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COGNITION

Cognition 82 (2001) B35–B49

www.elsevier.com/locate/cognit

Brief article

A functional disconnection between spoken and visual word recognition: evidence from unconscious priming

Sid Kouider*, Emmanuel Dupoux

Laboratoire de Sciences Cognitives et Psycholinguistique, EHESS/CNRS, Paris, France

Received 16 September 2000; accepted 4 July 2001

Abstract

The goal of the present study is to assess whether there is an automatic and obligatory activation of the phonological lexicon upon the presentation of a written word under unconscious processing conditions. We use a cross-modal version of the masked repetition priming procedure introduced by Forster and Davis (Journal of Experimental Psychology: Learning, Memory, and Cognition 10 (1984) 680) which consists of priming a spoken word by its written equivalent under masked conditions. These trials are randomly mixed with within-modal (visual–visual) repetition priming control trials. Our results show that cross-modal priming effects are absent unless primes are consciously perceived, as assessed by d' scores obtained with a letter/pseudo discrimination task. In contrast, priming effects within the written modality are observed under conscious as well as unconscious processing conditions. We conclude that the systems underlying written and spoken word processing are, respectively, autonomous and connected only under conscious conditions. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Masked priming; Cross-modal priming; Conscious and unconscious processing; Word recognition

* Corresponding author. Laboratoire de Sciences Cognitives et Psycholinguistique, Ecole des Hautes Etudes en Sciences Sociales (EHESS), 54 Boulevard Raspail, 75270 Paris Cedex 06, France. Fax: +33-1-45-44-98-35.

E-mail address: sidk@lscp.ehess.fr (S. Kouider).

PII: S0010-0277(01)00152-4

1. Introduction

Auditory word recognition precedes visual word recognition, both historically and developmentally. As far as we can tell, all cultures have used a spoken language; in contrast, the discovery of writing systems is fairly recent. Children spontaneously develop an auditory processing system; in contrast, mastering language in a written code requires several years of explicit drill and practice. These differences have prompted many researchers to consider spoken language to be linked to our biological endowment, whereas written language is seen as an example of cultural acquisition (Lenneberg, 1967). One question that arises, however, is what is the relationship between the two processing systems in the literate adult? Is the reading processing system dependent from the auditory system, or has it acquired the status of an autonomous processing module (Coltheart, 1999; Fodor, 1983)?

Neuropsychological investigations have demonstrated that in the literate adult, the two systems are quite autonomous (Caramazza & Hillis, 1990, 1991). In particular, visual word recognition is obtained even in the absence of a functional phonological system (e.g. Hanley & McDonnell, 1997; Shelton & Weinrich, 1997). These studies, among others, suggest that the adult has developed an independent input system for visual word processing that does not require phonological activation in lexical access (see Caramazza, 1997, for a review). This view has been labelled the *orthographic autonomy hypothesis* (Rapp, Benzing, & Caramazza, 1997). According to Caramazza and colleagues, access to meaning can be achieved directly from the orthography without any mandatory phonological mediation, this mediation being performed only optionally in the recognition process (Caramazza, 1997; Coltheart & Coltheart, 1997).

Within psycholinguistics, however, there is more controversy regarding the relative autonomy of orthographic and phonological systems. Indeed, significant interactions between the orthographic and phonological systems have been reported in many tasks. For instance, in a visual lexical decision task, nonwords that sound like words (e.g. brane) take more time to respond to than nonwords that do not sound like words (e.g. brame) (Coltheart, Davelaar, Jonasson, & Besner, 1977; Rubenstein, Lewis, & Rubenstein, 1971). Van Orden (1987) reported similar effects in a semantic classification task using homophonous stimuli like “rows” and “rose”. These results and others suggest that phonology is involved in tasks that could in principle be performed solely on the basis of written information. Conversely, Seidenberg and Tanenhaus (1979), Dijkstra, Roelofs, and Fieuws (1995), and Hallé, Chereau, and Segui (in press) among others found that purely phonological tasks like rhyme detection or phoneme monitoring are strongly influenced by the orthographic code. Accordingly, many current psycholinguistic models assume direct and automatic connections between the orthographic system and the phonological input system. For instance, in the interactive activation MROM-P model of Jacobs, Rey, Ziegler, and Grainger (1998), the two systems are connected by two sets of bidirectional links: one set is prelexical, and the other is lexical. Similarly, in distributed models such as that of Plaut, McClelland, Seidenberg, and Patterson (1996) phonological, orthographic and semantic representations are heavily interconnected. Some authors even consider that there is, functionally speaking, a single amodal lexical system (Marslen-Wilson, Tyler, Waksler, & Older, 1994), and use a *cross-modal priming* technique in which a visual target is presented subsequent to or simultaneous with consciously presented auditory stimuli, to study the on-line activation of speech processing (Marslen-Wilson & Zwitserlod, 1989; Swinney, 1979; Warren, 1972; see Tabossi, 1996, for review).

How can we reconcile these two contradictory views? A word of methodological caution is needed here. Most psycholinguistic tasks involve two stages: automatic processing of the stimuli and task-specific decision making (e.g. Neely, 1991; Posner & Snyder, 1975; Seidenberg, Waters, Sanders, & Langer, 1984). The decision making stage involves the central executive (Fodor, 1983; Shallice, 1988), a horizontal system, the purpose of which is to connect and integrate information coming from several sources in order to make a decision. In this light, coactivation of multiple codes in an experiment could arise either because the input processing systems are interconnected or because participants take into account multiple (and sometimes irrelevant) codes during decision making (Dupoux & Mehler, 1992). In order to distinguish between these hypotheses, it is important to control for the involvement of the central executive in the tasks at hand. Fortunately, masked priming offers an experimental tool for such a control. The working assumption within this paradigm is that when stimuli are sufficiently masked, they do not reach the central executive and hence cannot enter into response strategies, nor can they be consciously reported by the participants (e.g. Forster, 1998). Yet, to the extent that the masked stimuli have an effect on the subsequent processing of the target word, this paradigm can be used to assess the processing routes that are automatically activated without the involvement of conscious strategies.

In this study, we do not address all aspects of the relationship between auditory and visual processing. Rather, we wish to focus on these relationships at the *lexical* level. Specifically, the question is whether the phonological input lexicon is mandatorily and automatically engaged upon the presentation of written words, or whether such activation only arises through strategies controlled by the central executive. This question is important for three reasons. First, it could help in teasing apart connectionist models that postulate automatic interconnections between the auditory and visual input lexicons from these models that postulate autonomous lexicons. Second, it could help in understanding the locus of effects obtained with the "conscious" cross-modal priming technique that has been extensively used to study on-line activation of spoken words. Third, it could illustrate the usefulness of the masked priming paradigm in studying the functional architecture of the linguistic system using neurologically intact subjects.

2. The present study

In this paper, we use a paradigm that has been used extensively to study automatic/unconscious processing: the masked priming paradigm (Marcel, 1980). In the classical masked repetition paradigm (Forster & Davis, 1984, 1991), a prime letter string in lower-case is presented for a brief duration (around 50–60 ms) and both forward masked by a pattern mask (e.g. ######) and backward masked by a target letter string are in upper-case. Priming is said to occur when latencies to the targets (e.g. DOG) are facilitated by the presence of a preceding related prime (e.g. *dog*) as compared to an unrelated control prime (e.g. *bin*). Such a paradigm has been argued to tap automatic lexical processing. The strongest effect obtained in this paradigm is identity priming, i.e. when the prime and target are identical (except for case). Form priming has been reported for one-letter different primes (e.g. aptitude–ATTITUDE) (Forster, Davis, Schoknecht, & Carter, 1987), as well as morphological priming (sent–SEND) (Frost, Forster, & Deutsch, 1997). The failure to find strong effects of the visual similarity between prime and target (Bowers, Vigliocco, & Haan, 1998), and of semantic/conceptual priming (Perea & Gotor, 1997) as well as the weakness of nonword repetition effects in lexical decision suggests that this situation allows one to study rather specifically the input lexical system (see Forster, 1998). Under the correct timing conditions, it can be demonstrated that the prime is not consciously perceived, but can be automatically processed by the system.[1]

We adapted this masked priming technique to study cross-modal activation. The logic is very simple: if the two input systems are interconnected, one should be able to observe a repetition effect across modalities (visual to auditory), even in a situation where the participants do not consciously perceive the visual prime. In contrast, if the two systems are only connected through the central executive, cross-modal repetition priming should only be found when participants start to consciously perceive the prime.

As in the Forster and Davis paradigm, the prime is always a visually presented letter string. However, the targets can either be visual (within-modal trials) or auditory (cross-modal trials). When the targets are auditory, there is a visual post-mask in order to mask the prime. The two types of trials are randomly intermixed in the experiment so that participants have no way of knowing prior to the appearance of the target whether a given trial will be visual or auditory. This was done to insure that they pay equal attention to the visual primes in both types of trials. The guiding assumption was that if we do find within-modal priming, we can conclude that participants processed the prime in the cross-modal condition as well as in the within-modal condition.

To control for the accessibility of the prime to conscious awareness, we manipulated factorially prime duration across three groups of participants: at 33, 50 and 67 ms. Those values have been used because both authors were able to see (at least)

[1] Unfortunately, most studies in visual word recognition using masked priming do not use visibility tests to check that the precise conditions used prevented prime awareness. As discussed in Holender (1986), it is important to conduct visibility tests to insure that the prime or fragments of the prime are not available to conscious awareness. For instance, with a prime duration of 60 ms, Forster and Davis (1984) have shown that participants are better than chance at deciding whether the prime and the target are the same or different. Bodner and Masson (1997, Experiment 1) found that 42% of the participants noticed that at least "something" was presented between the forward mask and the target during the experiment. Yet, prime durations close to 60 ms are very commonly used in studies of masked visual word recognition, and it is possible that in some of these studies, participants are aware of sub-lexical (letters) information.

some lower-case letters at 67 ms whereas we were unable to report them at 33 ms (see below for generalization of those results to naive participants). Further, participants were interviewed after the experiment and asked to describe a trial. This allowed us to determine whether they had a conscious recollection of the presence of the prime. Finally, a prime visibility test (letter string vs. pseudo-letter string) was conducted for all prime durations.

3. Method

3.1. Participants

Ninety-six students participated in the study (respectively, 32, 32 and 24 participants in the 33, 50 and 67 ms prime duration conditions, and eight in the prime visibility test). All participants reported normal or corrected-to-normal vision, no hearing impairment and were native French speakers.

3.2. Stimuli and design

3.2.1. Lexical decision

Eighty words and 80 nonwords served as target items. In addition, 80 plus 80 matched control items were established. The word controls shared the same orthographic and phonological CV structure and were matched for frequency of occurrence. The nonword controls were just matched for orthographic and phonological CV structure. Half the stimuli were CVC (in terms of phonological structure) monosyllabic items and the other half were CV-CV disyllabic items. Words as well as nonwords were 4 to 7 letters long with an average length of 5.3 and 5.0, respectively. Half the words were high-frequency words (with an average log frequency of 3.80 for test items and 3.74 for controls) and the other half were low-frequency words (2.02 for test items and 2.01 for controls) selected from the BRULEX French database (Content, Mousty, & Radeau, 1990). The nonwords were constructed by exchanging phonemes or syllables of target words. They were all legal combinations of sounds in French. All nonword targets differed from an existing French word by only one phoneme.

Four counterbalanced lists of 160 prime–target pairs were constructed. Across the lists, a word target, for example "BÂTON" (*stick*), would either appear in the visual modality ("BATON") or in the auditory modality (/batõ/), and would be preceded either by the identity prime "bâton" or the control prime word "filet" (*net*). The same counterbalancing was done with nonword targets. A given list then included exactly 40 trials in each experimental condition (half of them with word targets, and half with nonword targets). Each participant was run on only one list. A trial consisted of a fixation point (*) for 1.5 s, a forward mask (##########) for 500 ms followed by the prime in lower-case. Then, either the target was presented in upper-case, or a backward mask (@@@@@@@@@@) was presented, simultaneous with the auditory target via headphones (see Fig. 1). The visual target or the backward mask disappeared when participants responded on a two-button response box. Participants were

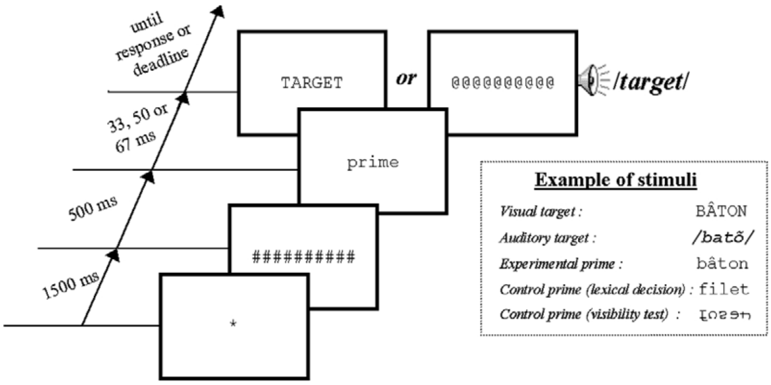

Fig. 1. Sequence of events and example of stimuli used in the experiment. Every target is presented randomly in a modality-independent manner.

asked to decide as quickly and as accurately as possible whether the letter or the phoneme strings constituted a word or not. They were not informed about the presence of a prime. They received a training session consisting of 12 trials (six within- and six cross-modal) before the experiment started. They received feedback messages on the screen when making an “ERROR” or when being “TOO SLOW”. The response deadline was 3 s and the inter-trial interval was 1.5 s.

Visual events were presented in a white fixed-width font (i.e. `Courier`) against a black background. Auditory targets were recorded by a male French native speaker and were digitized on a PC Compatible computer using an OROS-AU22-A/D board. The experiment was run using the EXPE software package (Pallier, Dupoux, & Jeannin, 1997) on a 233 MHz Pentium PC with a TFT screen with a refresh screen rate of 60 Hz.

3.2.2. Prime visibility test

The same procedure was used with the exception that (1) control primes were replaced by pseudo-letter symbol strings consisting mostly of real letters rotated or inverted, making up symbols with similar low-level characteristics as the real letters (see Fig. 2), (2) there was no response deadline, (3) the three prime durations were mixed in the list and (4) trials using a prime duration of 83 ms were added (25% of

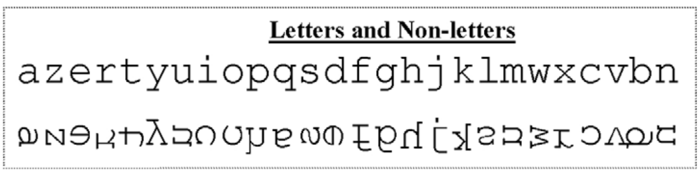

Fig. 2. Symbols used in the prime visibility test (note that, as in the lexical decision task, stimuli were presented in white on a black background).

the total). Participants performed a letter/pseudo-letter string decision on the primes. The sets of letters and pseudo-letters were presented on the computer screen to the participants before the visibility test. Moreover, there was a training session with feedback where the primes were displayed for 200 ms. As to the visibility test itself, there were 320 trials per cell.

4. Results

4.1. Lexical decision

Error responses were discarded from the analysis and response times more than two standard deviations above or below the mean were trimmed to the appropriate value. Mean lexical decision latencies and errors are given in Table 1. An ANOVA on the reaction times was performed with Prime Type, Prime Duration, Modality and Lexicality as main factors. Preliminary analyses revealed a significant effect of word frequency, and no effect of number of syllables; however, since neither variable interacted with the main factors quoted above, they are not included in the following analysis. F values are given by subject ($F1$) and by item ($F2$).

There were significant main effects of Prime Type ($F1(1,76) = 49.50$, $P < 0.0001$; $F2(1,152) = 30.21$, $P < 0.0001$) with a 25 ms advantage for identity primes over control primes, of Lexicality ($F1(1,76) = 174.53$, $P < 0.0001$; $F2(1,152) = 41.12$, $P < 0.0001$) with a 98 ms advantage on words over pseudowords, and of Modality ($F1(1,76) = 259.14$, $P < 0.0001$; $F2(1,152) = 241.34$, $P < 0.0001$) with a 112 ms advantage of visual over auditory targets. Prime Type interacted significantly with Modality ($F1(1,76) = 14.57$, $P < 0.0005$; $F2(1,152) = 10.95$, $P < 0.005$), Prime Duration ($F1(2,76) = 4.77$, $P < 0.05$; $F2(1,152) = 7.37$, $P < 0.001$) and Lexicality ($F1(1,76) = 23.13$, $P < 0.0001$; $F2(1,152) = 17.43$, $P < 0.0005$).

Planned comparisons (i.e. between identity and controls primes) on word trials showed a significant priming effect for visual targets at all prime durations (at 33 ms, $F1(1,28) = 16.50$, $P < 0.005$; $F2(1,76) = 7.92$, $P < 0.01$; at 50 ms, $F1(1,28) = 52.84$, $P < 0.0001$; $F2(1,76) = 20.40$, $P < 0.0001$; at 67 ms, $F1(1,20) = 32.53$, $P < 0.0001$; $F2(1,76) = 20.20$, $P < 0.0001$). However, planned comparisons for auditory targets showed a significant effect only at the 67 ms prime duration ($F1(1,20) = 11.41$, $P < 0.005$; $F2(1,76) = 22.13$, $P < 0.0001$). Planned comparisons on nonword trials showed a significant priming effect for visual targets at the 67 ms prime duration ($F1(1,20) = 12.93$, $P < 0.005$; $F2(1,76) = 6.45$, $P < 0.05$). None of the other comparisons reached significance by subjects or by items (all $P > 0.10$).

The error analysis showed a main effect of lexicality ($F1(1,76) = 49.43$, $P < 0.0001$; $F2(1,152) = 7.32$, $P < 0.001$). There was no main effect of priming. However, priming interacted significantly with lexicality ($F1(1,76) = 11.90$, $P < 0.005$; $F2(1,152) = 11.54$, $P < 0.005$). Planned comparisons showed signifi-

Table 1
Lexical decision latencies (in milliseconds), errors and prime visibility values across modality, lexicality and prime durations

Prime duration (ms)	Identity		Control		Priming effect		Prime visibility[a]		
	Latency	Errors (%)	Latency	Errors (%)	Latency	Errors (%)	HR (%)	FA (%)	d'
Within-modal words									
33	693	9.7	732	10.6	39**[b]	0.9	68.8	65.0	0.09
50	665	6.9	728	10.8	63***	3.9*	83.8	63.8	0.94*
67	663	7.3	733	10.6	70***	3.3(*)	89.4	40.0	2.07**
Cross-modal words									
33	808	9.5	812	9.8	4	0.3	51.9	55.6	−0.24
50	801	8.0	818	8.0	17	0.0	73.1	61.9	0.47
67	783	7.5	844	11.5	61**	4.0*	95.6	41.3	2.19**
Within-modal nonwords									
33	791	4.1	808	3.4	17	−0.6	74.4	68.1	0.24
50	795	4.4	811	3.0	17	−1.4	80.6	65.6	0.62*
67	762	7.7	798	4.2	36*	−3.5(*)	88.8	40.0	1.76**
Cross-modal nonwords									
33	909	5.9	900	7.0	−8	1.1	55.6	55.0	−0.10
50	928	6.3	937	4.2	9	−2.0	66.3	51.3	0.55
67	901	4.0	897	4.4	−4	0.4	88.1	46.3	1.48**

[a] HR, hit rate; FA, false alarms.
[b] (*)$P < 0.1$; *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

cant (or marginal) effects in four conditions: for visual word targets at 50 ms ($F1(1,28) = 8.03$, $P < 0.01$; $F2(1,76) = 5.94$, $P < 0.05$) and at 67 ms ($F1(1,20) = 4.74$, $P < 0.05$; $F2(1,76) = 3.01$, $P < 0.10$), for visual nonword targets at 67 ms ($F1(1,20) = 2.57$, $P < 0.15$; $F2(1,76) = 6.56$, $P < 0.05$) and for auditory word targets at 67 ms ($F1(1,20) = 5.63$, $P < 0.05$; $F2(1,76) = 4.02$, $P < 0.05$).

4.2. Prime visibility test

A measure of prime recognizability was computed for each participant in each prime duration, modality and lexical status condition in the form of a d' measure. It was obtained by treating the presence of real letters as signal and the presence of pseudo-letters as noise. Table 1 shows the values of the hit rate, false alarms rate and d' in each condition. We also ran a *t*-test against the null mean to determine whether the observed d' was significantly different from 0. Briefly, the d' values were at chance level for a prime duration of 33 ms, they were numerically higher, but only significant in the visual–visual condition for a

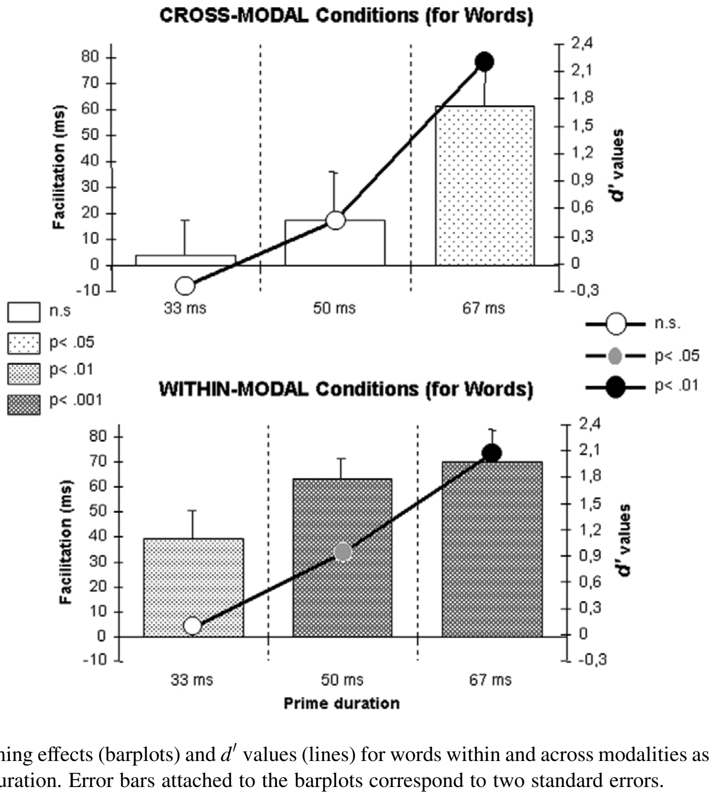

Fig. 3. Priming effects (barplots) and d' values (lines) for words within and across modalities as a function of prime duration. Error bars attached to the barplots correspond to two standard errors.

prime duration of 50 ms, and they were significantly above chance for a prime durations of 67 ms.

5. Discussion

This experiment tested the existence of an unconscious cross-modal priming effect. The results are clear-cut (see Fig. 3). Cross-modal priming is only found when participants start to consciously perceive the prime. At 33 ms of prime duration, the perceptibility of the prime is close to zero. Accordingly, no trace of cross-modal priming is found. At 50 ms of prime duration, d' scores are somewhat higher but do not reach significance. Accordingly, no significant cross-modal priming effect emerges, although there is a numerical trend of 17 ms that fails to reach significance.[2] At 67 ms of prime duration, d' scores are significantly above chance, and a significant cross-modal priming effect emerges. In contrast with the cross-modal priming, within-modal priming is found at all prime durations, including 33 ms, suggesting that such a small duration is enough to allow for a robust priming effect to take place. A rather straightforward interpretation of these effects is that unconscious repetition priming exists within the visual modality but not across modalities. Of course, this is not the only interpretation. Models that postulate links between orthography and phonology predict some delay in cross-modal priming compared to within-modal priming. Could it be that the difference we found between the two situations is due to time instead of awareness (for a thorough discussion of this issue, see Dehaene & Naccache, 2001)?

To address this issue, we analyzed the response of the participants who were asked to describe a trial and say whether or not they saw any lower-case letter or letter string flashed before the target. It turned out that none of the 32 participants reported seeing the prime at 33 ms, 3/32 at 50 ms and 12/24 at 67 ms. We ran a post-hoc analysis of the 67 ms condition. The 12 participants who reported seeing the prime had a significant cross-modal priming effect for words of 97 ms ($P < 0.01$) whereas those who did not see the prime had a non-significant effect of only 14 ms. In contrast, in the within-modal conditions, participants had the same amount of priming regardless of whether they reported seeing the prime or not (89 and 78 ms, respectively).[3] This suggests that it is not prime duration per se but rather conscious awareness of the prime that determines whether cross-modal priming is obtained. This is of course not definitive evidence since the observed dissociation may reflect

[2] Our results are congruent with an unpublished master's thesis of Spinelli (1995, advised by Grainger), who found, with a different masked cross-modal paradigm, no trace of cross-modal identity priming with a prime duration of 33 ms. She reported a trend with a prime duration of 50 ms, which only showed up in subanalyses and was not replicated in later studies (Spinelli and Grainger, pers. commun.).

[3] We introduced a new "prime-seen" between-subject factor. This factor yielded a significant two-way interaction with priming ($P < 0.03$ in both analyses) and a three-way interaction with priming and modality ($P < 0.02$ by subject, $P = 0.06$ by items). These interactions were due to the fact that the "prime-seen" factor affected the amount of priming in the cross-modal conditions, and not in the within-modal conditions.

individual differences in the speed of processing. It would be important to establish the effect of awareness on a within-subject, trial by trial basis.

Note that our results, at first sight, could be seen as contradicting other results obtained in the purely visual domain. There is, in fact, a large (although controversial) literature that centres on the role of phonological knowledge in visual word recognition. For instance, Ferrand and Grainger (1992) used the masked priming paradigm of Forster and Davis and showed that in French, a target word “FAIM” /fɛ/ is facilitated by a pseudo-homophone prime “fain” /fɛ/ compared to an orthographic nonword control “faic” /fɛk/. Similarly, Lukatela, Frost, and Turvey (1998) found a significant phonological priming effect in English, although it was not replicated in Davis, Castles, and Iakovidis (1998) and Shen and Forster (1999). Using a different paradigm (the visual backward masking procedure), Perfetti and Bell (1991) found similar phonological effects, but this was in turn criticized in Brysbaert and Praet (1992) and Verstaen, Humphreys, Olson, and d’Ydewalle (1995). Finally, Rayner and colleagues (Lee, Rayner, & Pollatsek, 1999; Rayner, Sereno, Lesch, & Pollatsek, 1995) measured eye fixation during written sentence processing and found that a prime presented only 36 ms at the fixation point was sufficient to elicit both semantic and phonological priming.

Regarding these sets of studies, we would like to point out that, first, many of them did not include a visibility test that could ascertain whether the prime is consciously accessible (or partially so). For instance, Ferrand and Grainger (1992, 1993) as well as Lukatela et al. (1998) reported masked phonological priming only with rather long prime durations (above 50 ms) but only orthographic priming with short prime durations. It could be that some of the reported phonological priming effects are due to the involvement of conscious processing. Similarly, the priming technique developed by Rayner et al. uses a shorter prime duration (36 ms), but only post-experiment questionnaires have been used to informally estimate prime awareness. The data tend to show fairly low rates of prime identification (approximately 5–10%), but somewhat higher rates of being aware of the prime–target change (up to 50%) leaving it open that participants identified some letters. It would be interesting to see whether phonological priming in the Rayner et al. paradigm is restricted or not to trials where the subjects identified the prime. Second, there is the logical possibility that phonological knowledge might be brought to bear in visual tasks without involving the input auditory lexicon (Taft, 1982, 1991). This could include a phonological code specific to orthographic processing, prelexical grapheme–grapheme correspondences, or even the output phonological code. What our results suggest, though, is that whatever the explanation of masked phonological effects might be, it cannot involve the auditory input lexicon, because otherwise we would have found a cross-modal priming effect under unconscious conditions. The extension of our methodology to the involvement of phonology in purely visual tasks is interesting and is open to further empirical work.

In brief, our results suggest a functional disconnection between the visual and the auditory input lexical modules. Of course, when one reads a text, one has the subjective feeling of “reading aloud”, which would imply activating the phonological *output* lexicon, and, ultimately, the phonological *input* lexicon. Without denying this, we propose that the activation of the phonological *input* lexicon by visual stimuli does not arise unless stimuli are consciously identified. That is, the central executive has to have access to the existence of the stimulus for this cross-modal activation of the input lexicon to take place. Note that this conclusion is also compatible with studies using the implicit (long-term) priming paradigm which have found that cross-modal effects are weaker, more linked to explicit memory, and more task-dependent than within-modal effects (Badgaiyan, Schacter, & Alpert, 1999; Morton, 1979; see Bowers & Kouider, in press, for a review). Our interpretation, of course, is not the only one. We acknowledge that a purely temporal interpretation of our data within an interactive model is still possible. Further research is needed to disentangle awareness from processing time.[4]

Before closing, let us point out that our results also have methodological implications. Numerous studies of speech processing using cross-modal "conscious" priming (in which the decision has to be made on a visual target preceded by an auditory prime) have been conducted with the assumption that cross-modal facilitative effects reflect the activation of a modality-independent lexical entry (e.g. Marslen-Wilson et al., 1994). Of course, if, as we suggest, there is no such thing as modality-independent lexical entries, but rather, redundant modality-specific lexical entries only connected through strategic processes, the adequacy of the "conscious" cross-modal priming technique for tapping automatic lexical activation would have to be reassessed.

Acknowledgements

This research was supported in part by a doctoral grant from the French Ministry of National Education, Research and Technology to the first author under the direction of the second author. We would like to especially thank Boris New for his help and comments on the preliminary part of this study. We also thank Jeff Bowers, Ken Forster, Jonathan Grainger, Christophe Pallier, Elsa Spinelli and Franck Ramus as well as the invited editor and three anonymous reviewers for their helpful comments on this study.

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[4] Note that this argument may as well apply to studies involving semantic priming. The absence of cross-modal repetition priming in our studies implies that semantic relatedness has no effect under subliminal processing of the prime. Our result is congruent with Perea and Gotor (1997) who used the Forster and Davis paradigm to study semantic relatedness effects in lexical decision and found reliable effects with a 67 ms prime duration but not with shorter prime durations.

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