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# How many words can we read at once? More intervenor effects in masked priming

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ABSTRACT

It is argued that the existence of masked translation priming from L1 to L2 with a 50 ms prime implies that processing of the prime must continue well after it has been replaced by the target, since it is estimated that the meaning of a word is not established until at least 120 ms after stimulus onset. This fact implies that the lexical processor must be equipped to handle two words simultaneously. However when a masked word intervenes between the prime and the target, three words must be processed simultaneously. Under these conditions, form priming is eliminated altogether, and identity priming is reduced, suggesting that the capacity of the lexical processor does not extend to three words. Four experiments are reported showing that this disruption of priming only occurs when the intervenor triggers lexical processing. It is argued that the differential effect of the intervenor on identity and form priming can be explained on the assumption that priming takes place at the level of form, and at the level of meaning. As support for this interpretation, it is shown that an identity prime is capable of generating a congruence effect in a semantic categorization experiment despite the presence of a masked intervenor.



## Introduction

The investigation of visual word recognition plays a critical role in the development of cognitive theory. It deals primarily with a special case of the more general issue of pattern recognition and information retrieval. Each time we read a word, we must recover the stored information about the orthography, phonology, syntax, and semantics of that word. Moreover, this information must be retrieved extremely rapidly, given how fast we can read, and given that each word also has to be integrated into the developing sentence. So much processing has to be done that it seems obvious that the processing of one word must overlap to some degree with the processing of the next word. For example, given that we have just retrieved the properties of word N from our mental lexicon, the process of integrating that word with the previous context might be carried out while the properties of word $N+1$ are being retrieved. This seems reasonable, given that these processes are independent. But what if the processes involved are not independent, but are in fact the same process? Is it possible that lexical access of word $N+1$ could be attempted while the system is still accessing word N? The answer to this question will have profound implications for models of visual word recognition.

One line of evidence comes from eyetracking experiments, where it can be shown that some of the properties of word $N+1$ are established while the eye is still fixating word N. This is known as the parafoveal preview effect, and occurs when the fixation duration on the currently fixated word is shorter if parafoveal information about that word was available during the fixation of the previous word (for a review, see Rayner, 1998). This could mean that access of word $N+1$ begins while word N is still being accessed (partial overlap), or it could mean that access of word $N+1$ begins when access of word N has been completed, and continues during the saccade to the next

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word (zero overlap). Which of these accounts is correct is currently a matter of debate. The SWIFT model (Engbert, Longtin, & Kliegl, 2002) argues for parallel, overlapped processing, while the EZ Reader model (Reichle, Rayner, & Pollatsek, 2003) argues for non-overlapped processing. Recent evidence (Wang & Inhoff, 2013) favors the parallel overlapped model.

Another line of evidence comes from the masked priming literature. In a typical masked priming experiment, the stimulus sequence consists of a forward mask, followed by a very brief (40–60 ms) presentation of a prime, which is in turn followed by presentation of the target stimulus, which acts as a backward mask. Despite the fact that under these conditions, subjects are unaware of the identity of the prime, the response to the target is affected if the prime is related to the target either in form or meaning (e.g., Ferrand & Grainger, 1993; Forster & Davis, 1984; Forster, Davis, Schoknecht, & Carter, 1987; Grainger & Frenck-Mestre, 1998; Kouider & Dehaene, 2007; Rastle, Davis, Marslen-Wilson, & Tyler, 2000). Sometimes the effect is facilitatory (faster responses), sometimes inhibitory (slower responses), depending on the nature of the prime and target, and the task. To understand the nature of this effect, we must address the question of how priming occurs with such a short time interval between the onset of the prime and the onset of the target. One relevant piece of information is that there is clear evidence for masked cross-language translation priming from L1 (the native language) to L2 (the second language) with a 50 ms prime (Duñabeitia, Perea, & Carreiras, 2010; Finkbeiner, Forster, Nicol, & Nakamura, 2004; Gollan, Forster, & Frost, 1997; Wang & Forster, 2010). Since translation priming in languages with different scripts (e.g., Chinese and English) depends solely on shared meanings, it follows that the semantic properties of the prime must have been established. One possibility is that the processing of the prime is so fast that it can be completed within 50 ms. However, there are several reasons for doubting whether this is possible. For one thing, the difference in lexical decision time for high and low frequency words can be as much as 80–100 ms (e.g., Murray & Forster, 2004; Schilling, Rayner, & Chumbley, 1998), suggesting that at least low-frequency words must take longer than 50 ms to access. Second, if access had to be completed while the prime was still physically present in order to produce priming, then many low-frequency primes would never be accessed in time, and hence they would produce weaker priming effects than high-frequency words. Yet low-frequency words either show just as much identity priming as high-frequency words (Forster & Davis, 1984; Rajaram & Neely, 1992) or in some cases more (e.g., Kinoshita, 2006). Finally, evidence from ERP experiments suggests that semantic processing requires at least 150 ms (Hauk, Davis, Ford, Pulvermüller, & Marslen-Wilson, 2006; Segalowitz & Zheng, 2008). These facts, and others, suggest that the semantic properties of the prime could not have been established within 50 ms, and therefore the processing of the prime must somehow continue while the target is being processed.

Further evidence relevant to this issue comes from a variant of the normal masked priming paradigm. This technique involves inserting an additional unrelated word between the prime and the target. This word is referred to as an intervenor (Forster, 2009). The reason that this experimental design is of interest is that in a lexical decision task, the effect of the prime on the target survives across the intervening word. This result is problematic for models of word recognition based on the interactive activation model (McClelland & Rumelhart, 1981). In these models, the priming effect is assumed to be due to the fact that the prime pre-activates the lexical representation of the target, and this activation persists until the target is presented, giving it an advantage. However, when an unrelated word intervenes between the prime and the target, no further activation from the prime can occur once the letters of the prime are replaced, and it seems unlikely that any activation produced by the prime would persist for very long since the intervenor letters would generate letter-to-word inhibition, which would inhibit activation in the word unit for the prime. Finally, the activation in the word unit corresponding to the intervenor would suppress activation in the word unit for the prime (word-to-word competition), and hence it is surprising that there should be any priming at all.

But the priming is not completely normal. The normal situation (i.e., no intervening stimulus between the prime and target) is that an identity prime (e.g., crescent-CRESCENT) produces very strong priming (40–50 ms), whereas a nonword prime that overlaps with the target orthographically (e.g., crescont-CRESCENT) produces weaker priming (20–30 ms). However, when the intervenor is visible and easily recognized, identity priming is cut back to the level of form priming, but form priming is virtually unaffected (Forster, 2009, Exps. 1–2). This result suggests that identity priming consists of two components: one that depends on the prime having a similar form as the target, and one that depends on the prime being the same word as the target. We could refer to these components as "Type A" and "Type B", but it seems natural to think of the first component as a form component, and the second as a semantic component (cf. Evett & Humphreys, 1981). According to this interpretation, the semantic component appears to be wiped out by the visible intervenor, but the form component is left more or less intact, and hence there is no difference between identity and form priming. However, this pattern of results changes when the intervenor is itself a masked word, and is presented for the same brief period as the real prime (50 ms). So the sequence looks like this: ####### <crescent> <producer> CRESCENT, where the angle brackets indicate a very brief exposure. One might have expected that a masked intervenor would have a similar, but weaker effect compared to the visible intervenor. In fact, the effect is quite different. Under these conditions, identity priming is maintained at the same reduced level as with a visible intervenor, but form priming is wiped out altogether (Forster, 2009, Exp. 3–4).

How might these results be explained? Taking the case of the visible intervenor first, lexical processing of the prime would have to continue in parallel with the processing of the intervenor, but the relatively long exposure of the visible intervenor (500 ms) means that there would be enough time for the prime to be fully processed by the time the target was presented. So in this case, no more than two words