Cross-Modal Effects in Repetition Priming: *A Comparison of Lipread Graphic and Heard Stimuli*

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Visible Language XXII, 1
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A series of experiments investigated the processing of lipread information, as compared to that of heard and read stimuli, using the repetition priming paradigm. Experiment 1 showed that lipread priming facilitated the semantic categorization of lipread words to the same extent as that found for auditory prime, auditory test, and graphic prime, graphic test conditions. Experiments 2, 3 and 4 measured the effects of cross-modal priming. Lipreading primed both auditory and graphic processing, and is primed by both. While auditory priming did not speed the processing of graphic stimuli, graphic priming facilitated the semantic categorization of heard words. A tentative explanation of the findings is offered: lipreading provides incomplete information about words, and thus there is a need to access stored linguistic knowledge to 'fill in' missing features, allowing identification of the stimulus.

Lipread stimuli are of great interest because they share some common characteristics with both auditory and graphic stimuli. Like orthographic stimuli, lipread stimuli are perceived visually. However, they also differ in one important respect. Orthographic stimuli are static, and can be perceived as a gestalt at the moment of display. Lipread stimuli are dynamic, consisting of sets of transient features.

Speech perception is often assumed to be specific to the auditory modality. However, interest in the role of lipreading as a complementary source of information about spoken language has recently generated a great deal of research (Dodd and Campbell, 1984). Lipread stimuli are of interest because they share some common characteristics with both auditory and graphic stimuli. Like orthographic stimuli, lipread stimuli are perceived visually. However, they also differ in one important respect. Orthographic stimuli are static, and can be perceived as a gestalt at the moment of display. Lipread stimuli are dynamic, consisting of sets of transient features. The relationship between lip movements and heard speech is unique. The two sources of information are congruent, and provide complementary information. No other everyday activity provides such complex bimodal stimuli as face-to-face communication. Both are dynamic, and phonological. However, they are perceived through different modalities. Lipreading differs from both reading and hearing in that lipread stimuli are partial and therefore difficult to identify, whereas print and words heard in a quiet environment are easy to discriminate.

Comparison of the three types of stimuli, lipread, heard and graphic, have provided some interesting findings concerning the organization of short term memory. Until recently, it was assumed that verbal short term memory was organized along modality-specific lines. That is, heard stimuli are processed separately and differently from seen stimuli. Evidence supporting this hypothesis came from experiments showing limited cross-modal interference in short term memory tasks. For example, when a list of digits are recalled in serial order, there is enhanced accuracy of recall for the last items of the list if it has been heard, as compared to that found for read lists (Morton and Holloway, 1970). Providing further evidence, Wood (1974) found that when two successive stimuli from the two senses have to be compared, the stimuli are matched in the modality code of the second stimulus. For example, when a seen letter E was followed by a heard C, interference was more likely to occur than when a heard E was followed by a seen C. In the first case there is phonological similarity, in the second there is no visual (graphic) similarity. The results were interpreted as an indication that stimuli perceived by different modalities are recoded into the modality-specific code of the second stimulus for comparison.

One common feature of these experiments is that the visual stimuli were presented graphically. However, subsequent experiments showed that cross-modal interference effects do exist if the visual stimuli are lipread rather than text read. There is enhanced end of list recall of lipread lists, and cross-modal suffix effects (Campbell and Dodd, 1980; Gardiner, Gathercole and Gregg, 1981). Subjects have more difficulty remembering if they have lipread or heard a word, than if they have heard or read a word (Dodd and Campbell, 1984). These results have led to the conclusion that lipread and heard speech share a degree of common processing (Summerfield, 1984; Campbell, 1987).

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However, the investigation of more central processing of lipread information has been limited by the inherent difficulty of lipreading as a task. Normally hearing subjects can only identify 25% of a silently presented word list correctly (Dodd, 1977), although when a closed set is presented (e.g. numbers, color names) subjects make few errors. The number of paradigms able to be adapted for the presentation of lipread stimuli is therefore restricted. One paradigm that has been extensively used to clarify the nature of language processing is repetition priming (e.g. Kirsner and Dunn, 1985; Monsell, 1985). Subjects are asked to perform a verbal task, e.g. lexical decision. Some of the stimuli occur twice. Reaction times show that subjects can perform the task more quickly the second time they process a word. The degree of advantage varies according to a number of factors, e.g. whether the two stimuli have been presented to the same sensory modality. This phenomenon has been used to explore aspects of the mental lexicon, such as the modality specificity of codes (Clarke and Morton, 1983), levels of representation (Meyer and Schvanevelt, 1971), and bilingualism (Christoffanini, Kirsner and Milech, 1986). Many short term memory tasks, like serial ordered recall, do not necessitate the involvement of the mental lexicon. Nonsense syllables or graphic shapes can also be effectively used as stimuli. However, word repetition priming tasks can require the recognition of meaningful stimuli, and may therefore tap a more central level of representation. So far there has been no report of how lipread stimuli are processed in repetition priming tasks.

The experiments reported here are a preliminary exploration of the repetition priming phenomenon using lipread stimuli. Lipread stimuli may be processed similarly to heard stimuli. That is, there may be effective priming between heard and lipread stimuli but little or none between lipread and heard versus orthographic stimuli. If this were so, it would be in agreement with the pattern of results found using short term memory paradigms, and would provide evidence that lipread and heard speech share a common processing code when accessing the mental lexicon. Another possibility is that there may be absolute or relative same-modality priming. That is, visually perceived stimuli (lipread and text read) may prime each other to a greater extent than they prime, or a primed by, auditorally perceived stimuli. This hypothesis fits with previous findings (e.g. Clarke and Morton, 1983) showing significantly less cross-modal facilitation than within-modality facilitation. A third hypothesis arises from the fact that lipread stimuli are difficult to identify because they provide only partial information. The lipreader has to 'fill in' missing information, e.g. voicing. The recognition of lipread words is therefore likely to involve a greater use of stored knowledge about words than either hearing or reading. The increased "top-down" processing involved in perceiving lipread words might result in lipread stimuli being primed equally by both heard and text read words. If this were so, the pattern of priming should be unidirectional. That is, lipreading should be primed by everything, but prime nothing (except itself). These three hypotheses are not necessarily mutually exclusive, since an advantage in processing time may result from the operation of a number of factors.

The lipreader has to "fill in" missing information, e.g. voicing. The recognition of lipread words is therefore likely to involve a greater use of stored knowledge about words than either hearing or reading.

Experiment 1

While it has been demonstrated that within-modality repetition priming effects can be obtained for both auditory and visual (graphic) stimuli, there has been no investigation of whether prior lipreading experience can prime lipread performance. Before the cross-modal priming effects between lipread, auditory and graphic stimuli can be assessed, it is necessary to establish whether lipread information is subject to within stimulus-type priming effects, and if so, the extent of the effect compared to that found for auditory and graphic stimuli.

Method

Subjects. Twenty unpaid volunteers, 6 female and 14 male, acted as subjects. They were students and staff in a university department. All have Australian-English as their native language, and were aged between 18 and 45 years of age. None had any detected hearing loss, or uncorrected visual impairment.

Procedure. Subjects participated in one experimental session, lasting less than half an hour, in a soundproof room. They sat facing a VDU, and were given a small hand-held panel on which there were two buttons. One button was labeled "A" for animal, the other button, "P" for plant. Subjects were told that they would see/hear/lipread words, and that they were to decide whether each stimulus word was an animal or a plant, and to press the appropriate button as quickly as possible. The need for accuracy was stressed.

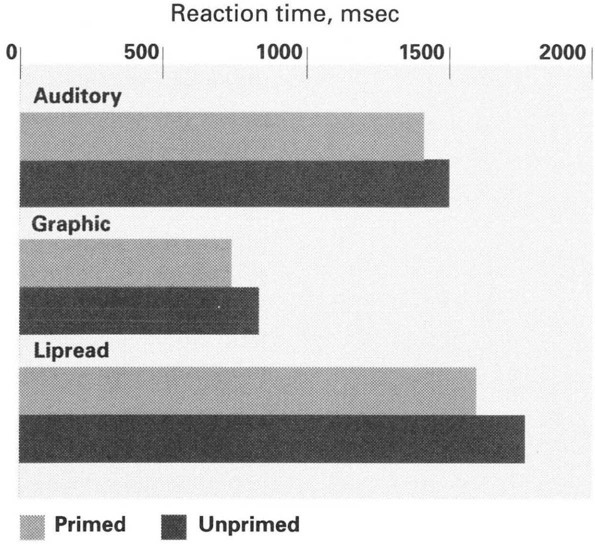
Each subject performed three conditions: auditory priming task, auditory test; graphic (written words) priming task, graphic test; and lipread priming task, lipread test. The task was identical in both priming and test phases of the experiment, i.e. categorization of words as either animal or plant. The test phase followed the priming phase after an interval of approximately two minutes. There were 10 items in the priming list, and 20 (10 primed and 10 unprimed) in the test list. The order of presentation of the three conditions was randomized across subjects.

Stimuli. There were three lists of twenty words, matched for frequency of occurrence (Thorndike and Lorge, 1944) and syllable length. There were ten animal and ten plant words in each list. Words for the lipreading conditions were carefully chosen in terms of their "lipreadability". This was achieved by limiting the words to a closed set (Australian native animals and common plants). The final list of words to be lipread was determined by asking 20 students to lipread a long list of words, and selecting only those words that were lipread accurately by at least 16 of the students in a noisy, distracting environment (the enrollment hall). Only one experimental subject showed significant lack of accuracy when lipreading stimuli, and was replaced. The other two word lists, for graphic and auditory conditions, were alternated. That is, while each subject had the same stimuli in the lipread condition, half the subjects heard one of the other lists, which other subjects read. Each list of twenty words was further divided into two lists of ten containing five animals and five plants; List A and List B. Half the subjects received List A in the priming task, and half List B.

In both priming and test phases the stimuli were presented at a rate of one every 5 seconds. In the lipreading conditions, subjects watched the VDU showing a lifesize head in color, which remained on the screen for the entire stimulus presentation, but in the interstimulus interval the presenter did not look at the camera. The presentation was silent, since no audio track had been recorded. In the graphic condition (driven by a S100 microcomputer), subjects saw words in upper case (height:15mm), in bold, enclosed in a box in the center of the screen. The word was visible for 0.5 of a second, approximately the length of time taken to say each word. In the auditory condition subjects heard the stimuli through headphones.

Measurement. The dependent variable was reaction time. When subject pressed a button to categorize the stimuli as animals or plants, they stopped a timer that had been activated as each stimulus was presented. In the auditory and lipread conditions this was done by placing a tone (not heard by the subjects) on a second channel of the stimulus tape that coincided with the onset of the stimulus. In the graphic condition, presentation of the stimulus item activated the timer. At the end of each test phase the printer provided a sheet stating subject name, order of condition presentation, prime list (A or B), condition tested, and each stimulus word of the test list, with subjects' categorization choice, and reaction time.

Figure 1 Within-Modal Priming



Results

Data for each subject were analyzed to provide the mean reaction time for the ten primed and ten unprimed words in each condition (figure 1). A two-factor analysis of Variance (condition: lipread, auditory or graphic; priming: primed or unprimed) was used to analyze the data. The conditions term was significant ($F=178.1$, d.f. 2,34; $p < 0.001$). Post hoc Newman Keuls tests indicated that reaction times were shorter in the graphic condition than in the auditory condition; reaction times in the lipread condition were longest. The Priming term was also highly significant ($F = 37.5$, d.f. 1, 17; $p < 0.001$). Priming resulted in consistently faster reaction times. The interaction term was not significant, indicating that the extent of the priming effect was the same for all three conditions. Accuracy was high in all conditions. The mean number of categorization errors for the lipread condition was 3.7, while it was 0.65 for graphic condition and 1.1 for the auditory condition.

Discussion

Experiment 1 showed that lipread stimuli could be successfully used in the repetition priming paradigm. Although reaction times in the lipreading condition were significantly longer than those for the graphic and the auditory condition, the extent of priming advantage did not differ across conditions. One contributing factor to the short reaction times for graphic stimuli is that they can be perceived as a whole at the moment of display, whereas identification of both auditory and lipread stimuli awaits the completion of the stimulus presentation. The finding that lipread stimuli took longer to process than auditory stimuli may result from lipread stimuli providing incomplete information. That is, subjects needed to "fill in" missing features, e.g. voicing, from stored representations of words. This additional processing would result in longer reaction times.

Experiment 1 provided evidence that it is possible to use lipread stimuli in cross-modal repetition priming experimental designs. Experiment 2 tested the effect of auditory priming on the semantic categorization of lipread and read words.

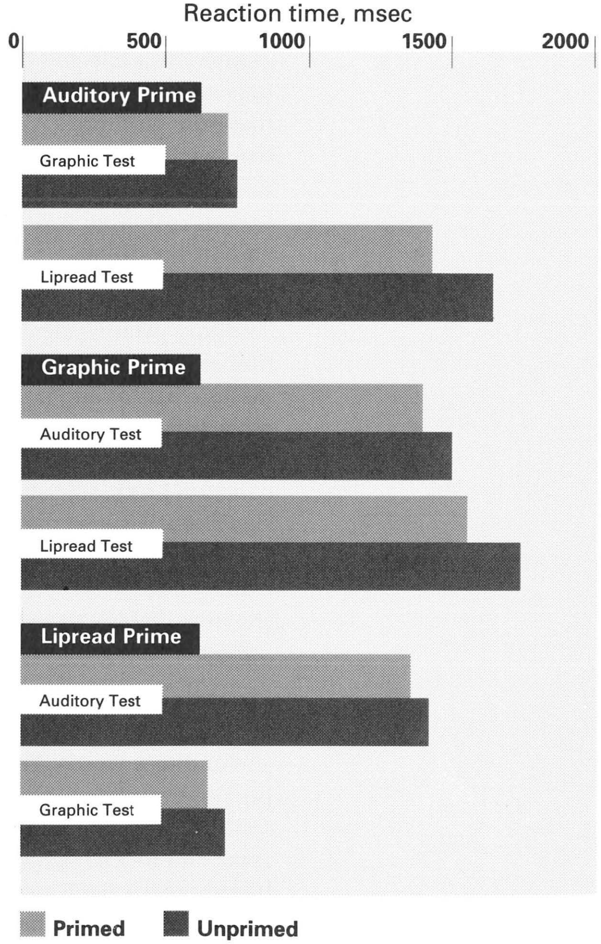
Experiment 2

Method

Subjects. The subjects were 20 unpaid volunteers recruited from the undergraduate population of Macquarie University. There were 14 females and 6 males. All of the subjects had normal hearing and (corrected) vision. They were aged between 18 and 45 years of age. None of the subjects had participated in experiment 1.

Procedures and Materials. The procedure was similar to that used in experiment 1. Subjects were presented with a list of words which had to be categorized as plant or animal in a priming phase and a test phase. The test phase consisted in one case of the list being presented graphically on the computer visual display, and in the other case, lipread from a television monitor (see experiment 1 for details). In both cases the priming task was auditory. The order of presentation of the graphic test and lipread test was alternated. The two word lists were alternated across conditions. In the priming task, half the subjects were presented with 10 of the words (5 animal and 5 plant), whereas the other subjects were primed with the remaining ten words.

Figure 2 Cross-Modal Priming



Results

Data for each subject were analyzed to provide a mean reaction time for the ten primed and ten unprimed words in each condition (figure 2). A two-factor Analysis of Variance was conducted on these scores (lipread versus graphic test; primed versus unprimed). The results showed that the conditions term was significant ($F= 263.2$, d.f. 1, 19; $p < 0.001$). Post hoc tests showed that graphic reaction times were significantly shorter than lipread reaction times. The effect of priming was also significant ($F = 5.77$, d.f. 1, 19; $p = 0.025$). Priming again resulted in faster reaction times. However, the interaction term was significant ($F = 5.317$, d.f. 1, 19; $p = 0.03$), indicating that the condition of presentation (lipread or graphic) was affected differentially by the auditory priming encounter. Post hoc Newman Keuls testing showed that prior auditory experience primed the perception of words when they were lipread but not when they were read. The mean number of categorization errors for the lipread condition was 3.6, while it was 0.65 for the graphic condition.

Discussion

Auditory priming significantly speeded the categorization of subsequently lipread words (mean increase of 216 msec). This finding is consistent with the results from other paradigms, e.g. serial ordered recall, showing that lipread and auditory stimuli appear to share a common processing stage. Auditory priming did not significantly speed the categorization of graphically presented words (mean increase 10 msecs). This finding is in agreement with those of Monsell (1985) and others, showing that the processing of graphic stimuli is not influenced by prior auditory experience.

The third experiment investigated the effect of a graphic priming task on the semantic categorization of lipread and auditory words. The findings of experiment 2 and previous reviews of research (e.g. Allport and Funnell, 1981) suggest that graphic priming should not affect the speed of processing heard words. No previously published reports have measured the effect of graphic priming on the reaction times for lipread word semantic categorization.

Experiment 3

Method

Subjects. The subjects were 20 undergraduates enrolled at Macquarie University: 13 females and 7 males. No subject took part in more than one of the experiments. All subjects were aged between 18 and 45 and had normal hearing, and (corrected) vision.

Procedures and materials. The procedure was similar to the other experiments although in this case, graphic stimuli were used in the priming encounter and the test encounter comprised a lipread and an auditory condition. The order of presentation of the test and priming lists was randomized across subjects.

Results

The data were analyzed with a two factor Analysis of Variance. The conditions term was significant ($F = 6.1$, d.f. 1, 19; $p < 0.025$), indicating that reaction times in the lipread task were significantly longer than those in the auditory task (see figure 2). The effect of priming was also significant ($F = 25.6$, d.f. 1, 19; $p < 0.001$). The interaction term was not significant ($F = 2.4$, d.f. 1, 19; $p = 0.138$), indicating that the extent of the priming effect did not differ for the auditory and lipread tests. The mean number of categorization errors for the lipread task was 3.6, while it was 1.3 for the auditory task.

Discussion

The results indicate that a graphically presented priming task increased the speed of semantic categorization of both auditory (mean increase 69 msec) and lipread (mean increase 179 msec) stimuli. The finding that reading words could prime their processing when they were heard is at odds with some previous findings (e.g. Clarke and Morton, 1983) and reviews of the literature (e.g. Allport and Funnell, 1981). However, it is not the first reported case of cross-modal priming. Monsell (1985) reported that graphic priming speeded the processing of auditory stimuli in a lexical decision task. He commented that although cross-modal effects may be numerically small compared to within-modality effects, they should not be dismissed as null effects. Experiments 2 and 3 indicated that the priming effect was asymmetrical: while a graphic stimulus primed auditory categorization, the reverse was not true. This pattern replicated Monsell's (1985) findings. Experiment 4 investigated whether a lipread input, which showed an increased reaction time when primed by auditory and graphic stimuli, could in turn prime semantic categorization of heard and read words.

Experiment 4

Method

Subjects. 20 undergraduates, 12 female and 8 male, volunteered for the experiment. They were all aged between 18 and 45 and possessed normal hearing and (corrected) vision.

Procedures and materials. The procedure followed that of the other experiments. In this experiment the priming stimuli were lipread words and the test stimuli were auditorally and graphically presented words.

Results

An Analysis of Variance was performed on the mean reaction time scores of subjects. The conditions term was significant ($F = 188.3$, d.f. 1, 19; $p < 0.001$) indicating that reaction times were shorter for the graphic test than for the auditory test (see figure 2). The effect of priming was also significant ($F = 5.981$, d.f.1, 19; $p < 0.025$). The interaction term was not significant ($F < 1$). That is, lipread priming equally increased reaction times in an auditory categorization task and a graphic categorization task. The mean number of categorization errors for the graphic task was 0.75, while it was 1.25 for the auditory test.

Discussion

While the interactive relationship between lipread and heard speech was predicted from the results of other paradigms, the priming of read words by lipreading was surprising.

Prior lipread experience of words facilitated their semantic categorization when they were heard and read. While the interactive relationship between lipread and heard speech was predicted from the results of other paradigms, the priming of read words by lipreading was surprising. Since lipreading is a more difficult, and less familiar, task than hearing or reading words, it is likely that any prior information about what a lipread stimulus might be would be used, irrespective of its modality of input. It is more difficult to explain why lipread experience should enhance the processing of read words. A comparison of the four experiments might clarify the pattern of findings.

Comparison of experiments 1, 2, 3 and 4

Table 1 sets out the mean difference scores (unprimed minus primed), and the percent difference expressed as a proportion of total reaction time, for each condition. A two-factor (prime mode, and test mode) Analysis of

Variance using percent difference scores, where each condition was treated as an independent group, was used to compare the four experiments. The priming term was not significant ($F < 1$), i.e. the type of priming (audi-tory, graphic and lipread) did not influence the extent of the priming effect. Obviously, the large analysis, treating the scores for each condition independently, swamped the finding that auditory priming does not affect the semantic categorization of read words (see experiment 2). This is hardly surprising, as all other conditions show a significant priming effect. The test term was significant ($F = 3.7$, d.f. 2, 65; $p < 0.025$), i.e. mode of test stimuli presentation affected the extent of the priming effect. Inspection of Table 1 shows that the priming effect was strongest for lipread test stimuli. The interaction term did not reach significance.

Table 1
Unprimed/Primed mean difference scores (msec) according to test and priming mode, and percentage increase due to priming

Test Mode						
Increase:	Δ	%	Δ	%	Δ	%
Graphic Prime	**64**	**9.4**	**69**	**4.3**	**179**	**10.5**
Auditory Prime	**10**	**1.4**	**90**	**6.1**	**216**	**14.3**
Lipread Prime	**55**	**6.7**	**47**	**1.9**	**164**	**7.7**

General Discussion

The experiments reported investigated the processing of lipread words in comparison to that of heard and read words using the repetition priming paradigm. The results were somewhat unexpected, and are difficult to explain. Lipreading was primed by everything, and primed everything. The only case when cross-modal priming did not arise was when the priming encounter was auditory and the test encounter was graphic. This finding is asymmetrical in that graphic presentations primed auditory tests. The findings cannot be explained by any *one* of the three hypotheses set out in the introduction.

A comparison of lipread and heard stimuli shows that each primed the other. This fits with the hypothesis that lipread and heard speech share a processing code at the level of lexical access. However, this hypothesis cannot account for all the priming effects found. Lipreading also primed reading, and reading primed auditory perception. The results suggest that at the level of lexical access, verbal information is coded differently from its form in short term memory, where it has been shown that lipread and heard speech share a code that excludes orthographic information (Campbell, Dodd and Brasher, 1983).

The second hypothesis, that same modality of perception would underpin the priming effects found, must also be rejected, since lipread and heard stimuli primed each other and reading primed auditory perception. The third hypothesis, that lipreading will be primed by everything because it is partial information, is rejected because although this was true, lipreading also primed everything.

Lipread stimuli behave differently from both heard and read stimuli. Lipreading primed reading, but hearing did not prime reading. Lipreading was primed by hearing, but reading was not primed by hearing. The pattern of findings cannot be simply explained by saying that lipread information is processed like heard information because they share a code; or like read information because they share a common modality of perception. Further, the fact that lipread stimuli are difficult to perceive has no general explanatory power because lipreading primed both heard and read stimuli.

The pattern of findings cannot be simply explained by saying that lipread information is processed like heard information because they share a code; or like read information because they share a common modality of perception.

Perhaps more than one factor is operating to produce the pattern of results found. Although the comparison across experiments must be considered with caution, an inspection of table 1 shows that the two largest percent priming advantages were both for a lipread test encounter, primed by auditory and graphic stimuli. Because lipreading is a more difficult task than hearing and reading, the lipreader has to "fill in" missing information. That is, lipreading involves more top-down processing. The fact that reaction times were longer for lipread stimuli than for heard and read stimuli may be explained by subjects' need to access stored information that aids identification of a perceptually unclear stimulus. Knowing which particular words were to be lipread dramatically improved reaction times. A large fraction of the priming advantage must be attributed to that factor, and consequently obscures the findings. If the effect of stimulus "incompleteness" could be partialled out, the results might be different, and easier to interpret.

Another factor that may have influenced the results was that repetition priming would be reduced in conditions where the prime was lipread because subjects did not recognize all of the stimuli during the priming phase. Despite these difficulties, lipread stimuli are still useable in the repetition priming paradigm. The within-modal priming advantage (experiment 1) was consistent across conditions. Even though lipreading takes longer, priming produced an advantage no greater than that found for hearing or reading. This result suggests that the priming effects found for lipread stimuli cannot be solely attributed to uncontrolled variables like task difficulty.

Further evidence that lipread stimuli are effective comes from the finding that lipreading primes both auditory and graphic processing (experiment 4). Since lipread information is partial, and the stimuli in both auditory and graphic test conditions are easily discriminable, the results seems counter-intuitive. One possible explanation is that during a lipread priming task, subjects access stored information from a variety of sources, including graphic and phonological representations of words, in order to identify the partial stimuli. This "deep processing" would be likely to enhance recognition memory, and speed the processing of identified words when they appeared in the auditory and graphic test phases.

The asymmetrical priming effect found for auditory and graphic stimuli is not new (see Monsell, 1985). Reading primed hearing, but hearing did not prime reading. This finding may reflect different reading strategy use in the two auditory/graphic cross-modal priming conditions. Written words can be processed by the brain in two ways. Studies of patients with brain injury have shown a double dissociation. Some patients can only read words using the grapheme-phoneme conversion route, others can only read words that they recognize as an orthographic gestalt (Coltheart, 1980). Subjects with normal brain function could use either route according to task demands. In a task where speed of response is the known measure, and the decision is one of semantic categorization of read words, recognizing gestalts would be more efficient, and the auditory priming could be ignored. When words are read as a priming task for a list that will be heard, subjects may choose to code the phonological shape of the stimuli because it would provide an advantage during the auditory test phase. This speculative hypothesis is not necessarily weakened by the finding that prior lipreading experience of words speeded response in a graphic test. The "deep processing" required for lipread stimuli during the priming phase may have accessed graphic representations that would contribute to, or account for, the priming advantage for read words in the test phase.

Written words can be processed by the brain in two ways. Studies of patients with brain injury have shown a double dissociation. Some patients can only read words using the grapheme-phoneme conversion route, others can only read words that they recognize as an orthographic gestalt. Subjects with normal brain function could use either route according to task demands.

The experiments reported are an initial exploration of the repetition priming effect using lipread stimuli. The processing of lipread stimuli differed from that of both read and heard stimuli. This is not necessarily surprising. Lipread stimuli share some characteristics of both heard and read stimuli. They also differ from heard and read stimuli in important ways. Logically, the pattern of cross-modal priming effects gained when using lipread stimuli should show similarities and differences with the two other means of verbal communication. Current experiments are investigating two hypotheses: that normal and degraded auditory and graphic stimuli will show different pattern of cross-modal priming, and that forcing subjects to code graphic stimuli phonologically will give rise to symmetrical cross-modal priming effects between hearing and reading.

Acknowledgements

We thank the N.H. & M.R.C. for financial assistance. We are grateful to Kim Kirsner for critically reviewing the manuscript.

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Ray Robinson is a professional Electronic Engineer and is in charge of the Speech, Hearing and Language Research Centre at Macquarie University. He holds a Bachelor of Engineering degree from the New South Wales Institute of Technology and is presently completing a Master of Arts (Honors) degree in Applied Linguistics and Computing Science.

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