Available online at www.sciencedirect.com
ScienceDirect
Consciousness and Cognition 17 (2008) 688–698
Consciousness and Cognition
www.elsevier.com/locate/concog

Unconscious auditory information can prime visual word processing: A process-dissociation procedure study ☆

Dominique Lamy [a,*], Liad Mudrik [a,b], Leon Y. Deouell [b]

[a] *Department of Psychology, Tel Aviv University, Ramat-Aviv, P.O. Box 39040, Tel Aviv 69978, Israel*
[b] *Department of Psychology and the Interdisciplinary Center for Neural Computation, The Hebrew University of Jerusalem, Israel*

Received 18 June 2007
Available online 20 December 2007

Abstract

Whether information perceived without awareness can affect overt performance, and whether such effects can cross sensory modalities, remains a matter of debate. Whereas influence of unconscious visual information on auditory perception has been documented, the reverse influence has not been reported. In addition, previous reports of unconscious cross-modal priming relied on procedures in which contamination of conscious processes could not be ruled out. We present the first report of unconscious cross-modal priming when the unaware prime is auditory and the test stimulus is visual. We used the process-dissociation procedure [Debner, J. A., & Jacoby, L. L. (1994). Unconscious perception: Attention, awareness and control. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *20*, 304–317] which allowed us to assess the separate contributions of conscious and unconscious perception of a degraded prime (either seen or heard) to performance on a visual fragment-completion task. Unconscious cross-modal priming (auditory prime, visual fragment) was significant and of a magnitude similar to that of unconscious within-modality priming (visual prime, visual fragment). We conclude that cross-modal integration, at least between visual and auditory information, is more symmetrical than previously shown, and does not require conscious mediation.

Keywords: Unconscious priming; Cross-modal priming; Visual-to-auditory priming; Process-dissociation procedure

1. Introduction

The ability to assimilate stimuli presented in different modalities into unified percepts is a fundamental component of perceptually guided action and cognition. Such ability is illustrated by phenomena in which perception in one modality is dramatically affected by stimulation in another modality. For instance, in the McGurk effect (McGurk & MacDonald, 1976), the same sound is heard as a different phoneme depending on what lip movements are seen. While it is clear that information from different modalities is initially coded in distinct

☆ Support was provided by the Israel Science Foundation Grant No. 1382-04 to Dominique Lamy.
* Corresponding author. Fax: +972 3 6409547.
E-mail address: domi@post.tau.ac.il (D. Lamy).

1053-8100/$ - see front matter
doi:10.1016/j.concog.2007.11.001

sensory areas, the processing levels at which cross-modal links is a matter of ongoing research. For instance, recent studies have shown multi-sensory integration to take place early in the cortical processing hierarchy, in brain regions traditionally held to be unisensory (see Ghazanfar & Schroeder, 2006, for a review). Such early locus suggests that integration processes are 'hard-wired' and automatic. However, it is unclear whether processing of a stimulus that is not perceived consciously, affects perceptual processing systems in other modalities, or if the output of such processing remains encapsulated within its own modality.

Several studies suggested that information from different sensory modalities may be integrated even when at least one modality is not attended (e.g., Driver & Grossenbacher, 1996; but see Dufour, 1999). However, while perception without attention and perception without awareness are frequently discussed in parallel (e.g., Debner & Jacoby, 1994), instructing subjects to ignore a given channel does not guarantee lack of awareness without an independent measure of conscious perception. Studies of preattentive cross-modal integration were typically not concerned with unconscious perception and did not therefore include such an independent measure.

The direct exploration of unconscious perception calls for dedicated experimental tools, with the *classical dissociation procedure* (Merikle & Reingold, 1998) being the most extensively used approach. The rationale of this procedure is to demonstrate a dissociation between two measures of perception, a direct measure held to index conscious perception and an indirect measure held to index unconscious perception. In a typical version of this paradigm, the masked implicit repetition priming paradigm (e.g., Forster & Davis, 1984), a word (henceforth, prime) is briefly presented and followed by a mask. Prime duration is set at a level where subjects either report not seeing the prime (subjective report, e.g., Cheesman & Merikle, 1986) or show zero sensitivity in judging between two different states of the prime (objective threshold, e.g., Draine & Greenwald, 1998). Exposure to the prime and mask is followed by say, a word-stem completion task, in which subjects must complete the stem with the first word that comes to mind (other tasks such as fragment-completion and lexical decision are also routinely used). Unconscious priming is said to occur when subjects complete the stem with a word related to the prime (target) significantly more often than is expected by chance. Putatively, such an effect demonstrates that a prime not consciously perceived can nonetheless bias performance, and is taken to reflect automatic or unconscious activation of representations shared by prime and target.

The classical dissociation procedure has been criticized on various grounds (e.g., Holender, 1986). Its opponents have claimed that the use of two different measures to index conscious and unconscious perception opens the possibility that the dissociation observed might result from a difference in sensitivity between the two measures rather than from the existence of two different underlying processes. The process-dissociation procedure (Jacoby, 1991) was designed to overcome these problems. This approach rests on the basic assumption that consciously perceived information is subject to voluntary control, whereas information perceived without awareness leads to more automatic responses. Debner and Jacoby (1994) relied on this qualitative difference to study unconscious perception by pitting conscious and unconscious processes in opposition. They used the masked repetition priming paradigm (e.g., Forster & Davis, 1984) with an important twist: In one condition ("inclusion"), subjects had to complete the stem with the prime, and if unable to, to provide the first word that came to mind. In another condition ("exclusion"), subjects were instructed *not* to complete the word-stem with the prime or, if they did not see it, to provide the first word that came to mind. Suppose for instance that the prime word had been FLOWER and the stem was FL - - -. In the inclusion condition, if the subject came up with FLOWER (correct inclusion trials), this might indicate either that the subject consciously perceived the prime or that conscious perception failed, but the effects of unconscious perception were sufficient for the word FLOWER to be the first to come to mind. Thus, the proportion of correct inclusion trials in the inclusion condition reveals the effects of an unknown combination of conscious and unconscious perception. In the exclusion condition, the subject could err and provide the prime word despite the instructions if the effect of unconscious perception was sufficient for the prime word to be the first to come to mind, but only if the prime word was *not* also consciously perceived. Had the subject consciously seen the prime, she or he would have followed the rules and avoided using this word as an answer. Thus, a proportion of *exclusion errors* (i.e., completing the stem with the prime, despite the instruction not to do so) that is larger than can be expected by chance, indicates that unconscious perception has occurred.

Only three previous studies have addressed the issue of unconscious cross-modal integration (Grainger, Diependaele, Spinelli, Ferrand, & Farioli, 2003; Kouider & Dupoux, 2001; Nakamura et al., 2006). A visual-prime word was briefly presented. A word or non-word was then presented either visually or aurally, and subjects had to decide whether or not it was a word (lexical decision task). To verify that the prime had not been perceived consciously, a prime visibility test was conducted at the end of each experiment. Both within-modality and cross-modal visual-to-auditory unconscious priming were found in all three studies (but in Kouider & Dupoux, 2001, cross-modal priming correlated with prime visibility). However, the inferences from these studies may be limited for two main reasons. First, unconscious perception was assessed at the end of the experiment rather than on a trial-by-trial basis. As awareness thresholds may fluctuate in the course of the experiment, effects attributed to unconscious processing may in fact result from a proportion of trials in which the prime was consciously perceived. Second, these studies relied on the classical dissociation procedure, with its potential caveats described above. Thus, the possibility that residual conscious perception produced the observed cross-modal priming effects cannot be ruled out. In the present study we used the process-dissociation procedure to investigate unconscious cross-modal integration.

The present experiment was similar to Debner and Jacoby's (1994), with two major changes. First, it included two sessions differing in prime-presentation modality: visual or auditory. In both sessions, the test was a visually presented fragment-completion task. No study to date has examined unconscious cross-modal priming when the prime is auditory and the test stimulus is visual. Second, instead of using brief exposures, stimulus degradation was achieved by lowering stimulus contrast relative to background while maintaining long exposure durations. The critical question in the present study is whether stimuli that were adequately processed, albeit without conscious awareness, can integrate with consciously perceived information. When prime stimuli are rendered invisible by limiting exposure time, they may fail to affect the processing of the target not because of lack of awareness, but because the sensory input was not available for long enough to get adequately processed (Grainger et al. 2003). To avoid this ambiguity, awareness of the prime was limited while using prime durations long enough to allow cross-modal integration of unconscious information, if this is at all possible.

Thus, our study aimed to confirm the possibility that information perceived in one modality without awareness can be integrated with processing in another modality, while better controlling for contamination by conscious processing. This, together with generalization of the phenomenon beyond the unidirectional visual-to-auditory influence, would lend strong support for non-conscious cross-modal effects.

2. Materials and methods

2.1. Subjects

Ten undergraduate students from Tel Aviv University participated in the study for course credit or for pay (the equivalent of $10). All had normal or corrected to normal vision and normal hearing, and were native Hebrew speakers.

2.2. Apparatus and stimuli

Stimuli were displayed on a 17″ CRT monitor. A chin-rest was used to set viewing distance at 40 cm from the monitor. The stimuli consisted of 560 Hebrew words, drawn from the Frost, Forster, and Deutsch (1997) word list. All words were at least 4-letter long and had a familiarity score of less than 3.5 (1 = very unfamiliar and 7 = very familiar). In each prime-modality condition, 80 words served for the calibration phase and 200 words for the experimental phase. Different word lists from the same pool were randomly constructed for each subject.

Each potential prime word was initially paired with a suitable word fragment. Baseline levels (i.e., the probability of completing a word fragment with the target prime when that word was not primed) were determined by pre-testing 100 subjects required to complete the word fragments. A word and associated fragment was selected for the experimental phase if its baseline level was no more than 10%, and the probability of choosing a specific alternative completion did not exceed 30% (to avoid fragments with prepotent responses).

The visually presented word primes were gray and appeared against a filled rectangle ($3.58^\circ \times 2.1^\circ$ of visual angle) of a different shade of gray. The gray level of the rectangle was 212 on a scale of 0 (black) to 255 (white)[1]. The aurally presented word primes were recorded in a female voice and presented against a background noise of 60 dB[2] through earphones. Prime brightness and prime intensity levels in the visual and auditory conditions, respectively, were set according to calibration tests described below. Word fragments were white on exclusion trials and red on inclusion trials for half of the subjects, and had the reverse color assignment for the remaining subjects.

2.3. Procedure

Each subject underwent the visual-prime (within-modality) condition and the auditory-prime (cross-modality) condition in two consecutive sessions, with order counterbalanced between subjects. Each session began with an individual calibration phase, followed by an experimental phase.

2.4. Calibration phase

The calibration phase served to determine a level of contrast (henceforth, calibrated contrast) at which exposure to the prime yielded a level of conscious perception low enough to produce incorrect exclusions (i.e., trials in which subjects completed the fragment with the prime when instructed NOT to) and high enough to produce correct inclusions (i.e., trials in which subjects completed the fragment with the prime when so instructed). The calibration was not intended to preclude residual awareness, as is typically the case with the classical dissociation procedure: fully eliminating conscious perception was not necessary because the process-dissociation procedure allowed us to distinguish between conscious and unconscious perception on every trial of the test phase itself.

On each calibration trial, a target word was presented for 500 ms. Subjects had to read it aloud (in the visual condition) or repeat it (in the auditory condition), and if unable to, to provide a "don't know" response. Using a staircase procedure (Levitt, 1971), stimulus contrast was decreased following a response that shared two letters or more with the target word, and increased following an error or "don't know" response, separately for each subject, with steps of 1 on a gray scale of 0 (black) to 255 (white) in the visual condition, and 1 dB in the auditory condition. Calibrated level was set at one step above the lowest contrast level reached by the subject throughout the calibration phase.

2.5. Experimental phase

In each trial, a barely visible word (in the visual-prime condition), or a barely audible word (in the auditory-prime condition) was presented at the individual calibrated contrast level for 500 ms. A visual word fragment, either red or white, followed after a 2-s inter-stimulus interval. A new trial began after the experimenter had coded the subject's response. Exclusion and inclusion trials were randomly mixed. Hence, the subject knew what response to emit (inclusion or exclusion) only on the basis of the fragment color (red or white), that is, 2 s after the prime was no longer present. At the beginning of each experimental phase, the inclusion and exclusion instructions were thoroughly explained and followed by five practice trials. In particular, in order to ensure that the subjects fully complied with the exclusion instructions, the following clarifications were provided: "The target primes are always compatible with the fragments. So, if you see only a few letters, for instance "LOM", and later see the fragment "X _ _ _ M", you can infer that the target prime was "XALOM" ("DREAM", in Hebrew). In that case, you should not use "XALOM" to complete the fragment."

[1] Colors on cathode ray tube (CRT) monitors with 8-bit color resolution are set in a range of 0 (dark) to 255 (maximum luminance) for each red, green and blue (RGB) channels of the CRT. To produce gray, the red, green and blue intensities are set to be equal. Thus, the gray scale ranges from RGB(0,0,0) for black and RGB(255,255,255) for white.

[2] Because the present experiment was designed to be run also using functional magnetic resonance imaging (fMRI), the background noise was recorded from an fMRI scanning session.

2.6. Results

The pre-test baseline rates obtained for the prime words to be used in the visual and auditory conditions were 2.6% vs. 2.7%, respectively, $t(98) = 0.1$, $p > .9$. Mean visual calibrated gray level was 208.4, $SD = 3.7$, and mean auditory calibrated level was 30 dB, $SD = 3.97$. Fragments were completed by the visual-prime words in 0.42 of inclusion trials and 0.21 of exclusion trials on the average (Fig. 1). For auditory primes the rates were 0.42 and 0.21, respectively. Subsequent analyses were performed on an arcsine transformation of the square root of the proportion of correct inclusions and incorrect exclusions for each subject (Zar, 1984).

To determine whether unconscious perception occurred in each of the two prime-modality conditions, performance on exclusion trials was compared to baseline. The percentage of incorrect exclusions was significantly higher than baseline in the visual-prime condition, $t(58) = 15.5$, $p < .0001$, as well as in the auditory-prime condition, $t(58) = 13.98$, $p < .0001$ (Fig. 1). Thus, unconscious priming occurred in both the within-modality and cross-modality conditions.

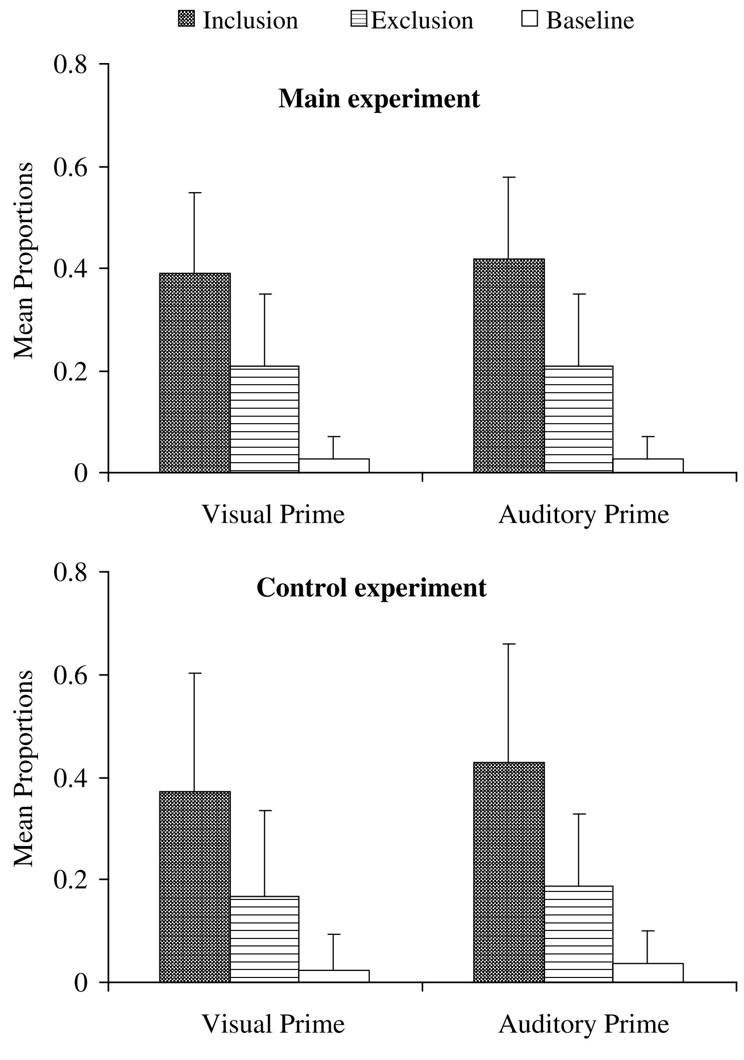

Fig. 1. Means and standard errors of the observed proportions of completing visual word fragments with target words by conditions of prime modality and instructions. For the main experiment, baseline rates were established in a pre-test outside of the experiment, whereas in the control experiment, "baseline" trials were mixed with the "inclusion" and "exclusion" trials.

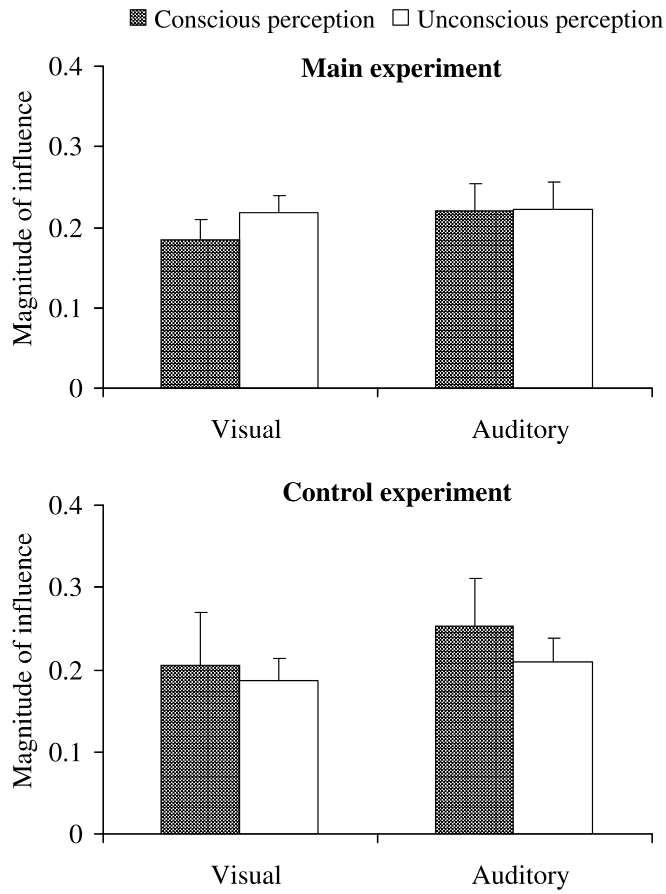

Fig. 2. Means and standard errors of the estimated contributions of conscious perception and unconscious perception to visual word fragment-completion performance by conditions of prime modality. See Appendix A for the formulas used to calculate these values.

To measure the contributions of conscious and unconscious processes, we used the equations derived by Debner and Jacoby (1994, p. 307) and described in Appendix A. Fig. 2 shows the mean estimates of unconscious and conscious perception in the within-modality and cross-modality conditions. The influence of unconscious processes was of comparable magnitude in the within- and between-modalities conditions, and so was the influence of conscious processes, Fs < 1.

3. Control experiment

In the main experiment, baseline performance and exclusion performance were assessed in different settings and with different subjects. The advantage was that all subjects in the main experiment could be tested with the same set of primes and probes for which 'normative' data were previously collected. However, with this design, the increased probability of using the prime in the main experiment, relative to its selection rate in the baseline experiment may, might have reflected factors other than the hypothesized unconscious perceptual processes. These factors may include, among others, individual subjects' idiosyncratic language experience (although unlikely considering the large size of cohort tested for normative baseline data), the enhanced time pressure during the main experiment, and the necessarily different instructions given. In order to eliminate this possible confound, we ran a control experiment with six new subjects.

4. Methods

4.1. Subjects

Six undergraduate students from Tel Aviv University participated in the study for course credit or for pay ($10). All had normal or corrected to normal vision and normal hearing, and were native Hebrew speakers.

4.2. Apparatus, stimuli and procedure

The apparatus, stimuli and procedure were the same as in the main experiment, except for the following changes. Half of the inclusion trials and half of the exclusion trials were now baseline trials, which were randomly mixed with the other trials in the experimental phase. Baseline trials were trials in which the prime word was replaced by an empty background rectangle with no prime word (in the visual-prime condition) or by the background noise with no spoken word (in the auditory-prime condition). Blank primes on baseline trials were equally likely to be followed by a word fragment in the color denoting exclusion or an inclusion instruction. Exclusion baseline rates were calculated as the proportion of fragments presented in exclusions trial, which were completed by their target word, even though there was no prime word presented.

4.3. Results

The results were similar to those of the main experiment. Mean visual calibrated gray level was 206.8, $SD = 0.75$, and mean auditory calibrated level was 29 dB, $SD = 2.8$. Fig. 1 (bottom panel) shows a summary of the fragment-completion performance in the visual and auditory-priming conditions of the control experiment. Exclusion error rates in both the visual-prime condition and the auditory-prime condition were much higher than the baseline rates (visual: 0.168 vs. 0.024, $p < .005$; auditory: 0.186 vs. 0.036, $p < .0006$). The influence of unconscious processes was again of comparable magnitude in the within- and between-modalities conditions, and so was the influence of conscious processes, Fs < 1 (Fig. 2, bottom panel). Thus, the results of the control experiment replicated the results of the main experiment and eliminated the possibility that strategic differences between baseline and exclusion conditions rather than unconscious processing accounted for the observed results.

4.4. Discussion

In this study, we examined whether information perceived without awareness in one modality can bias the processing of information presented in another modality. We used the process-dissociation procedure to distinguish between effects of conscious and unconscious perception, and compared unconscious priming within-modality (vision to vision) and across modalities (audition to vision). The results revealed significant unconscious priming effects both within and between modalities, with no significant difference between the two effects. Thus, information perceived without conscious awareness can nonetheless affect the processing of information subsequently perceived not only in the same, but also in a different modality.

The methods for quantification of conscious and unconscious processes within the process-dissociation paradigm (outlined in Appendix A) have been criticized for assuming that conscious and unconscious processes are independent. As an alternative, the redundancy model (e.g., Joordens & Merikle, 1993) suggests that these processes may overlap, such that the independence assumption may result in an underestimation of unconscious perception. Thus, under the redundancy hypothesis, estimates for cross-modal (and within-modality) unconscious perception would be even higher than those reported here. In addition, it should be noted that even without deriving estimates of conscious and unconscious perception, the direct comparison between exclusion error and baseline rates by itself provides evidence for unconscious perception (e.g., Merikle, Joordens, & Stolz, 1995). The independence issue cannot therefore undermine the conclusions of the present study showing cross-modal auditory-to-visual unconscious priming.

Kouider and Dupoux (2004) suggested that under certain conditions, partial awareness may account for findings attributed to unconscious word perception. Along this argument, one may argue that *conscious* perception of some of the word's lower-level features (e.g., a few individual letters or phonemes) may have influenced the subjects' completions in the exclusion condition of the present study. As with all previous studies addressing the issue of unconscious priming (visual-visual or visual-auditory), the partial awareness alternative explanation cannot be completely rejected. Several arguments, however, make the partial awareness account of our findings less likely. First, although it does not preclude partial awareness, the exclusion paradigm is better suited than other paradigms to limit the influence of partial awareness effects because if subjects comply with the instructions of not using the prime word, partial awareness is less of a concern. Moreover, as noted in the methods section, the way our instructions were phrased actually gave an example of the situation of partial awareness, and explicitly instructed subjects how not to use this information. Last, the unlikely possibility that despite these instructions our subjects nevertheless used a partial information strategy is incompatible with a post-hoc analysis of exclusion error rates. It follows from the partial awareness account that shorter words are more likely than longer words to be entirely specified by the conjunction of the to-be-completed fragment and the consciously perceived letters or phonemes, because the number of these was limited by the calibration procedure, regardless of word length. Thus, by this account, shorter words should have higher exclusion error rates. Yet, further analyses of our data showed, as is clear from Table 1, that exclusion error rates for shorter words (4-letter and 2-phoneme words, in the visual-visual and auditory-visual conditions, respectively) were not higher than for longer words (5-letter and 3-phoneme words).

Because the prime word and word fragment were separated by a 2-s interval, our findings may arguably reveal effects of memory rather than effects of unconscious perception. That is, subjects may have consciously perceived the prime but then forgotten it by the time the word fragment appeared. If this were the case, the above-baseline proportion of incorrect exclusions observed here would have resulted from traces that were laid by conscious perception but had degraded with time. This possibility, however, is unlikely for several reasons. First, since the inter-stimulus interval was blank, there was no retroactive interference to the prime, and no forgetting over the course of 2 s should be expected under these conditions. Second, additional analyses of the calibration-phase data revealed that subjects were able to read or repeat the target words on a relatively small proportion of the trials in which contrast level was at the calibrated level (29.6% and 26.0%, in the visual and the auditory conditions, respectively), although they were required to respond immediately after being exposed to the target word, that is, when the probability of forgetting was minimal. Finally, we conducted a control study, with inter-stimulus intervals of 0, 2 or 4 s. Had the apparent unconscious effect been nothing but forgetting, we should have found fewer exclusion errors with the 0 lag, and more with the 4-s lag, as more forgetting is expected the longer time has elapsed between prime and fragment. The data from six new subjects showed that, if anything, the proportion of incorrect exclusions decreased with longer inter-stimulus intervals (16.5%, 13.8% and 12.7% for the 0, 2 and 4-s ISI, respectively). Moreover, the proportion of correct inclusions was unaffected (29%, 29% and 30% for the 0, 2 and 4-s ISI, respectively), suggesting again that no forgetting occurred during the empty 2-s interval. It seems therefore safe to conclude that our results reflect unconscious perception rather than memory effects.

From a psycholinguistic viewpoint, the finding that a spoken word perceived without awareness can prime that word in visual form is open to different interpretations. Heard words may be connected to seen words through direct phonology-to-orthography links or via the mediation of semantic representations. The presence of cross-modal priming as found here suggests that activation of at least one of these two levels can occur without a need for conscious control. Models of normal word recognition typically assume links between orthography and phonology at either the pre-lexical or lexical levels. Most of these models postulate that spo-

Table 1
Means and standard errors (in parentheses) of the exclusion rates by conditions of word length and prime modality in the main experiment

	Within-modality (visual-visual)		Cross-modality (auditory-visual)	
	4-Letter words	5-Letter words	2-Phoneme words	3-Phoneme words
Mean	0.125	0.128	0.124	0.124
SD	0.08	0.127	0.1	0.07

ken words are perceived without reference to their orthography (e.g., Marslen-Wilson, 1987), and that activation flows only from orthography to phonology. This view is based on numerous findings showing that phonology influences performance on purely orthographic tasks (e.g., Coltheart, Davelaar, Jonasson, & Besner, 1977). However, orthography effects in spoken word recognition have also been reported (e.g., Frost, Repp, & Katz, 1988), suggesting that hearing a spoken word activates this word's orthographic representation. The present finding may provide an important extension to this conclusion, by showing that orthographic activation by auditory word perception occurs automatically and in the absence of conscious control. The alternative interpretation is that a spoken word not consciously perceived automatically activates its semantic representation, which in turn primes the orthographic representation of the same word. Further research is needed to resolve these two options.

We manipulated prime modality, with word fragments (i.e., the test phase) presented visually in both prime-modality conditions. The reverse situation prevailed in the three previous studies of unconscious cross-modal integration (Grainger et al., 2003; Kouider & Dupoux, 2001; Nakamura et al., 2006): primes were always visual, and modality of the target was manipulated. Therefore, the present study is the first report of unconscious cross-modal priming with an auditory prime and a visual test. Yet, like Grainger et al. (2003) we also found that unconscious priming effects were equally large within and between modalities. Taken together, these findings suggest that the magnitude of cross-modality priming (between the auditory and visual modalities) is similar to that of within-modality priming (within the visual modality). This is the case both when priming takes place from an auditory prime perceived without awareness to a visual test stimulus (as in the present study) and from a visual prime perceived without awareness to an auditory test stimulus (as in Grainger et al.'s study).

This pattern of results contrasts with findings from the memory literature. Studies using repetition priming with study and test phases separated by much longer lags have shown comparable within- and cross-modality priming when modality at study was visual (visual-visual vs. visual-auditory, e.g., Loveman, van Hooff, & Gale, 2002). However, in contrast to our findings, auditory to visual priming with long lags was found to be about half the magnitude of within-modality visual to visual priming (e.g., Roediger & Blaxton, 1987). As comparison with memory studies was not the goal of our study, we can only speculate on the reasons for this discrepancy. An important difference between our design and the long-lag memory studies is that the primes in the present study were perceived without conscious awareness, whereas subjects were clearly aware of the primes in memory studies. Apparently, awareness of the primes *per se* is unlikely to account for the discrepancy between the findings of our study and those of the memory literature because we found the magnitude of conscious influence of the prime to be comparable in the within- and between-modalities conditions, although it is possible that over longer lags, conscious processing confers advantage mostly within-modality, and thus within-modality priming appears stronger. Of note is the fact that in our experiment, unaware perception was induced by presenting the stimuli at threshold contrast. This might reduce intra-modal perceptual priming, which is based on unimodal sensory areas (e.g., Schacter, Alpert, Savage, Rauch, & Albert, 1996). In contrast, more conceptual or abstract levels, which may be more equivalent for within- and cross-modality priming, and rely on heteromodal or amodal cortices, may be less sensitive to this perceptual manipulation (see Schacter, Wig, & Stevens, 2007, for review of the neuroanatomy of priming). This may explain why in our case there was no advantage for within-modality priming. Alternatively, one may speculate that information transferred through phonology-to-orthography links (whether direct or mediated by semantic representations) decays relatively fast, reducing priming at long lags, whereas information transferred through direct orthographic activation might have a slower decay rate. Further research should clarify these issues.

5. Conclusions

The present findings show that conscious mediation is not necessary for cross-modal integration of visual and auditory information. As such, they are in line with the attentional literature suggesting that cross-modal links are preattentive. Our results also suggest that preconscious links exist between phonological codes and orthographic codes in the phonology-to-orthography direction, although they are not conclusive as to whether such links are direct or mediated by semantic representations.

Appendix A

The prime word should be given as a completion on an exclusion trial only if unconscious perception (U) was sufficient for this word to be the first to come to mind AND the prime word was NOT also consciously perceived ($1 - C$), OR if the subject came upon this word by chance. Thus probability of giving the prime word as a completion in the exclusion condition is:

$$\text{Exclusions} = U\ (1 - C) + \text{Baseline} \tag{A.1}$$

According to the process-dissociation procedure (Debner and Jacoby, 1994), conscious perception (C) can be estimated as:

$$C = \text{Inclusions} - \text{Exclusions}. \tag{A.2}$$

From which it follows that:

$$U = (\text{Exclusions} - \text{Baseline})/(1 - \text{Inclusions} + \text{Exclusions}). \tag{A.3}$$

References

Cheesman, J., & Merikle, P. M. (1986). Distinguishing conscious from unconscious perceptual processes. *Canadian Journal of Psychology, 40*, 343–367.

Coltheart, M., Davelaar, E., Jonasson, J. T., & Besner, D. (1977). Access to the internal lexicon. In S. Dornic (Ed.), *Attention and performance VI* (pp. 534–555). New York: Academic Press.

Debner, J. A., & Jacoby, L. L. (1994). Unconscious perception: Attention, awareness and control. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20*, 304–317.

Draine, S. C., & Greenwald, A. G. (1998). Replicable unconscious semantic priming. *Journal of Experimental Psychology: General, 127*, 286–303.

Driver, J., & Grossenbacher, P. G. (1996). Multimodal spatial constraints on tactile selective attention. In J. L. McClelland & T. Inui (Eds.), *Attention and performance XVI: Information integration in perception and communication* (pp. 209–235). Cambridge, MA: US: The MIT Press.

Dufour, A. (1999). Importance of attentional mechanisms in audiovisual links. *Experimental Brain Research, 126*, 215–222.

Forster, K. I., & Davis, C. (1984). Repetition priming and frequency attenuation in lexical access. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 10*, 680–698.

Frost, R., Forster, K. I., & Deutsch, A. (1997). What can we learn from the morphology of Hebrew: A masked priming investigation of morphological representation. *Journal of Experimental Psychology: Learning Memory, and Cognition, 23*, 829–856.

Frost, R., Repp, B. H., & Katz, L. (1988). Can speech perception be influenced by simultaneous presentation of print?. *Journal of Memory and Language 27*, 741–755.

Ghazanfar, A. A., & Schroeder, C. E. (2006). Is neocortex essentially multisensory? *Trends in Cognitive Sciences, 10*, 278–285.

Grainger, J., Diependaele, K., Spinelli, E., Ferrand, L., & Farioli, F. (2003). Masked repetition and phonological priming within and across modalities. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 29*, 1256–1269.

Holender, D. (1986). Semantic activation without conscious identification in dichotic listening, parafoveal vision and visual masking: A survey and appraisal. *Behavioral and Brain Sciences, 9*, 1–23.

Jacoby, L. L. (1991). A process dissociation framework: Separating automatic and intentional uses of memory. *Journal of Memory and Language, 30*, 513–541.

Joordens, S., & Merikle, P. M. (1993). Independence or redundancy? Two models of conscious and unconscious influences. *Journal of Experimental Psychology: General, 122*, 462–467.

Kouider, S., & Dupoux, E. (2001). A functional disconnection between spoken and visual word recognition: Evidence from unconscious priming. *Cognition, 82*, B35–B49.

Kouider, S., & Dupoux, E. (2004). Partial awareness creates the illusion of subliming semantic priming. *Psychological Science, 15*, 75–81.

Levitt, H. (1971). Transformed Up–Down methods in psychoacoustics. *The Journal of the Acoustical Society of America, 49*, 467–477.

Loveman, E., van Hooff, J. C., & Gale, A. (2002). A systematic investigation of same and cross modality priming using written and spoken responses. *Memory, 10*, 267–276.

Marslen-Wilson, W. D. (1987). Functional parallelism in spoken word recognition. *Cognition, 25*, 71–102.

McGurk, H., & MacDonald, J. (1976). Hearing lips and seeing voices. *Nature, 264*, 746–748.

Merikle, P. M., & Reingold, E. Y. (1998). On demonstrating unconscious perception: Comment on Draine and Greenwald. *Journal of Experimental Psychology: General, 127*(3), 304–310.

Merikle, P. M., Joordens, S., & Stolz, K. A. (1995). Measuring the relative magnitude of unconscious influences. *Consciousness and Cognition, 4*, 422–439.

Nakamura, K., Hara, N., Kouider, S., Takayama, Y., Hanajima, R., Sakai, K., & Ugawa, Y. (2006). Task-guided selection of the dual neural pathways for reading. *Neuron, 52*, 557–564.

Roediger, H. L., & Blaxton, T. A. (1987). Effects of varying modality, surface features and retention interval on priming in word-fragment completion. *Memory and Cognition, 5*, 379–388.

Schacter, D. L., Alpert, N. M., Savage, C. R., Rauch, S. L., & Albert, M. S. (1996). Conscious recollection and the human hippocampal formation: Evidence from positron emission tomography. *Proceedings of the National Academy of Sciences of the United States of America, 93*, 321–325.

Schacter, D. L., Wig, G. S., & Stevens, W. D. (2007). Reductions in cortical activity during priming. *Current Opinion in Neurobiology, 17*, 171–176.

Zar, J. H. (1984). *Biostatistical analysis* (2nd ed.). New Jersey: Prentice Hall.