming effects at this probe position. However, since the cross-modal priming results in Experiment 2a already suggest less ambiguity than was predicted from gating, changes at this probe position may be less marked.

The final probe position (AP_4), used in Experiment 2d, is placed 100ms after AP_3 (equivalent to gate 7 in Experiment 1). This was chosen to be a place at which the majority of responses in the gating experiment correctly identified the target word for both types of stimuli. Consequently, no facilitation of targets that do not match the prime words would be predicted at this probe position.

Participants

Across the three experiments, 181 paid participants from the same population used previously were tested (54 on Experiment 2b, 72 on Experiment 2c, 55 on Experiment 2d[2]). None of these had taken part in any of the previous experiments.

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[2] Differences between the number of participants tested in these experiments reflect differences in the amount of prior experience groups had had with the lexical decision task, and hence how many participants were rejected for slow and error prone responses.

Design and materials

The design and materials used in these three experiments were identical to the previous experiments using the same sets of 40 items. The prime stimuli were presented up to AP_2 in Experiment 2b, up to AP_3 in Experiment 2c and up to a point 100ms after AP_3 in Experiment 2d. As in the previous experiment short and long target words were visually presented at the point at which the speech was cut off, with participants making a yes/no lexical decision response to the target word.

Prime Type	Prime Stimulus	Short Target	Long Target
Short Test	*The soldier saluted the flag with his* ***cap t[b]u[c]ck[d]ed*** *under his arm*	CAP	CAPTAIN
Long Test	*The soldier saluted the flag with his* ***capt[b]ai[c]n[d]*** *looking on*	CAP	CAPTAIN
Short Control	*The soldier saluted the flag with his* ***palm*** *facing forwards*	CAP	–
Long Control	*The soldier saluted the flag with his* ***rifle*** *by his side*	–	CAPTAIN

Table 5.3: Prime stimuli and target stimuli for experiments 2b-d with approximate probe positions marked for the test stimuli.

The only significant divergence from Experiment 2a was in the number of control prime conditions used. Previously there were two separate control prime conditions, each matched in length and frequency to one of the pair of target words. In Experiment 2a both control primes were used with each target word. Since no significant differences were found between these two control primes, the design of each experiment was reduced to include only one control prime for each target type. These were chosen to be matched in length and frequency to each target (i.e., short control primes were used for short targets and long control primes were used for long targets). This produced three experiments each with six conditions (three prime types and two target types) as shown in Table 5.3.

As in Experiment 2a, related non-word fillers were added to ensure that form overlap between prime and target was not associated with a ‘yes’ response. The same set of 20 items were used in Experiment 2b, with an additional seven related non-word fillers used in Experiment 2c and 2d. Unrelated trials were also added to each experimental version, 20 with word targets and 40 with non-word targets for Experiment 2b. An additional 35 unrelated trials were added in Experiments 2c and 2d, 21 with word targets, 14 with non-word targets. This produced experimental versions where the overall proportion of trials that included a related test item was 18% in Experiment 2b and just over 14% in Experiment 2c and 2d.

Procedure

The procedure for each of Experiment 2b-d was identical to that used previously except that test stimuli were presented up to the end of the onset segments of the second syllable of the test words (AP_2) in Experiment 2b, up to the vowel of the second syllable (AP_3) in Experiment 2c and up to a point 100ms after AP_3 in Experiment 2d (AP_4). Targets were visually presented at the offset of the auditory prime. See Section 4.2.2 in Chapter 4 for further details of the alignment points used.

Analysis

Results from this series of three experiments were analysed following data trimming as carried out for Experiment 2a. Participants were rejected for slow or error prone responses (mean test and control RT greater than 750ms and/or more than 12.5% errors on responses to test words). As previously, the target word BRAN produced consistently slow and error prone responses and was removed (along with the bisyllable BRANDY) from the analysis of all three experiments. Outlying response times were removed by excluding data-points above a response time cut-off set by examination of an RT histogram for each experiment.

Our goal in these experiments was to use the magnitude of priming as a measure of the lexical activation of competing interpretations. Consequently, analyses of overall reaction times and error rates are relegated to Appendix B in order to focus on statistical analyses that directly investigate the priming effects obtained in these experiments. Pairwise comparisons of response times and error rates following test and control primes were used to evaluate the magnitude and significance of priming effects. As in Experiment 2a these comparisons use repeated measures ANOVAs including a between groups factor of version (in analysis by participants) and item-group (in analysis by items). Comparisons between priming effects obtained for different primes and targets will be made using RT differences following test and control primes as the dependent measure (see Monsell & Hirsh (1998) for a similar approach to the statistical analysis of priming experiments).

5.2.1. Results of Experiment 2b – AP_2

Of the 54 participants tested, five were rejected for slow and/or error prone lexical decision responses. Two outlying data-points over 1400ms were also removed. Mean response times and error rates for the remaining subjects and items are given in Table 5.4. Analysis of variance on this data is reported in Appendix B.

		Short Target (CAP)		Long Target (CAPTAIN)	
Prime Type	Prime Word	RT (ms)	Error (%)	RT (ms)	Error (%)
Short Test	*cap*	549	2.2	584	4.2
Long Test	*captain*	556	2.6	552	1.5
Control	*palm/rifle*	570	3.0	607	7.5

Table 5.4: Experiment 2b. Mean response times and error rates by prime and target type.

Pairwise comparisons of response times following test and control primes showed that short word targets were significantly facilitated by short primes ($\underline{F}_1[1,43]=5.92$, $p<.05$; $\underline{F}_2[1,33]=4.46$, $p<.05$) with no significant facilitation by long primes ($F_1[1,43]=2.53$, $p>.1$; $F_2[1,33]=3.92$, $p<.1$). Conversely, long word targets were significantly primed both by long word prime stimuli items ($F_1[1,43]=22.01$, $p<.001$; $F_2[1,33]=26.93$, $p<.001$) and by short word stimuli ($F_1[1,43]=4.35$, $p<.05$; $F_2[1,33]=4.12$, $p<.05$). The magnitude and significance of these priming effects is illustrated in Figure 5.2.

Analysis on test-control difference scores with factors of prime type (short vs long prime stimuli) and target type (short vs long target words) showed more priming by long word primes than short word primes, as indicated by a significant main effect of prime type in this analysis (F_1[1,43]=5.73, p<.05; F_2[1,33]=5.77, p<.05). There was also a marginally significant main effect of target type (F_1[1,43]=3.54, p<.1; F_2[1,33]=3.49, p<.1) reflecting a tendency for long word targets to be primed more strongly overall than short words. The interaction between prime and target type (see Figure 5.2) was also significant (F_1[1,43]=7.63, p<.01; F_2[1,33]=7.17, p<.05) suggesting that, despite the conflicting information coming from continuations of the short word stimuli, greater facilitation is observed where the prime stimulus is identical to the target.

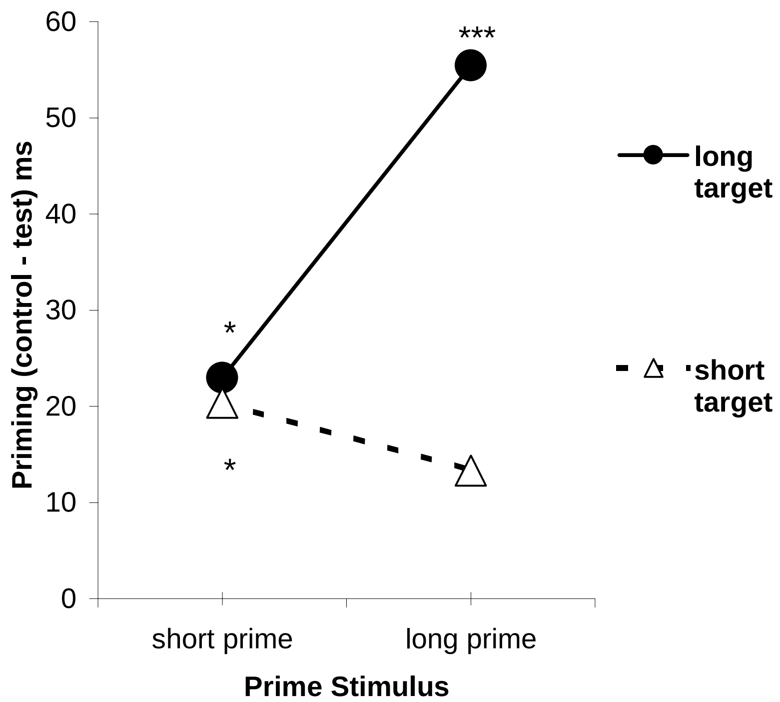

Figure 5.2: Experiment 2b – Magnitude and significance of repetition priming by prime and target type. * priming p<.001, * priming p<.05**

Pairwise comparisons of error rates also showed significant facilitation of responses to long words. Participants made significantly fewer errors to long targets when they were preceded by a long word prime (F_1[1,43]=19.66, p<.001; F_2[1,33]=9.92, p<.01) compared to error rates following control primes. There was also a marginal reduction in error rate when bisyllabic targets followed monosyllabic primes in the items analysis (F_1[1,43]=2,49, p>.1; F_2[1,33]=3.56, p<.1). There were no significant differences in error rates to monosyllabic targets following either short or long control primes (all p>.1).

At the probe position tested in this experiment, participants started to hear the onset of the syllable following an embedded word (the /t/ segment in stimuli such as *cap tucked* or *captain*). Priming effects at this probe position suggest that this information plays a role in the identification of the long word stimuli – indicated by significantly greater priming from long word stimuli and for long word targets. This pattern of results for short word primes suggests that these stimuli are more ambiguous than long word primes at this probe position. This question of how garden-path continuations of embedded words affect the activation of short and long competitors will be considered further in subsequent experiments.

5.2.2. Results of Experiment 2c – AP_3

Out of 72 participants tested, 14 were discarded for slow or error prone responses by the same criteria used previously. Data from an additional participant whose mean response times were more than two standard deviations faster than any other participant were also removed. Also excluded were 12 individual outlying responses slower than 1350ms. Mean response times and error rates following these exclusions are shown in Table 5.5 with ANOVAs on these data in Appendix B.

		Short Target (CAP)		Long Target (CAPTAIN)	
Prime Type	Prime Word	RT (ms)	Error (%)	RT (ms)	Error (%)
Short Test	*cap*	521	3.2	565	4.2
Long Test	*captain*	548	2.0	536	3.3
Control	*palm/rifle*	552	3.1	593	8.3

Table 5.5: Experiment 2c. Mean response times and error rates by prime and target type.

Pairwise analysis of priming effects at this probe position indicates relatively little change between this and the previous probe position, although there is an increasingly clear separation of the priming effects elicited by short and long primes (see Figure 5.3). Short primes significantly speed responses to short word targets ($F_1[1,51]=14.47$, $p<.001$; $F_2[1,33]=10.80$, $p<.01$) with numerically similar but statistically weaker effects for long targets ($F_1[1,51]=5.36$, $p<.05$; $F_2[1,33]=3.33$, $p<.1$). This indicates that there is still some ambiguity present in these short word stimuli – both competing interpretations can be primed at this probe position. For the long word primes there is strong priming of long word targets ($F_1[1,51]=36.40$, $p<.001$; $F_2[1,33]=24.27$, $p<.001$) but no evidence of significant facilitation of short word targets ($F_1<1$; $F_2<1$). Long word primes are clearly less ambiguous than short word primes at this probe position.

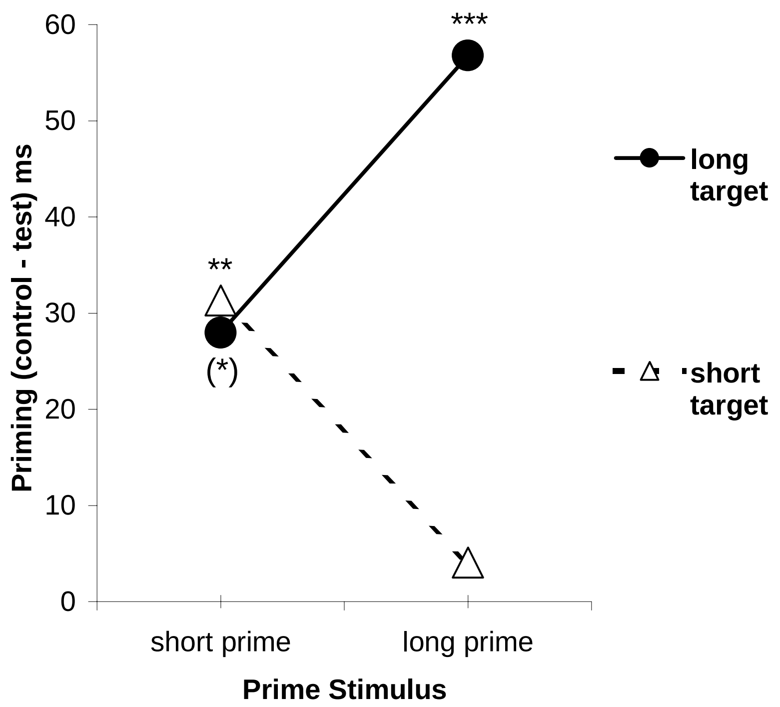

Figure 5.3: Experiment 2c - Magnitude and significance of repetition priming by prime and target type. * priming p<.001, ** priming p<.01, (*) priming p<.1**

A similar pattern is obtained in comparisons of error rates for long word targets following test and control primes. Participants made significantly fewer errors to long words after hearing long test primes than following control primes ($F_1[1,51]=7.92$, $p<0.01$; $F_2[1,33]=10.91$, $p<0.01$). Error rates were also reduced for long words following short word primes compared to controls ($F_1[1,51]=4.84$, $p<0.05$; $F_2[1,33]=4.21$ $p<0.05$). No significant differences in error rates were found for short word targets.

Analysis of response time differences between test and control primes shows a pattern more similar to that obtained in Experiment 2b than would be predicted on the basis of the gating data. The magnitude of priming showed a significant interaction between prime and target type (F_1[1,51]=15.84, p<.001; F_2[1,33]=19.57, p<.001) such that greater facilitation was observed where prime and targets matched. As in Experiment 2b there was a main effect of target type though this was non-significant by items (F_1[1,51]=4.81, p<.05; F_2[1,33]=2.58, p>.1). The main effect of prime type was non-significant (F_1<1; F_2<1).

This pattern of results, where long word stimuli only prime long word targets, again suggests that the perceptual system can distinguish bisyllabic from onset-embedded monosyllables at this probe position. This is consistent with the high proportion of correct responses to long word stimuli at this alignment point in the gating experiment. More surprising is the continuing ambiguity of the short word stimuli, with significant priming of long as well as short word targets. At AP_3 in Experiment 1, more participants responded with the short target word than the long target word. Given that the prime stimuli differ phonemically at AP_3 (in the vowel of the second syllable) it would have been expected that a clear preference for short word interpretations of short word stimuli would be observed at this probe position.

This discrepancy between the results obtained in gating and cross-modal priming may simply reflect the greater time available to subjects for the processing of stimuli in the gating task. However, it is necessary to rule out the possibility that there is some systematic difference in the measures of lexical activation obtained for short and long words in the cross-modal priming experiments. It is therefore of interest to compare the priming of short and long words from short word stimuli at a probe position where it was expected that these stimuli would be unambiguous at AP_4 - 100ms beyond AP_3 (equivalent to gate 7 in Experiment 1).

5.2.3. Results of Experiment 2d – AP_4

Out of 55 participants tested on the six versions of this experiment, eight were rejected for slow and/or error prone responses. Also removed were two data-points over 1400ms. Mean response times and error rates are shown in Table 5.6 with ANOVAs by prime and target type reported in Appendix B.

Prime Type	Prime Word	**Short Target** (CAP) RT (ms)	Error (%)	**Long Target** (CAPTAIN) RT (ms)	Error (%)
Short Test	*cap*	510	3.2	577	7.9
Long Test	*captain*	543	5.9	540	4.3
Control	*palm/rifle*	541	5.7	586	6.8

Table 5.6: Experiment 2d. Mean response times and error rates by prime and target type.

Priming effects were analysed by planned comparisons illustrated in Figure 5.4 showing that responses to short targets were significantly speeded by short primes ($F_1[1,41]=17.47$, $p<.001$; $F_2[1,33]=11.65$, $p<.01$) but not by long primes ($F_1<1$; $F_2<1$). Similarly long targets were significantly primed by long primes ($F_1[1,41]=18.05$, $p<.001$; $F_2[1,33]=17.03$, $p<.001$) but not by short primes ($F_1[1,41]=1.13$, $p>.1$; $F_2[1,33]=1.83$, $p>.1$). For this experiment, comparison of error rates following test and control primes did not shown any significant differences.

As can be seen in Figure 5.4, there is a cross-over interaction of priming effects by prime and target length in this experiment. ANOVAs using the difference between response times following test and control primes as the dependent variable showed no main effects of either prime length ($\underline{F}_1<1$; $\underline{F}_2<1$) or of target length ($\underline{F}_1[1,41]=1.32$, $p>.1$; $\underline{F}_2[1,33]=1.63$, $p>.1$) with a highly significant interaction between these factors ($\underline{F}_1[1,41]=27.59$, $p<.001$; $\underline{F}_2[1,33]=30.08$, $p<.001$).

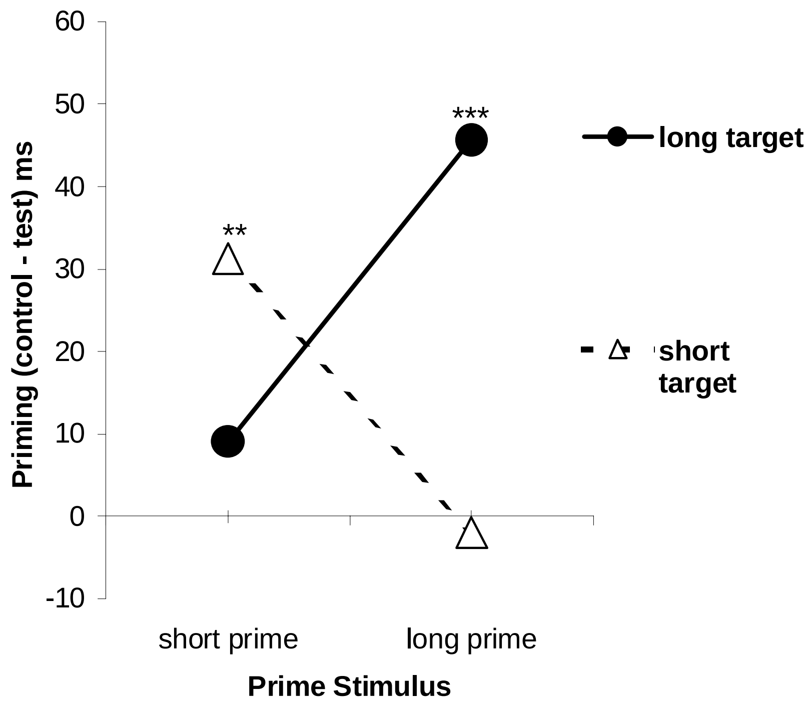

Figure 5.4: Experiment 2d – Magnitude and significance of repetition priming by prime and target type. * priming p<.001, ** priming p<.01**

The results obtained in experiment 2d indicate that reliable priming is only observed where prime and target stimuli are identical – irrespective of whether the prime is a short or a long word. Although priming effects at earlier probe positions suggested that short embedded words had been ruled out as interpretations of long word stimuli, it is only at this probe position that there is sufficient mismatch between short stimuli and long words for the perceptual system to rule out longer lexical hypotheses. Since stimuli presented up to AP_3 incorporated sufficient mismatch to allow a majority of participants to successfully identify short word stimuli in Experiment 1, it appears that the gating task is more sensitive to effects of mismatch between short word stimuli and long word candidates than cross-modal priming. Cross-modal priming required an additional 100ms of mismatching information in the speech presented after AP_3 to produce unambiguous priming of short words in the absence of any facilitation of long word targets.

5.2.4. Combined analysis of Experiments 2a-d

In order to investigate whether priming effects changed across the four probe positions, an analysis was carried out on data combined from all four experiments. To aid this comparison, reaction times were normalised by participants (dividing individual RTs by the mean response time for all (non-filler) targets for that participant and multiplying by the mean response time over all participants in the four experiments). Differences between responses following test and control primes were calculated for these normalised RTs and are shown in Figure 5.5. These difference scores were also entered into a three-way ANOVA with the factors of prime type, target type and probe position. Probe position is coded as a within groups factor in the items analyses and a between groups factor in the analysis by participants.

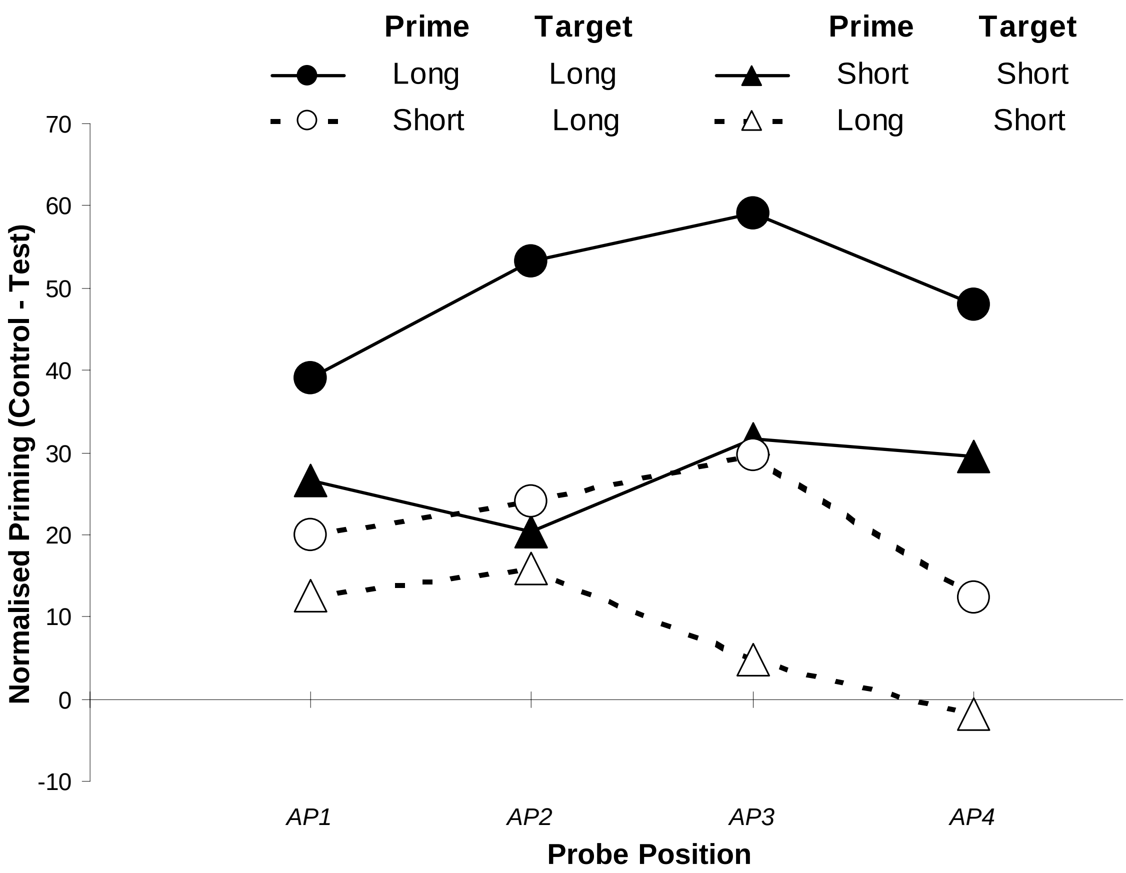

Figure 5.5: Normalised magnitude of priming in Experiments 2a-d by prime and target type.

There was a main effect of target type ($F_1[1,214]=7.44$, $p<.01$; $F_2[1,38]=6.53$, $p<.05$) indicating that overall more priming was observed for long targets. One possible explanation, which will be explored in later experiments is that short word stimuli with continuations that match long targets increased the activation of long words, especially at later probe positions (AP_2, AP_3 and AP_4). However, the effect of target length did not interact with probe position ($F_1<1$; $F_2<1$).

The combined analysis also revealed a significant interaction between prime and target length ($F_1[1,214]=51.47$, $p<.001$; $F_2[1,38]=56.87$, $p<.001$) reflecting the pattern observed in each of the experiments (see Figure 5.1 to 5.4) for priming to be strongest between prime and targets of the same length. This effect did not interact with probe position ($F_1[3,214]=1.23$, $p>.1$; $F_2[3,114]=1.52$, $p>.1$) indicating that information to distinguish short from long stimuli was present at all four probe positions.

5.3. General discussion

The overall results of Experiment 2 primarily confirm one of the main results of the gating study; namely that the perceptual system can distinguish between monosyllabic words and the onset of a bisyllable even at the offset of the first syllable (AP_1). One striking consequence is that in none of the four priming experiments is significant priming of short word targets from long word primes observed. It can therefore be concluded that differences in the acoustic form of syllables from short and long words can directly affect relative levels of lexical activation for the short and long target words. This indicates that the presence of embedded words in our long word stimuli is not producing significant levels of ambiguity at the levels of lexical representation tapped into by the repetition priming task.

A second finding of these experiments is that, unlike gating, cross-modal priming does not produce a bias towards short word interpretations of lexical items that contain an onset-embedded word. This result appears to challenge the account of lexical segmentation and lexical access provided by models such as TRACE that through their implementation of lexical competition predict greater activation of lexical units representing short words.

With reference to the two empirical predictions invoked in arguments from the presence of onset-embedded words to the necessity of lexical competition models, the experiments reported in this chapter present a considerable challenge on both of these points. The implications of these results will be discussed in turn.

5.3.1. Acoustic cues to word length

Our results indicate that some acoustic difference between short and long word stimuli allows the perceptual system to discriminate between onset-embedded words and the start of longer competitors. As reviewed in Chapter 2, a variety of acoustic cues have been proposed that might be able to account for this result. The two most strongly attested cues are qualitative changes in the initial segments of words compared to segments that are in the middle or at the offset of words (Lehiste, 1960; Nakatani & Dukes, 1977), and differences in segment and syllable duration between monosyllables and longer words (Klatt, 1976; Lehiste, 1972; Nakatani & Schaffer, 1978).

The results of experiments carried out by Gow and Gordon (1995) have been used to argue that qualitative differences in onset segments are used to distinguish otherwise ambiguous stimuli such as *tulips* and *two lips*. Gow and Gordon conclude that these onset segments contribute more strongly to the processes of lexical access and segmentation than other sections of a word (see Gow, Melvold & Manuel (1996) for more details of this ‘Good Start’ model). However, without directly manipulating these cues while controlling other aspects of the stimuli, it is unsafe to conclude that these onset-cues (and not other differences in their stimuli) are responsible for their results.

Similar caution is also required in drawing conclusions from the results of the current experiments. The stimuli used have not been directly manipulated to include only controlled acoustic differences. However, since the methods used to present speech to participants do allow control of which sections of the stimuli can be heard in a particular experimental condition, it is possible to determine <u>when</u> in the speech stream the relevant acoustic differences can be found. Since the participants in these experiments were able to rule out embedded words when hearing the onset of a longer word – when a marked word onset had not been presented and would not be expected – we can conclude that the onset cues described by Gow and Gordon (1995) are unlikely to be responsible for the pattern of results obtained in these experiments. It is also worth noting that differences in the duration of word onsets were not statistically reliable for the stimuli used in these experiments.

The acoustic cue that is most likely to be available to participants is the duration difference observed between syllables in short and long test words. If listeners are able to detect these differences in syllable duration and use them as a cue to the location of word boundaries the early discrimination of short and long words that was observed in our experiments might result. There is already evidence suggesting that listeners have ready access to duration information in other aspects of speech perception. Experiments have demonstrated that changes in syllable duration can induce changes in voice-onset time boundaries for the perception of voiced and voiceless stop consonants (Miller & Lieberman, 1979; Miller, Green & Reeves, 1986; Volatis & Miller, 1992; Kessinger & Blumenstein, 1998) while rate dependant information has been shown to be important in the perception of time compressed speech (Foulke & Sticht, 1969; Dupoux & Green, 1997; Pallier, Sebastian-Galles, Dupoux, Christophe & Mehler, 1998) Follow-up experiments that directly manipulate the duration of segments and syllables in short and long words are required in order to establish that duration, and not some previously unconsidered cue, is responsible for the discrimination of stimuli in short and long words.

5.3.2. Lexical competition and short word biases

Having taken these acoustic differences into account, a further conclusion that is supported by these results is that cross-modal priming does not show the same bias towards short word hypotheses as was observed at early gates in Experiment 1. Indeed, the combined analysis of the four experiments shows a significant main effect of target type indicating that more priming was observed for long targets than for short word targets. Consequently, the time course of identification predicted by lexical competition models (i.e., that where two words are activated in the speech stream, short words will be more strongly activated) was not supported by the cross-modal priming experiments reported here. None of the four cross-modal priming experiments reported in this chapter showed greater priming for short words than for long words.

Although these results may favour recurrent network accounts that predict approximately equal activation for competing words irrespective of length, without directly simulating the pattern of results produced in these experiments it is not possible to interpret this data as supporting models without direct inter-lexical competition. Consequently, in the next chapter the recurrent network model developed in Chapter 3 was extended to account for the processing of acoustic cues to word length. Only by directly simulating the time course of identification of embedded words and longer competitors can the results of these priming experiments be considered to support recurrent network accounts.