Transposed-letter priming of pre-lexical orthographic representations

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As at August 12, 2008

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Abstract

A prime generated by transposing two internal letters (e.g., *jugde*) produces strong priming of the original word (*judge*).  In lexical decision, this transposed-letter (TL) priming effect is generally weak or absent for nonword targets, thus it is unclear whether the origin of this effect is lexical or pre-lexical.  We describe the Bayesian Reader theory of masked priming (Norris & Kinoshita, in press) which explains why nonwords do not show priming in lexical decision, but why they do in the cross-case same-different task. We follow this analysis with three experiments that show that priming in this task is not based on low-level perceptual similarity between the prime and target, nor on phonology, to make the case that priming is based on pre-lexical orthographic representation.  We then use this task to demonstrate equivalent TL priming effects for nonwords and words. We take this as the first reliable evidence based on masked priming procedure that letter position is not coded absolutely within the pre-lexical, orthographic representation.  We also discuss the implication of the results for current letter position coding schemes. (177 words)

Transposed-letter priming of pre-lexical orthographic representations


An issue currently receiving much attention in visual word recognition research is how letter order is coded in orthographic representations.   Most current computational models of word recognition such as the Dual Route Cascaded model (Coltheart, Rastle, Perry, Ziegler & Langdon, 2001), the multiple read out model (MROM, Grainger & Jacobs, 1996) - both of which are based on the interactive-activation model (McClelland & Rumelhart, 1981) - and the Bayesian Reader (Norris, 2006), use the "slot-coding" scheme.  In this scheme, there are separate slots for each possible letter position within a word, and letter identities are associated with specific slots.  However, there is now a wealth of evidence (e.g., Perea & Lupker, 2004; Schoonbaert & Grainger, 2004) that letter strings generated by transposing two adjacent letters in a word (e.g., *JUGDE*) are perceived as being more similar to the base word (*JUDGE*) than are letter strings generated by replacing the same letters with other letters not in the word (e.g., *JUNPE*). In both cases the slots corresponding to the third and forth position letters have the wrong letter identities. According to slot models therefore, strings with transposed letters (TLs) and substituted letters (SLs) should be equally similar to the base word.

Much research effort is thus currently directed at developing an alternative to the slot-coding scheme (for reviews of the models, see e.g., Davis & Bowers, 2006; van Assche & Grainger, 2006).  Two of the approaches make use of the idea of open bigrams, in which letter positions are coded in terms of the set of ordered letter pairs contained in the string. Earlier models considered all bigrams contained in a letter string irrespective of distance between the letter pairs, but the more recent models limit the separation to

two intervening letters. In Grainger and colleagues' Open Bigram (OB) coding scheme (e.g., Grainger & Van Heuven, 2003; Schoonbaert & Grainger, 2004), all bigrams are weighted equally, irrespective of the separation between the letter pairs. In Whitney's (2001; 2007; Whitney & Cornelissen, 2005; 2008) SERIOL model, bigrams are weighted differently according to the separation between the letter pair; and in the most recent version, the bigrams involving the initial or final letter in the string and an 'edge' character ("edge bigrams") are also weighted more. Both of these schemes explain the similarity between two letter strings in terms of the number of open bigrams shared by the letter strings. For example, *JUDGE* shares with *JUGDE* the bigrams *JU, JD, JG, JE, UD, UG, UE, DE, GE* but not *DG*; whereas *JUDGE* shares with *JUNPE* only the bigrams *JU, JE, UE*. Davis' (1999) SOLAR model does not rely on bigrams, but instead codes order in terms of the relative activation letter identity node (which are themselves position-independent). The first letter in a string has the highest activation, the second the next highest, and so forth. Thus, *JUDGE* and *JUGDE* will be perceived as similar but can be distinguished because they share the identical set of letter identities but slightly different 'spatial' codes. Finally, in the Overlap model proposed by Gomez, Ratcliff and Perea (in press), each letter within a letter string is assumed to be associated with more than one position. For example, in *JUDGE*, the letter *D* will be associated with position 3, but to a lesser degree with positions 2 and 4, and to even a lesser degree, with positions 1 and 5. The amount of overlap in letter position (which is different for each letter position) is coded as a standard deviation (SD) parameter, which is treated as a free parameter in the model. To the extent that the SD parameter is non-zero, *JUGDE* will be perceived as similar to *JUDGE*.

*Is order coding lexical?*

An issue that has received relatively little attention is whether the order coding schemes should apply to orthographic representations in general, or are restricted specifically to the lexical access process.  In Davis's (1999) SOLAR model the implication is that the activation gradient that encodes order operates over a pre-lexical representation of input letters. In contrast, Whitney and Cornelissen (2005, 2008) explicitly state that open-bigrams in the SERIOL model are "specific to the lexical route": According to Whitney and Cornelissen (2008), "differences in orthographic encoding along the two routes suggest that letter order is encoded more reliably on the sub-lexical route" (p.161).

Grainger and van Heuven's (2003) description of their OB model does not explicitly limit the operation of OBs to a lexical route. However, the lexical representations in their interactive activation model are driven directly from open-bigrams (the 'relative position letter map', see figure 1). The open-bigrams are generated from an "alphabetic array". In this version of the model, the alphabetic array contains an accurate representation of serial order, and it would appear that this is the only representation available for processing nonwords. However, if the alphabetic array is available for processing nonwords, this begs the question of why it is not used directly in lexical access. It seems that the only purpose of open-bigram coding is to introduce order errors (see Gomez, et al., in press, for similar criticisms).

Grainger, Granier, Farioli , Van Assche and van Heuven (2006) introduced a modified version of the OB model: the overlap open-bigram model (see figure 2). In this

version of the model the letter-detectors in the alphabetic array have large overlapping receptive fields, as in the Overlap model of Gomez, et al. They suggest that this will lead to three different types of bigram: correct contiguous bigrams, correct non- contiguous bigrams, and contiguous letters in the wrong order. They also suggest that "Noncontiguous combinations would provide a fast, approximate orthographic code useful for providing an initial constraint on word identity, whereas contiguous letter combinations would provide a more fine-grained orthographic representation that would be useful for deriving a phonological code." (p 897). If contiguous letter bigrams can be used to derive a phonological code this implies that they are available to support at least some non-lexical processing. It also implies that TL effects in non-lexical processing should be weaker than for lexical processing. However, the model leaves unanswered the questions of how an accurate phonological code might be derived from the bigram representation, and why the code would not be derived directly from the alphabetic array.

The most straightforward way to differentiate between models that assume that TL effects are due solely to the lexical access process, and those that assume the effects are a consequence of a general orthographic processing mechanism, is to determine whether TL effects can be observed with nonwords as well as words. However, there is very little data that addresses this issue directly.[1.] This is largely because the most popular method for studying TL effects has been the masked priming procedure using the lexical decision task pioneered by Forster and Davis (1984). There are few reported instances of any form of priming for nonwords using this task, so there is simply no scope for observing TL effects. The Forster and Davis procedure consists of a sequence of three events: an uninformative forward mask (consisting of a series of #'s); a briefly presented

prime in lowercase letters, and a clearly visible target in upper case to which a lexical decision is required. As the prime is both forward-masked and backward-masked (the target itself acts as a backward-mask), participants are unaware of the prime's identity, and hence it is generally assumed that masked priming reflects automatic processes that are free of strategic influences. (As is standard practice in the literature, we use the term "priming" and "priming effect" in a descriptive sense, referring to the faster/more accurate response to the target preceded by a prime related in some way to the target relative to an unrelated, control prime.) Masked priming effects, such as identity and form priming, are weak or absent for nonword targets (for a review, see Forster, Mohan, & Hector, 2003). Only a few studies have investigated TL priming in nonwords. Unsurprisingly, given the generally weak masked priming effect for nonwords, TL priming for nonword targets is rarely observed and is always weaker than that for word targets (e.g., Perea & Lupker, 2003, Schoonbaert & Grainger, 2004). Although there have been occasional reports of statistically significant TL priming effects with nonwords (e.g., Perea & Carreiras, 2008, Experiment 2) which have been taken to argue for a pre-lexical locus of TL priming, there are many other reports of absence of TL priming with nonwords (sometimes even in the same paper that found TL priming for nonwords e.g., Perea & Carreiras, 2008, Experiment 1), and there is no clear explanation of these mixed findings. Ideally, any attempt to compare TL priming in words and nonwords would start with a task that could produce similar sized effects of identity priming in word and nonwords. This would guarantee that the task would have the same potential to detect TL priming for both kinds of stimuli. Fortunately, such a task does exist: the cross-case same-different matching task.

Recently, we (Norris & Kinoshita, in press) proposed an account of masked priming based on the Bayesian Reader model of word recognition (Norris, 2006) which explains why priming is absent for nonwords in the lexical decision task. The model also made the novel prediction that, by changing the task, it should be possible to generate masked priming effects for nonwords (and to eliminate masked priming effects for words). Norris and Kinoshita examined masked priming in a cross-case same-different match task. In that task, the presentation conditions of the prime and target are identical to those in the conventional Forster and Davis paradigm, but the prime is preceded by a clearly presented reference stimulus. The task is to decide whether the target (which is always presented in a different case from the reference) is the same as, or different from, the reference. The Bayesian Reader predicted that this task should produce priming for both words and nonwords on *Same* trials, but no priming for either words or nonwords on *Different* trials. The results were exactly as predicted. For our present purposes the critical finding is that it is possible to produce masked priming of nonwords in the same-different task. This suggests that the cross-case same-different matching task might be a useful paradigm for studying pre-lexical orthographic processing.

The aim of the current study is to evaluate the cross-case same-different match task further, and then to see whether it is possible to demonstrate reliable TL priming effects with nonwords. First we summarize the Bayesian Reader theory of masked priming in order to explain why it predicts that the pattern of priming should vary as a function of the task. According to the model only word targets should be primed in lexical decision, and only 'same' trials should be primed in the same-different task. Nevertheless, both tasks are driven by the same orthographic representations. The same-

different task would therefore appear to be a useful task for investigating non-lexical orthographic processing. We show that the existing literature on the same-different matching task supports this claim, and we also report three new experiments that provide further evidence that masked priming effects in the same-different task are mediated by pre-lexical orthographic representation. The final experiment in the paper uses the same-different task to examine TL effects in nonwords.

*Masked priming in the Bayesian Reader*.

Perhaps the most popularly held view of masked priming (as instantiated in simulations of masked priming in models based on the interactive-activation framework, e.g., Davis, 2003) is that it reflects activation of abstract lexical representations which are independent of physical features like case and font. This fits well both the fact that priming is absent for nonwords (as they do not have lexical representations) in the lexical decision task, and the fact that priming is observed across a change in case between the prime and target (because the representation is abstract). Within this view, a masked prime "automatically" activates a lexical representation, hence the priming effects are expected to be invariant across tasks. The only factor that determines the pattern of priming should be the relationship between the prime and target. However, the pattern of priming is not invariant across tasks. As noted above, Norris and Kinoshita (in press; Norris, Kinoshita & van Casteren, 2006) showed that words that produced priming in a lexical decision task showed no priming when they appeared as 'different' trials in the same-different task. In contrast, nonwords that had shown no priming in lexical decision did produce priming when they appeared as 'same' trials in the same-different task. In

fact, priming for 'same' targets was equally large for words and nonwords. Norris and Kinoshita (see also Kinoshita & Kaplan, 2008) also showed that using the same prime-target pairs in the same-different letter match task, priming was equal for cross-case similar letters (e.g., c/C, x/X) and dissimilar letters (e.g., a/A, b/B) when participants were required to respond *Same* irrespective of difference in case (e.g., responding *Same* to a-A and c-C), whereas it was limited to cross-case similar letters when participants were required to respond *Same* only to case- and letter identity (e.g., responding *Same* to a-a or A-A but not a-A). That is, even within the same-different task, the pattern of priming (the shift from dependence on abstract letter identity to a lower level perceptual representation) depends on the exact nature of the task instructions.

The Bayesian Reader theory of masked priming explains this variation in the pattern of masked priming across tasks in terms of difference in the nature of decision required by the task, and of the representations used to make the decision. The Bayesian Reader was developed from the perspective that perception involves Bayesian inference based on accumulation of noisy evidence. The hypothesis for which evidence is accumulated is determined by the goal of the task. A critical assumption of the theory is that, under the circumstances of masked priming, the prime and target are processed as a single perceptual object. Evidence from both the prime and the target continuously updates the probability of the hypotheses required to perform the task. In the case of lexical decision the hypothesis being evaluated is "Is the input a word or a nonword?". Note that this does not require unique identification of the word: the decision is not about which word is present, but whether any word is present. The Bayesian Reader performs lexical decision by comparing the overall evidence that the input was produced by a

word, with the evidence that it was produced by a nonword. The Bayesian Reader is a stimulus sampling theory in which the perceptual input consists of a series of independent noisy samples. Each sample provides an independent piece of evidence which can be used to revise the probabilities of the alternative hypotheses. Two important things follow from this assumption. The first is that if the model is evaluating the hypothesis that the input is the word *cat,* it will make no difference whether or not the prime and target are presented in the same or different case. The letters "T" and "t" will both provide equal support for the hypothesis that the input is the word *cat*. The model combines independent sources of evidence and does not simply combine or average the raw perceptual input. Thus the model explains how it is that masked primes have their effect despite the fact that they are presented in a different case from the target. Second, for nonword targets in lexical decision and for different targets in the same-different task, there will be no advantage for identity primes over unrelated primes. The reason for this is perhaps easiest to appreciate in the case of the same-different task. Each input sample contributes evidence to the decision "Is the target the same as the reference". Consider the case where the reference is 'page', the prime 'fist' and the target is 'FIST'. The evidence from the prime 'fist' supports the hypothesis that the target is different from the reference. But, the unrelated prime 'ship' would provide equally strong evidence that the target is not 'page'. Because the model does not need to evaluate a hypothesis about the specific form of a *different* target, there is no need to accumulate evidence as to its identity. It simply needs to be classified as *same* or *different*. An analogous argument applies to lexical decision. The exact form of the nonword doesn't matter. A nonword prime will contribute evidence that the nonword is not a word, and the target will

contribute more evidence. It doesn't matter if the prime and target are different. All that counts is whether the target is a word or not.  Norris and Kinoshita (in press), and Norris, Kinoshita and van Casteren (2006) report simulations of masked priming in both the lexical decision and the same-different matching tasks that confirm the verbally derived predictions outlined above.[2.]

*The nature of representation used in the same-different match task.*

In the present context, the value of the same-different task depends on whether it taps into the same pre-lexical orthographic representations as those that support word recognition. In practice this means asking whether performance in the same-different task is based on the same representations of abstract letter identity that support word recognition (e.g. Bowers, Vigliocco & Haan, 1998).  In fact there are two questions here. One is whether the task is performed on the basis of abstract letter identities. The second is whether the influence of masked primes is at the same level of representation. It is conceivable that the decision might be made on the basis of abstract letter identities, but that the effect of masked priming operates, for example, at a lower level of perceptual representation.

There is a rich literature base on the same-different match task dating from the 1970's (for a review, see e.g., Proctor, 1981).  There is evidence that matching in this task is based on abstract letter identities rather than, for example, a phonological code. In fact, the use of abstract letter identities appears to be so dominant that it interferes with performance even when participants are instructed to base their decisions only on the physical match. Besner, Coltheart and Davelaar (1984) showed that when participants are

instructed to respond *Same* only to physically identical letter strings (e.g., *HILE-HILE*), *Different* responses were slowed when the letter strings shared the same letters in different cases (e.g., *HILE-hile*). In contrast, *Different* responses were not slowed when the stimuli were phonologically identical. That is, pairs such as *HILE-hyle* were no slower than pairs such as *HILE-hule*.

The same-different matching task has been used to study the representation of letter order within a letter string (e.g., Angiolillo–Bent & Rips, 1982; Proctor & Healy, 1985; Ratcliff, 1981). Most of these studies used short consonant strings (e.g., *WDG*) as stimuli, and in many studies the reference and target were in the same case. Thus, caution is needed in generalizing from these studies to recognition of words, because the relative importance of order information may be different for short and long strings (e.g., transpositions of internal letters within longer letter strings may be particularly confusable), and also because in these early studies the decision could have been based on physical identity. Nevertheless, a clear empirical consensus emerging from these studies is that the same-different match task is sensitive to letter order. This is evidenced in the fact that both when participants were instructed to respond *Same* regardless of the letter order (e.g., Angiolillo-Bent & Rips, 1982), and to respond *Same* only if the two strings contained the letters in the same order (e.g., Ratcliff, 1981), responses were affected by the amount of displacement for "rearranged" letter strings. It is important to note that Angiolillo-Bent and Rips (1982) found these letter order effects were equivalent for familiar, meaningful strings (e.g., *GDP, JFK*) and meaningless strings (e.g., *WDG*) even though the former were matched faster than the latter. The authors took this finding to argue against the idea that the familiar strings are matched holistically at a higher-

level; instead, they suggested that the unit of match is the letter for all types of letter strings. These authors also found the letter order effects were not affected by whether the reference and target strings were in the same or different case, suggesting that the letter units used for matching are abstract with regards case. Thus, these findings suggest that cross-case same-different match task has the potential to reveal the nature of letter order coding within pre-lexical orthographic representations.

From the perspective of the Bayesian Reader, masked priming in the cross-case same-different match task reflects the evidence contributed by the prime in making the decision about whether or not the target is the same as the reference string. The findings of studies using the same-different match task described above suggest that when matching letter strings, the representation used in this task is based on abstract letter identities and not phonological codes, and that letter order information is used in making this decision, which provide a rationale for expecting TL priming effects in this task. Also, as already noted, we (Norris & Kinoshita, in press; Norris, Kinoshita & van Casteren, 2006) have found robust identity priming for nonwords in this task, which suggests that it would be a promising procedure for demonstrating pre-lexical effects than the lexical decision task. Before testing for TL priming with nonwords, however, we need to address the second question raised above. That is are masked priming effects found in the same-different task also driven by overlap at the level of abstract letter identities rather than, for example, low-level perceptual similarity?

Given that the masked prime and the target are presented in different cases, an explanation based on low level perceptual similarity seems unlikely. We will however first empirically establish whether there is any evidence for low-level perceptual effects

by manipulating the similarity between prime and target letters. In Experiment 1 we will establish whether we can replicate our earlier (Norris & Kinoshita, in press; Norris, Kinoshita & van Casteren, 2006) demonstration of priming for words and nonwords using stimuli composed only of letters that are dissimilar cross-case (e.g., *edge/EDGE, adge/ADGE*). In Experiment 2 we will establish whether cross-case letter similarity (e.g., similar: c/C, k/K, s/S; dissimilar: a/A, e/E, g/G) can modulate the size of priming. The manipulation of cross-case letter similarity was used by Bowers, Vigliocco and Haan (1998) with the lexical decision task to make the case that the (lexical) representations that support priming in this task are abstract. They found that words consisting of cross-case similar letters (e.g., *kiss/KISS*) or cross-case dissimilar letters (e.g., *edge/EDGE*) showed priming of equivalent size and they took the result as evidence that priming in the lexical decision task is based on representations comprised of abstract, and not case-specific, letter identities. We expect to replicate this finding using the cross-case same-different match task. Such a demonstration of lack of sensitivity of priming to cross-case letter similarity would rule out the possibility that priming in this task is based on perceptual/physical similarity (which would also predict equal priming for words and nonwords in this task). In addition, in Experiment 3, we will show that priming in this task is not affected by phonological identity. These experiments will therefore provide the basis for the claim that the representation supporting masked priming in this task is pre-lexical, orthographic representations. Further, these experiments serve to illustrate that priming in this task is restricted to the *Same* responses, as predicted by the Bayesian Reader. Following these experiments, we will use the cross-case same-different match task to test TL priming effects for nonwords as well as words (Experiment 4).

Experiment 1

The main aim of Experiment 1 was to replicate the finding of equal priming for words and nonwords in the cross-case same-different match task (Norris & Kinoshita, in press), using stimuli consisting of words containing cross-case dissimilar letters (e.g., *edge/EDGE, able/ABLE*), and nonwords generated from these words (e.g., *adge/ADGE, eble/EBLE*). As the prime and target are dissimilar in low-level features, any of priming could not be explained in terms of low-level perceptual (featural) similarity. In addition, the Bayesian Reader predicts that only the *Same* response will show priming.

*Method*

*Participants*. Twenty-four volunteer psychology students from Macquarie University participated in Experiment 1 in return for course credit.

*Design*. All experiments reported in this paper used the cross-case same-different matching task. Experiment 1 constituted a 2 (Lexical status: words vs. nonwords) x 2 (Prime type: identity vs. control) x 2 (Response: Same vs. Different) factorial design, with all factors manipulated within subjects. The dependent variables were decision latency and error rate.

*Materials*. In Experiment 1, the critical stimuli were 36 words and 36 nonwords used as targets, all 4-letters long, containing only cross-case dissimilar letters (a/A, b/B, d/D, e/E, l/L, g/G, h/H, r/R), based on the cross-case letter similarity matrix of Boles and Clifford (1989). Pronounceable nonwords were generated by replacing (with another dissimilar letter) or transposing letters of word items (e.g., *EBLA* was generated from *ABLE*). Each word and nonword target was used twice, once requiring a *Same* response

and once requiring a *Different* response: In the former condition, the reference was the same as the target (e.g., *able/ABLE*), in the latter condition, the reference was another target item of the same lexical class (e.g., *reed/ABLE, rera/EBLA*), so that each item was used as a reference twice. A target was paired with either an identity prime (e.g., *able-ABLE*) or an unrelated control prime of the same lexical status (e.g., *cook-ABLE, kooc-EBLA*). The control primes for both the word targets and nonword targets contained the letters not used in the target set.

*Apparatus and Procedure*. Participants were tested individually. They were instructed that they would be presented with a pair of letter strings, one after another, and that their task was to decide for each pair whether they are the same or different, as fast and accurately as possible. The reference and prime were always presented in lowercase, and the target in uppercase. All stimuli were presented in white, in Courier 10 font, against black background. Participants were instructed to ignore the difference in case when making the Same-Different decision, and to press a key marked "+" for *Same* and a key marked "-" for *Different* responses. No mention was made of the presence of primes. Each participant completed 160 test trials, presented as two blocks of 80 trials each, with a self-paced break between blocks. In each block, half required a *Same* response and half required a *Different* response, and the eight experiment conditions were represented equally. A different random order of trials was generated for each participant.

Each trial began with the presentation of a reference in lowercase above a forward mask consisting of five hash signs for 1 second. The reference then disappeared, and the forward mask was replaced by a prime in lowercase presented for 53 ms, which was

replaced by a target presented in uppercase. The target remained on the screen either until participant's response or for 2,000 ms.

Stimulus presentation and data collection were controlled by the DMDX display system developed by K.I. Forster and J.C. Forster at the University of Arizona (Forster & Forster, 2003). Stimulus display was synchronized to the screen refresh rate (13.3 ms). Participants were given no feedback on either response times or error rates during the experiment.

### *Results and Discussion*

In this and all subsequent experiments, the preliminary treatment of trials was as follows. Any trial on which a subject made an error was excluded from the analysis of latency. To reduce the effects of extremely long and short latencies, the cutoff was set for each participant at 3 S.D. units from each participant's mean latency and those shorter or longer than the cutoff was replaced with the cutoff value. This data-trimming procedure affected 1.2% of trials in Experiment 1. *Same* and *Different* decision latencies and error rates were analyzed separately, using a two-way ANOVA with Lexical status (words vs. nonwords) and Prime type (identity vs. control) as factors. In the by-subjects analysis, both were within-subject factors, and in the by-items analysis, Lexical status was a between-item factor. Mean decision latencies and error rates are presented in Table 1.

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Insert Table 1 about here

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*Same responses*.  For latency, the main effect of *Lexical status* was significant, $F_1(1,23) = 10.14$, MSe = 2287.58; $F_2(1, 70) = 12.98$, MSe = 2080.24.  On average, words were responded 31 ms faster than nonwords.  The main effect of *Prime type* was highly significant, $F_1(1,23) = 116.88$, MSe = 838.88; $F_2(1, 70) = 85.62$, MSe = 2136.27.  On average, there was a 64 ms priming effect.  The two factors did not interact, $F_1(1,23) < 1.0$; $F_2(1, 70) < 1.0$.

For error rate, only the main effect of *Prime type* was significant, $F_1(1,23) = 4.94$, MSe = 47.21; $F_2(1, 70) = 7.29$, MSe = 69.43.  On average, identity-primed targets were 3.1% more accurate.  None of the other main or interaction effect reached significance, all $F < 1.21$, $p > .28$.

*Different responses*.  For latency, the main effect of *Lexical status* was significant, $F_1(1,23) = 4.19$, MSe = 2044.59; $F_2(1, 70) = 5.79$, MSe = 2523.47.  On average, words were responded 19 ms faster than nonwords.  The main effect of *Prime type* was significant by items but not by subjects, $F_1(1,23) = 2.24$, MSe = 1878.63; $F_2(1, 70) = 4.56$, MSe = 2.51.  The two factors did not interact, $F_1(1,23) < 1.0$; $F_2(1, 70) < 1.0$.

For error rate, none of the main or interaction effect reached significance, all $F < 1.81$, $p > .19$.

The results of Experiment 1 were clear-cut.  Using the same-different matching task, robust masked identity priming effects were found.  Importantly, the priming effects were equal in size for words and nonwords, which we take as evidence that masked priming in this task is not based on lexical representations.  Because all stimuli contained only cross-case dissimilar letters (e.g., a/A, b/B), it is unlikely that priming reflected low-

level perceptual similarity, as none of the prime and target letters (e.g., *edge-EDGE*) have much featural overlap.

It is relevant to note that words were matched faster than nonwords. Earlier studies that used the same-different match task have also found this word advantage, together with an advantage for matching high-frequency words relative to low-frequency words (e.g., Chambers & Forster, 1975; Marmurek, 1989; recall also that Angiolillo-Bent & Rips, 1982, reported faster matching of familiar strings like *GDP* than unfamiliar strings). Chambers and Forster (1975) interpreted these effects of lexical status and frequency to argue that what is matched is (frequency-sensitive) lexical representations for word stimuli and letters or letter clusters for nonword stimuli. Against this, recall that Angiolillo-Bent and Rips (1982) argued against the idea that matching is done involving higher-level unit for familiar strings, on the basis that letter displacement effects did not interact with familiarity of letter strings. Similarly, Marmurek (1989) argued against the idea of different units of matching for words and nonwords, and suggested instead that the word advantage reflects the ease of *encoding* of familiar stimuli. Marmurek found that the word advantage is reduced with sequential relative to simultaneous presentation (as was used by Chambers & Forster, 1975) of reference and target stimuli (and with a sufficiently long delay between the presentation of the reference and the target, it may be absent) and took these results to suggest that the greater ease in encoding familiar stimuli is reduced with advance viewing of reference stimuli. The whole pattern of data found here – overall word advantage together with the absence of an interaction with priming – is indeed more consistent with this possibility that the word advantage does not reflect a difference in the unit of matching.

Experiment 2

Experiment 1 used stimuli that contained only cross-case dissimilar letters (e.g.,

a/A, b/B) and it was argued that priming is therefore unlikely to be due to overlap in low-

level features.  Experiment 2 strengthens this case further by showing that priming in the

cross-case same-different match task is equal for words consisting of cross-case similar

letters (e.g., *kiss/KISS*) and words consisting of cross-case dissimilar letters (e.g.,

*edge/EDGE*) (cf. Bowers, et al., 1989); as well, we show that priming is insensitive to

frequency.  Stimuli consisted of high- and low-frequency words containing

predominantly cross-case dissimilar letters (e.g., *edge/EDGE, able/ABLE*) or cross-case

similar letters (e.g., *miss/MISS, soup/SOUP*).   If priming is driven by pre-lexical

orthographic representations based on abstract letter identities, size of priming should be

unaffected by either word frequency or cross-case letter similarity.

*Method*

*Participants*.  An additional twenty-four participants from the same population as

Experiment 1 took part in Experiment 2.

*Design*. Experiment 2 constituted a 2 (Frequency: high vs. low) x 2 (Cross-case

letter type: dissimilar vs. similar) x 2 (Prime type: identity vs. control) x 2 (Response:

Same vs. Different) factorial design, with all factors manipulated within subjects.  The

dependent variables were decision latency and error rate.

*Materials*.  In Experiment 2, the critical stimuli were 64 high-frequency words

(range 80-7289, mean 539.9 per million based on Kucera & Francis, 1967) and 64 low-

frequency words (range 1-18, mean 6.8 per million) used as targets, all 4-letters long.

Within each frequency class, half of the words contained at least three cross-case

dissimilar letters (a/A, b/B, d/D, e/E, l/L, g/G, h/H, r/R), and half contained at least three

cross-case similar letters (c/C, i/I, k/K, m/M, n/N, s/S, t/T, u/U, v/V, w/W), based on the

cross-case letter similarity matrix of Boles and Clifford (1989).

As in Experiment 1, each target was used twice, once requiring a *Same* response

and once requiring a *Different* response. The procedure for pairing of reference and

target in the *Same* response and *Different* response conditions was identical to

Experiment 1.

*Apparatus and procedure*. The apparatus, software used for stimulus presentation

and response collection, trial sequence, and instruction to participants were all identical to

Experiment 1.

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*Results and Discussion*

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This data-trimming procedure affected 2.23% of trials in Experiment 2. *Same* and

*Different* decision latencies and error rates were analyzed separately, using a three-way

ANOVA with *Frequency* (high vs. low), *Cross-case letter similarity* (dissimilar vs.

similar), and *Prime type* (identity vs. control) as factors. In the by-subjects analysis, all

were within-subject factors, and in the by-items analysis, Frequency and Cross-case letter

similarity were between-item factors. Mean decision latencies and error rates are

presented in Table 2.

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Insert Table 2 about here

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*Same responses*. For latency, the main effect of *Frequency* was marginally

significant by subjects, $F1(1,23) = 4.10$, $MSe = 705.07$, $p = .055$; but not by items, $F2(1,$

124) = 1.471, MSe = 1878.25, p = .23. The main effect of *Cross-case letter similarity* was significant, F1(1,23) = 19.73, MSe = 928.70; F2(1, 124) = 15.31, MSe = 1878.25. *Dissimilar* words (e.g., *edge/EDGE*) were judged as the *Same* 19 ms more slowly than *Similar* words. The 90-ms priming effect was highly significant, F1(1,23) = 279.16, MSe = 1395.67; F2(1, 124) = 447.86, MSe = 1303.09. There were no interactions between these factors, all F1(1,23) < 1.77, p > .20; F2(1, 124) < 2.55, p > .11.

For error rate, the only significant effect was the main effect of *Prime type*, F1(1,23) = 26.97, MSe = 129.56; F2(1, 124) = 51.58, MSe = 90.27. Identity-primed items were 8.5% more accurate than control-primed items. All other main and interaction effects were non-significant, all F1(1,23) < 3.49, p > .07; F2(1, 124) < 3.15, p > .08.

*Different responses*. For latency, the only significant effect was the main effect of *Cross-case letter similarity*, F1(1,23) = 6.14, MSe = 1349.00; F2(1, 124) = 4.45, MSe = 2446.46. This indicated that *Dissimilar* words were responded to 13 ms more slowly than *Similar* words. All other main and interaction effects were non-significant, all F1(1,23) < 1.88, p > .18; F2(1, 124) < 3.31, p > .07.

For error rate, no effect reached significance by subjects and by items, all F1(1,23) < 1.60, p > .22; F2(1, 124) < 3.23, p > .08. However, the main effect of *Cross-case letter similarity* was significant by subjects, F1(1,23) = 12.70, MSe = 12.66; F2(1, 124) = 1.19, MSe = 177.68, as was the interaction between *Frequency* x *Cross-case letter similarity*, F1(1,23) = 16.34, MSe = 26.38; F2(1, 124) = 3.22, MSe = 177.68, p = .08.

Experiment 2 again showed a robust priming effect that was limited to the *Same* responses. Also as expected, the size of priming was not affected by word frequency or

cross-case letter similarity. We take these results as further evidence that priming in this task is not based on low-level perceptual similarity, but is driven by letter representations that are abstract with regards case.

Experiment 3

The aim of Experiment 3 was to test if priming in the cross-case match task is phonological. To this end, we compared the effects of three types of primes: (1) identity prime (e.g., *score-SCORE*); (2) pseudohomophone prime (e.g., *skore-SCORE*), and (3) non-homophonic, one-letter-different (1LD) control prime (e.g., *smore-SCORE*). If priming is phonological, we expect both the identity prime and pseudohomophone prime conditions to facilitate *Same* responses relative to the 1LD control prime condition. On the other hand, if priming in this task is purely orthographic, based on abstract letter identities, we expect the pseudohomophone and 1LD control prime conditions not to differ, and the identity prime condition to be faster than the other two prime conditions.

In addition, we manipulated the position of the different letter in the pseudohomophone and 1LD prime conditions. If the letters are processed in parallel, there is little reason to expect the amount of identity priming relative to either of the latter conditions to depend on position of the changed letter. On the other hand, if letters are encoded (or mapped onto phonology) serially from left-to-right, then the amount of identity and/or phonological priming should be greater for earlier than later position (e.g., the difference between *score-SCORE* and *skore-SCORE* or *smore-SCORE* should be greater than the difference between *eject-EJECT* and *elekt-ELECT* or *elept-ELECT*).

*Method*

*Participants.* An additional twenty-four participants from the same population as Experiment 1 took part in Experiment 3.

*Design.* Experiment 2 constituted a 3 (Prime type: identity, pseudohomophone, 1LD) x 2 (Response: Same vs. Different) factorial design, with both factors manipulated within subjects. The dependent variables were decision latency and error rate.

*Materials.* In Experiment 3, the critical stimuli were 54 5-letter words, ranging in frequency from 1-160 (mean 23.7) per million. They each had either the letter c, k, g, or j in the second, third or fourth position, e.g., *SCORE, UNCLE, ELECT*. For each target, three types of prime were generated: identity (e.g., *score-SCORE*), pseudohomophone (e.g., *skore-SCORE*), and 1LD (e.g., *smore-SCORE*). A pseudohomophone prime replaced the critical letter with another letter so that the result was a nonword that was pronounced like the original word; 1LD primes replaced the same critical letter with another letter that did not preserve the pronunciation. These 54 words were used as targets requiring a *Same* response. In addition, another 54 5-letter words selected according to the same criteria were used as targets requiring a *Different* response. These words ranged in frequency from 1-628 (mean 72.5) per million. Three prime types were generated for each of these targets in the same way. Finally, there were 54 5-letter words (frequency range 1-355, mean 38.2 per million) used as reference strings for the targets requiring a *Different* response.

In Experiment 3, each target was used once only. Each target was paired with each of the three prime types so that each participant saw a target only once, and across

every three participants a target occurred in the each of the three prime conditions just once.

*Apparatus and procedure.* The apparatus, software used for stimulus presentation and response collection, trial sequence, and instruction to participants were all identical to Experiment 1.

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*Results and Discussion*

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This data-trimming procedure affected 1.31% of trials in Experiment 3. *Same* and *Different* decision latencies and error rates were analyzed separately, using a one-way ANOVA with *Prime type* (identity vs. pseudohomophone vs. 1LD) as a factor. In the by-subjects analysis, it was a within-subject factor, and in the by-items analysis, a within-item factor. Mean decision latencies and error rates are presented in Table 3.

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Insert Table 3 about here

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*Same responses.* For latency, the main effect of Prime type was significant, $F_1(2,46) = 7.44$, MSe = 794.33; $F_2(2,106) = 6.55$, MSe = 1685.25. Orthogonal contrasts tested showed that there was no difference between the pseudohomophone and 1LD prime conditions, $F_1(1,23) < 1.0$; $F_2(1,53) < 1.0$, but that the identity prime condition was significantly faster than both of these conditions, $F_1(1,23) = 14.36$, MSe = 1228.00; $F_2(1,53) = 12.74$, MSe = 2598.14.

For errors, the main effect of Prime type was non-significant, $F_1(1,23) < 1.0$; $F_2(1,53) < 1.0$.

In addition, we analyzed the amount of letter priming, indexed as the difference between the identity prime condition and the average of the pseudohomophone and 1LD prime conditions, as a function of position of the changed letter (second, third or fourth position). For latency, the mean letter priming effects were: 18 ms, 39 ms, 22 ms for second, third and fourth position, respectively. Letter priming did not interact with position: $F_1(2,46) < 1.0$, $MSe = 4096.20$; $F_2(2,51) < 1.0$, $MSe = 1727.68$. For error rate, the mean letter priming effects were -.69%, 1.39%, and .68% for second, third, and fourth position, respectively. Letter priming did not interact with position for error rate either: $F_1(2,46) < 1.0$, $MSe = 85.00$; $F_2(2,51) < 1.0$, $MSe = 100.08$.

*Different responses.* For latency, the main effect of Prime type was non-significant, $F_1(1,23) < 1.0$; $F_2(1,53) < 1.0$.

For error rate also, the main effect of Prime type was non-significant, $F_1(1,23) < 1.0$; $F_2(1,53) < 1.0$.

The results were straightforward: the identity prime condition facilitated *Same* responses relative to both the pseudohomophone and 1LD prime conditions, which did not differ from each other. These results suggest that phonology plays no role in priming in the cross-case same different task, and that priming is purely orthographic. In addition, the fact that the amount of letter priming (indexed as the difference in priming between the identity prime condition and the average of the pseudohomophone and 1LD prime conditions) did not depend on the position of the differing letter is consistent with the idea that letters in the prime were processed in parallel.

Experiment 4

The results of Experiments 1-3 support our claim that priming in the cross-case same-different task is based primarily on pre-lexical orthographic representations. We now turn to testing for TL priming using this task. To demonstrate TL priming, we will compare the TL prime (e.g., *fiath-FAITH*) condition with the all-letter-different (ALD) control prime condition (e.g., *agent-FAITH*); we will also include another control condition often used in previous studies, the 2SL prime condition (e.g., *fouth-FAITH*). An identity prime condition (e.g., *faith-FAITH*) was also included, to compare the size of TL priming relative to identity priming. In previous studies using the lexical decision task (e.g., Forster, Schoknecht, Davis & Carter, 1987) and word naming (Christianson, Johnson, & Rayner, 2005), negligible difference was reported between these two conditions when letter transpositions were word-internal.

In addition to these primes which have been used standardly in previous studies of TL priming, we included a "scrambled" prime condition (e.g., *ifhat-FAITH*), which contained the same letters as the target but in completely different positions. We had reasons to believe the same-different task to be sensitive to changes in letter position, independent of letter identities, on the basis of early studies of letter position coding using the this task described earlier. For example, Angiolillo-Bent and Rips (1982) have reported that when participants were asked to respond *Same* when the reference and target string contained the same letters irrespective of their position, responses were nevertheless affected by changes in letter position (e.g., participants were slower to respond *Same* to *WGD-WDG* than to *WDG-WDG*). This indicated that letter position within a string is coded automatically in the same-different task. However, we have not

yet demonstrated that *masked priming* in this task is sensitive to changes in letter position. The scrambled prime condition served to provide such evidence: If masked priming in this task is sensitive to changes purely in letter position, then the identity prime conditions should differ from this condition. In summary, we used five different prime conditions: identity, TL, 2SL, scrambled, and ALD, with both words as reference/target, and nonwords as reference/targets.

*Method*

*Participants.* An additional twenty participants from the same population as Experiment 1 took part in Experiment 4.

*Design.* The experiment constituted a two-way design involving Item type (Words vs. Nonwords) and Prime type (Identity, Transposed-letter: TL, Two-letter-substituted: 2SL, Scrambled, and All-letter-different: ALD) as factors. Both factors were manipulated within subjects. Each participant was presented with both a block containing only word stimuli and a block containing only nonword stimuli. Order of blocks was counterbalanced across participants. The dependent variables were decision latency and error rate.

*Materials.* The critical stimuli were 80 5-letter words and 80 nonwords generated from them. The words ranged in written frequency from 31-907 (mean 225) per 17 million according to the CELEX lexical database (Baayen, Piepenbrock, & van Rijn, 1995), and had N of 1, as defined using the N-metric of Coltheart, Develaar, Jonasson and Besner (1977). Each target word was paired with one of five primes: Identity, TL, 2SL, Scrambled, or ALD. Identity prime was the same word as the target, e.g., *faith-FAITH*. A TL prime was generated by transposing two adjacent, internal

letters, e.g., *fiath-FAITH*. The transposed letters were always two vowels or two consonants; none involved transposition of a consonant and a vowel. A 2SL prime was generated by substituting the two letters that were transposed in the TL prime with two other letters, e.g., *fouth-FAITH*. Consonants were replaced with consonants and vowels with vowels. A Scrambled prime contained the same letters as the target, but had their position changed so that: (1) no letter occurred in the original position, (2) no letter was adjacent to the letter it was adjacent to in the original string (i.e., there were no transpositions of adjacent letter pairs), and (3) no letter pairs were just shifted in position (i.e., relative order of letter pairs was not preserved), e.g., *ifhat-FAITH*. For the 5-letter strings used here, denoted 12345, there are only two permutations possible to meet these constraints: 24153 or 31524. We used the latter (the choice was random, there was no basis for preferring one over the other). The ALD primes were 20 5-letter words similar in characteristic to the target words, e.g., *agent*, *knock*. When pairing an ALD prime with a target, overlap of letters in the initial position such as *media* and *MERCY* was avoided. The stimuli are listed in the Appendix.

In addition to the 80 critical stimuli used for the *Same* response, 80 words were selected to be used as targets in the *Different* response condition. The construction of identity, TL, Scrambled, 2SL and the ALD primes was identical to that of the critical items used in the *Same* response condition. Each target was paired with one of 80 additional reference words that were different from the target e.g., reference – *anger*, target - *MONTH*.

The 80 critical targets (requiring the *Same* response) and the 80 filler targets (requiring a *Different* response) were each divided into 5 sets matched on mean

frequency, and the assignment of a set to a prime condition (Identity, TL, 2SL, Scrambled and ALD) was counterbalanced across participants so that each target was seen by a participant once, and appeared in each prime condition once across every five participants.

The nonword stimuli (critical targets requiring the Same response, filler targets requiring the Different response, practice and warm-up items) were generated by changing a letter of the word stimuli, usually the first letter, or the second letter, to make an orthographically legal string. The stimuli are listed in the Appendix.

Prior to each experiment involving words and nonwords, participants were given 16 practice items and 4 warm-up items selected according to the same criteria as the test stimuli.

*Apparatus and Procedure*. The apparatus, software used for stimulus presentation and response collection, trial sequence, and instruction to participants were all identical to Experiment 1. Each participant completed a block containing160 test trials consisting of word reference/targets and a block containing 160 test trials consisting of nonword reference/targets. Each block was presented as two half blocks of 80 trials each, with a self-paced break between blocks.

<center>*Results*</center>

In Experiment 4, decision latencies and error rates for the *Same* and *Different* responses were analyzed separately using a two-way analysis of variance (ANOVA) with Item type (Word vs. Nonwords) and Prime type (Identity, TL, 2SL, Scrambled and ALD) as factors. Both factors were treated as a within-subject factor and a within-item factor. Effects were considered to be significant when both subject and item analyses were

significant at the .05 level. The data-trimming procedure affected 1.4% of trials for Words, and 1.1% of trials for Nonwords. Mean decision latencies and error rates are presented in Table 4.

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Insert Table 4 about here

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*Same responses*. For latency, the main effect of Item type was significant, $F_1(1, 19) = 7.07$, MSe = 1781.44, $F_2(1, 79) = 16.41$, MSe = 2964.13. Responses to nonwords were 16 ms slower than to words. The main effect of *Prime type* was highly significant, $F_1(4, 76) = 63.85$, MSe = 693.18; $F_2(4, 316) = 38.54$, MSe = 5544.39. There was no interaction between the two factors, $F_1(4, 76) = 1.86$, MSe = 724.41; $F_2(4, 316) = 2.31$, MSe = 260.65. That is, priming did not differ in size for words and nonwords. Averaged over Item type, simple effect contrasts for the Prime type factor showed that each of identity, TL, 2SL, and Scrambled prime differed significantly from the ALD prime condition: id: $F_1(1, 19) = 109.19$, MSe = 2145.25; $F_2(1, 79) = 110.84$, MSe = 10457.16; TL: $F_1(1,19) = 221.49$, MSe = 1005.71; $F_2(1, 79) = 79.13$, MSe = 13869.28; 2SL: $F_1(1,19) = 124.50$, MSe = 1256.01; $F_2(1, 79) = 57.29$, MSe = 13667.51; Scrambled: $F_1(1,19) = 16.85$, MSe = 1898.29; $F_2(1, 79) = 15.83$, MSe = 12138.63. Further contrasts amongst the prime conditions showed that id = TL < 2SL < Scrambled < ALD: TL prime condition was significantly faster (by 12 ms) than the 2SL prime condition, $F_1(1,19) = 5.45$, MSe = 537.75, p = .031; $F_2(1, 79) = 3.12$, MSe = 4246.05, p = .081; 2SL prime condition was significantly faster (by 34 ms) than the Scrambled prime condition, $F_1(1,19) = 28.14$, MSe = 833.65; $F_2(1, 79) = 21.04$, MSe = 4739.55.

For error rate, the main effect of Item type was non-significant, $F_1(1, 19) < 1.0$; $F_2(1, 79) < 1.0$. The main effect of Prime type was significant, $F_1(4, 76) = 14.52$, MSe = 82.89; $F_2(4, 316) = 19.68$, MSe = 244.48. There was no interaction between the two factors, $F_1(4, 76) = 2.31$, MSe = 24.00; $F_2(4, 316) = 1.96$, MSe = 176.79. Averaged over Item type, all of identity, TL, 2SL and Scrambled prime conditions differed significantly from the ALD prime condition: id: $F_1(1,19) = 17.49$, MSe = 403.67; $F_2(1,79) = 46.12$, MSe = 611.90, TL: $F_1(1,19) = 21.68$, MSe = 310.64; $F_2(1,79) = 33.86$, MSe = 794.65, 2SL: $F_1(1,19) = 24.03$, MSe = 210.75; $F_2(1,79) = 25.19$, MSe = 803.80, Scrambled: $F_1(1,19) = 16.86$, MSe = 252.50,; $F_2(1,79) = 19.96$, MSe = 852.65. Further contrasts amongst the prime conditions showed that id = TL = 2SL = Scrambled < ALD.

*Different responses*. For latency, the main effect of Item type was non-significant by subjects, $F_1(1, 19) = 2.32$, MSe = 2736.50, but significant by items, $F_2(1, 79) = 6.43$, MSe = 3545.59. The main effect of Prime type was non-significant, $F_1(4, 76) < 1.0$; $F_2(4, 316) < 1.0$. There interaction between the two factors was also non-significant, $F_1(4, 76) < 1.0$, $F_2(4, 316) < 1.0$.

For error rates, the main effect of item type was non-significant by subjects, $F_1(1, 19) = 1.70$, MSe = 46.01, but significant by items, $F_2(1, 79) = 4.16$, MSe = 75.16. There was no main effect of Prime type, $F_1(4, 76) < 1.0$; $F_2(4, 316) = 1.21$, MSe = 86.10, nor an interaction between the two factors, $F_1(4, 76) = 1.43$, MSe = 23.03; $F_2(4, 316) = 1.50$, MSe = 87.35.

## Discussion

The main result of interest was that, in the cross-case same-different match task, nonwords produce the same pattern of priming as words. As in all previous experiments,

priming effects were limited to the *Same* responses. For both words and nonwords, there was a significant TL priming effect which was larger than 2SL priming. We take these results as the first reliable finding of TL priming with nonwords, and as direct evidence that during the initial stages of processing, letter positions are not coded accurately within pre-lexical orthographic representations.

There were other priming effects of interest in Experiments 4, observed with both words and nonwords: (1) Scrambled primes produced smaller priming than Identity primes and 2SL primes; (2) 2SL primes produced more priming than ALD primes; and (3) identity and TL primes had equal effects. The fact that Scrambled primes produced considerably smaller priming than the Identity primes indicates that masked priming in the cross-case same-different task is sensitive to letter position, and is not simply a consequence of shared letters. As mentioned, this was expected from the earlier studies (e.g., Angiolillo-Bent & Rips, 1982), and confirms that the task is suitable for investigating letter position coding. Implication of these findings for the various letter coding schemes will be considered below.

The degree of orthographic similarity between the prime and the target in the five prime conditions can be indexed by the "match scores" for the slot-coding, SOLAR (Davis, 1999), the Constrained Open Bigram (Schoonbaert & Grainger, 2004) and the most recent version of SERIOL (Whitney, 2007; Whitney & Cornelissen, 2008) models using Davis' (2005) Matchcalculator program[3], and is shown in Table 5. (The Overlap model does not output fixed "match scores", as the SD parameter that represents the amount of overlap in position for each letter position is a free parameter whose value

could vary depending on experimental settings. We will return to this model later in the Discussion).

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Insert Table 5 about here

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All models return a value of 1.0 for identical letter strings (e.g., *faith* and *faith*), and a value of 0 for letter strings that have no letters in common in any position (e.g., *noble* and *drift*). At an initial glance, the match scores seem to reflect the data pattern quite well. It is clear from Table 5 that SOLAR, COB, and SERIOL all predict the ordering id > TL > 2SL > ALD, and id > TL > Scrambled > ALD, whereas the slot-coding model predicts id > TL = 2SL = Scrambled > ALD. It can also be seen that the match score values are identical to those of word and nonword stimuli (except for a minor variation for the ALD primes condition, which was affected by particular pairings of prime and target). The advantage of TL primes over 2SL primes and ALD primes, is in agreement with the match scores from all of these letter coding schemes. However, the fact that we found equivalent priming for both words and nonwords is at odds with Whitney and Cornelissen's (2005, 2008) claim that open bigrams are specific to the lexical route. Treated simply as strings of letters, the words and nonwords produce the same match scores, but the OB coding scheme should apply only to words. Words and nonwords should therefore produce different patterns of priming.

Next, we focus on the comparison between the 2SL vs. ALD prime conditions. This finding of 2SL priming effect relative to the ALD prime condition is a notable departure from results reported with the lexical decision task: Neither Perea and Lupker

(2004, Experiment 1b) using 6-letter Spanish words (with non-adjacent consonant substitutions, e.g., *CAVIRO/casino*) nor Schoonbaert and Grainger (2004, Experiment 4) using 5-letter and 7-letter French words found facilitation by 2SL primes (when the substituted letters were word-internal) relative to the ALD primes. No model of orthographic coding would regard two letter strings that share three out of five letters in the same position (*faith* and *fouth*) as no more similar to each other than two unrelated letter strings that share no letters in common in the same position (e.g., *faith* and *agent*). In the lexical decision task both the absence of TL priming (in fact, all forms of priming) for nonwords and the absence of 2SL priming indicates that priming is not a direct function of orthographic similarity. Guererra and Forster (2008) have recently made exactly this point, noting that factors such as length, neighborhood density and frequency are known to modulate form priming effects in the lexical decision task. Instead, the size of priming in the lexical decision task likely reflects the ease of accessing lexical representation(s) [4.] from the orthographic representation of the input. This suggests that match scores are not sufficient to predict the size of priming in the lexical decision task.

Identify and TL primes produced equal amounts of priming. This result is inconsistent with all letter coding schemes because they all produce a larger match score for identity than TL pairs. Of course, it makes perfect sense for the models to assume that TL pairs are less similar to each other than are identical strings. With unlimited viewing time [5.] readers are indeed able to distinguish between *faith* and *fiath*. However, a single match score cannot simultaneously account for readers' ability to distinguish TL pairs and the fact that TL and identity primes have equivalent effects. Note that the lack of a difference between the identity and TL prime conditions cannot be explained away in

terms of lack of power in the present study, because a significant difference between the TL and 2SL prime conditions was observed; nor can it be explained in terms of the task being insensitive to difference in letter position, as a large difference was observed between the Identity and Scrambled prime conditions.  In addition, the lack of difference has also been observed in lexical decision (e.g., Forster et al., 1987, but see also Perea & Lupker, 2003 for a different result), naming (Christiansen et al., 2007), and eye movement measures using the parafoveal preview procedure (Johnson, Perea & Rayner, 2007).

What this dilemma highlights is that orthographic similarity is not static, but it must vary as a function of the amount of perceptual processing time.  The equal amount of priming observed with the identity and TL primes implies that the orthographic representations of *faith* and *fiath* (or *baith* and *biath*) are effectively identical at the end of the masked prime.  However, as processing progresses, readers can extract more information from the input and are able to reliably distinguish between *faith* and *fiath*. This means that the orthographic similarity between *faith* and *fiath*, relative to *faith* and *faith* reduces over time.  In this respect, match scores that are fixed over the time course have a fundamental problem, and we favour the general approach of the Overlap model (Gomez, et al., in press) which allows the SD parameter that codes the overlap in letter positions to vary, in so far as this leaves open the possibility that the uncertainty of letter position varies over time and hence allows it to account for the decrease over time in orthographic similarity between TL pairs.

Finally, greater priming was produced by 2SL prime than the Scrambled prime. The match scores differ in the ordering of 2SL and Scrambled conditions, with SOLAR (and

slot-coding): 2SL = Scrambled, Constrained OB: 2SL < Scrambled, and SERIOL: 2SL > Scrambled. That is, the observed pattern was captured better by SERIOL than by SOLAR (or slot-coding) or Constrained OB models. Note that the Scrambled prime contained all the correct letter identities but in wrong positions, whereas the 2SL prime contained three letters in the correct positions but two incorrect (unrelated) letters. Two points may be noted here. First, the fact that letters in the correct positions in the 2SL prime were external letters is particularly relevant to SOLAR, which allows the weighting given to the initial letter to be varied. This could in turn improve the fit between its match scores and the relative size of priming in the 2SL and Scrambled conditions. Second, recently, van Assche and Grainger (2006, p.416) suggested that there may be an inhibitory influence of unrelated letters which "hinder prime processing" relative to non-letters such as hyphens. An implication of adopting this letter inhibition assumption is that it may not be appropriate to directly compare match scores for a letter string containing all correct letters in wrong positions with a string containing unrelated letters. Note, however, that adopting the inhibitory letter assumption also presents a problem for using the 2SL prime condition as the "orthographic control" to test the presence of TL priming (e.g., Perea & Lupker, 2003; Schoonbeart & Grainger, 2004). This and other points mentioned already – such as the inability of match scores to predict the size of priming in the lexical decision task (e.g., the absence of TL priming for nonwords, the absence of difference between TL prime and 2SL prime conditions), and the inability of match scores to explain the equal sized priming produced by the identity and TL primes observed here - highlight the limitation of using the match scores to adjudicate between different letter position coding schemes. What is needed is an implementation of letter coding scheme

within a model of visual word recognition that makes processing assumptions (such as inhibitory effects of unrelated letters) explicit.

*General Discussion*

Experiments 1-3 provide evidence that priming effects in the same-different match task are attributable to prelexical orthographic representations that encode abstract letter identities, and not to low-level perceptual features or phonology. Experiment 1 replicated the finding of equal priming for words and nonwords originally found by Norris and Kinoshita (in press; see also Norris, Kinoshita & van Casteren, 2006), but using stimuli composed only of cross-case dissimilar letters (e.g., *edge-EDGE, adge-ADGE*). This finding indicates that priming in this task is not based on lexical representations. Experiment 2 showed that cross-case letter similarity does not modulate the size of priming, so strengthening the case that priming in this task is not dependent on low-level perceptual similarity. Experiment 3 showed that phonology plays no role in priming in this task, as effects produced by pseudohomophone primes (e.g., *skore-SCORE*) and non-homophonic one-letter-different primes (e.g., *smore-SCORE*) did not differ from each other. On the other hand, identity primes led to significantly faster *Same* responses than the former two, suggesting that letter identity clearly contributes to priming in this task. These results are exactly what we predicted on the basis of Norris and Kinoshita's (in press) analysis of masked priming in the Bayesian Reader. Experiments 4 then showed robust TL priming (e.g., *fiath-FAITH*, *biath-BAITH*) with both word and nonword targets, which was indistinguishable from identity priming. TL priming was significant when measured relative to both the all-letter-different (ALD) prime condition (e.g., *agent-FAITH, igent-BAITH*) and the 2SL prime condition (e.g., *fouth-FAITH, bouth-BAITH*),

which has been used frequently as another control condition (e.g., Perea & Lupker, 2003; Schoonbaert & Grainger, 2004). Taken together these results indicate that the locus of TL priming effects is at a stage of pre-lexical orthographic processing, and is not restricted to processes involved in lexical access.

At a methodological level these results suggest that the same-different task holds considerable promise as a tool for examining the nature of pre-lexical orthographic representations. The task appears to tap into the same representations that support word recognition, but not to be influenced by the lexical retrieval processes. The latter point is clear from the data reported by Norris and Kinoshita (in press) who found that priming in the same-different task was not modulated by either word frequency or lexical status.

However, much more importantly, these results have significant implications for theoretical accounts of how letter order is coded in word recognition, particularly for models incorporating open-bigrams. As noted in the introduction, the current models differ in terms of the proposed locus of order effects. The OB models of both Grainger and van Heuven, and Whitney and Cornilessen (2005, 2008) imply that the use of open-bigram representations is limited to the lexical access process itself. TL effects in masked priming are explained in terms of the similarity between the OB representations generated by the prime, and the OB representation of the target word. If this were true, TL effects should be restricted to word stimuli. While this is true for the lexical decision task, it is clearly not the case for the same-different task, where TL effects are equivalent for words and nonwords. It is not clear how either of these models might to be extended to produce TL effects in nonwords. An even greater challenge for these models is to

explain how the pattern of masked priming changes between the lexical decision and the same-different tasks.

Because they make fewer explicit claims, both Grainger and van Heuven's model and the Overlap open-bigram model of Grainger, et al. (2006) have more room to maneuver. One possibility would be to assume that the match task is performed by making a direct comparison between the OB representation derived from the reference stimulus, and the OB representation of the target. However, this possibility raises a number of further questions. For example, in this model, priming is assumed to be due to activation of lexical representations, so what mediates priming in the same-different task, where there are no lexical effects? Priming in the same-different task might possibly be mediated by the OBs themselves, but then why is there no priming for *Different* responses? The prime-target relationship is the same for both the *Same* and the *Different* conditions, but only *Same* responses produce priming. A further problem with relying entirely on OB representations of nonwords is that it is unclear how readers might perform simple tasks like reporting the third letter in a nonsense word. Such a task requires access to a serially ordered representation of the letters, so some procedure must be available to derive that representation from the OBs. It is much easier to extract OBs from a serially ordered input representation than to recover the ordered representation from the unordered set of OBs. (Consider the problem of reconstructing the string BANANA from its constituent OBs).

A second possibility is that the same-different task itself is performed on the basis of a serially ordered letter representation derived from OBs. However, if it is easy to derive a serial representation, why not make the lexical representations themselves serial?

If the lexical representations are serial, then the sole function of OBs is to intervene between an early perceptual representation, where order is sufficiently accurately encoded to permit the construction of OBs, to a further level of representation where order is also accurately encoded. That is, the only function of OBs would then appear to be to produce TL effects. The SERIOL model is explicitly committed to the view that open-bigrams are part of the lexical representations. SERIOL also has a sub-lexical representation that provides a more accurate representation of serial order. Consequently, it is much harder to see how SERIOL can accommodate the present data. Given that same-different decisions on nonwords cannot be performed lexically, there seems no alternative but to assume that the decisions must be made on the basis of the sub-lexical representations, and these representations are assumed to have a more precise coding of serial order. However, the TL effects we observe in the same-different experiments reported here are actually larger than any TL effects that have previously been reported for words in lexical decision. In fact, for both words and nonwords, responses to TL targets here are as fast as to identity primed targets. This suggests that, at least at the end of the prime, letter order is much less accurately encoded than letter identity information (cf. Adelman & Brown, submitted).

Although it might be possible to rescue both of these OB models, it is clear that none naturally accommodates the present data. Indeed, SERIOL would seem to predict that we should not have observed TL effects at all for nonwords. All of the models need some modification to explain how TL effects might arise in the same-different task, and also to explain how the pattern of masked priming can change between lexical decision and same-different tasks. In these models, priming is driven by the similarity of the prime

and the target. However, the same pairing of primes and targets that produces priming in lexical decision does not necessarily produce priming in the same-different task when those targets require a *Different* response (Norris & Kinoshita, in press). This makes the point that the only satisfactory way to evaluate the competing encoding schemes is to incorporate them into models that give an explicit account of how the different experimental tasks are performed.

In the OB models described here, the representation of order does not change over the course of processing. Open-bigrams are immediately derived from a serially ordered representation of the input letters, and that representation remains fixed during processing. The similarity of the letter strings *JUDGE* and *JUGDE* will not change over time. However, a rather different and more dynamic view of the representation of letter order comes from the perspective of the Bayesian Reader. The Bayesian Reader is a noisy sampling model. The model accumulates evidence about letter identity by noisy sampling from the input. The more samples are accumulated, the less uncertainty there is about letter identity. The original version of the model made the simplifying assumption that positional information was represented unambiguously as a slot code, and that the positional information was available immediately. However, it is likely that position or order information will also take time to accumulate. As more samples are accumulated, the representation of order will become more and more precise. So, for example, at the end of the prime in a masked priming experiment, the representation of order might still be very ambiguous. The representation of the letter-string *JUDGE* may be highly similar to both *JUDGE* and *JUGDE*. This is much like the situation in the Overlap model (Gomez, et al., in press) when there is a large degree of positional uncertainty. As time

goes on however, the uncertainty in both letter identity and order will be resolved, giving rise to an orthographic representation where serial order is precisely specified. This evolving pre-lexical orthographic representation is both the input to the lexical access process and the representation used in the same-different task. TL effects therefore arise because of ambiguity early on in the process of mapping a noisy representation of letter identity and order onto serially ordered orthographic representations (Norris & Kinoshita, 2007; Norris, et al., submitted). Those ordered representations correspond to lexical entries in the case of the lexical decision task, and the reference string in the case of the same-different task.

References

Adelman, J. S., & Brown, G. D. A. (submitted). The time course of letter position and identity information availability in visual word identification.

Angiolillo-Bent, J.S., & Rips, L.J. (1982). Order information in multiple-element comparison. *Journal of Experimental Psychology: Human Perception and Performance, 8*, 392-406.

Baayen, R.H., Piepenbrock, R., & van Rijn, H. (1995). *The Celex Lexical Database*. Release 2 [CD-ROM]. Linguistic Data Consortium, University of Pennsylvania, Philadelphia.

Besner, D., Coltheart, M., & Davelaar, E. (1984). Basic processes in reading: Computation of abstract letter identities. *Canadian Journal of Psychology, 38*, 126-134.

Boles, D.B., & Clifford, J.E. (1989). An upper- and lowercase alphabetic similarity matrix, with derived generation similarity values. *Behavior Research Methods, Instruments, & Computers, 21*, 579-586.

Bowers, J.S., Vigliocco, G., & Haan, R. (1998). Orthographic, phonological, and articulatory contributions to masked letter and word priming. *Journal of Experimental Psychology: Human Perception and Performance, 24*, 1705-1719.

Chambers, S., M., & Forster, K.I. (1975). Evidence for lexical access in a simultaneous matching task. *Memory & Cognition, 3*, 549-559.

Coltheart, M. (1981). Disorders of reading and their implication for models of normal reading. *Visible Language, 3*, 245-286.

Coltheart, M., Davelaar, E., Jonasson, J.T., & Besner, D. (1977). Access to the internal lexicon. In S. Dornic (Ed,), *Attention and Performance, VI.* (pp. 535-555). Hillsdale: Erlbaum.

Coltheart, M., Rastle, K., Perry, C., Ziegler, J., & Langdon, R. (2001). DRC: Dual Route Cascaded model of visual word recognition and reading aloud. *Psychological Review, 108*, 204-256.

Christianson, K., Johnson, R.L., & Rayner, K. (2005). Letter transpositions within and across morphemes. *Journal of Experimental Psychology: Learning, Memory and Cognition, 31*, 1327-1339.

Davis, C.J., & Bowers, J.S. (2006). Contrasting five different theories of letter position coding: Evidence from orthographic similarity effects. *Journal of Experimental Psychology: Human Perception and Performance, 32*, 535-557.

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.

Forster, K.I., Davis, C., Schoknecht, C., & Carter, R. (1987). Masked priming with graphemically related forms: Repetition or partial activation? *Quarterly Journal of Experimental Psychology, 39A*, 211-251.

Forster, K. I., & Forster, J. C. (2003). DMDX: A Windows display program with millisecond accuracy. *Behavior Research Methods, Instruments, & Computers, 35*, 116-124.

Forster, K.I., Mohan, J., & Hector, K. (2003). The mechanics of masked priming.  In S. Kinoshita, & S.J. Lupker (Eds.), *Masked priming: The state of the art.* (pp. 3-38).  New York: Psychology Press.

Gomez, P., Ratcliff, R., & Perea, M. (2008).  The overlap model: A model of letter position coding.  *Psychological Review*, in press.

Grainger, J., Granier, J. P., Farioli, F., van Assche, E., & van Heuven, W. J. (2006). Letter position information and printed word perception: the relative-position priming constraint. *Journal of Experimental Psychology: Human Perception and Performance, 32*(4), 865-884.

Grainger, J. & Jacobs, A. (1996).  Orthographic processing in visual word recognition.  A multiple read-out model.  *Psychological Review, 103*, 518-565.

Grainger, J., & van Heuven, W. (2003).  Modeling letter position coding in printed word perception.  In P. Bonin (Ed.), *The mental lexicon*.  (pp. 1-23).  New York: Nova Science.

Guerrera, C., & Forster, K.I. (2008).  Masked form priming with extreme transposition.  *Language and Cognitive Processes*, *23*, 117-142.

Johnson, R.L., Perea, M., & Rayner, K. (2007).  Transposed-letter effects in reading: Evidence from eye movements and parafoveal preview. *Journal of Experimental Psychology: Human Perception and Performance, 33*, 209-229.

Kinoshita, S., Castles, A., & Davis, C. (in press).  The role of neighborhood density in transposed letter priming.  Submitted to *Language and Cognitive Processes*, in press.

Kinoshita, S., & Kaplan, L. (2008). Priming of abstract letter identities in the letter match task. *Quarterly Journal of Experimental Psychology*, available online January 31.

Marmurek, H.H. (1989). Familiarity effects and word unitization in visual comparison tasks. *Memory & Cognition, 17*, 483-489.

McClelland, J.L., & Rumelhart, D.E. (1981). An interactive activation model of context effects in letter perception: Part 1. An account of basic findings. *Psychological Review, 88*, 375-407.

Norris, D. (2006). The Bayesian Reader: Explaining word recognition as an optimal Bayesian decision process. *Psychological Review, 113*, 327-357.

Norris, D. & Kinoshita, S. (in press) Perception as evidence accumulation and Bayesian inference: Insights from masked priming. *Journal of Experimental Psychology: General*.

Norris, D., & Kinoshita, S. (2007). Slow Slots with Slops: Evidence for 'slot-coding' of letter positions with positional noise. Paper presented at the 15th meeting of the European Society of Cognitive Psychology, Marseille, France, 29 August -1 September, 2007.

Norris, D., Kinoshita, S., & van Casteren, M. (2006). A Bayesian explanation of masked priming. Paper presented at the 4th International Conference on Memory (icom4). University of New South Wales, Sydney, Australia, 16-21 July.

Norris, D., Kinoshita, S., & van Casteren, M. (submitted). A stimulus sampling theory of letter identity and order. Paper submitted for publication.

Perea, M., & Carreiras, M. (2008). Do orthotactics and phonology constrain the transposed-letter effect? *Language and Cognitive Processes*, *23*, 69-92.

Perea, M., & Lupker, S.J. (2003). Transposed-letter confusability effects in masked form priming. In S. Kinoshita, & S.J. Lupker (Eds.), *Masked priming: The state of the art.* (pp. 97-120). New York: Psychology Press.

Perea, M., & Lupker, S.J. (2004). Can *CANISO* activate *CASINO*? Transposed-letter similarity effects with nonadjacent letter positions. *Journal of Memory and Language, 51*, 231-246.

Proctor, R.W. (1981). A unified theory of matching-task phenomena. *Psychological Review, 88*, 291-326.

Proctor, R.W., & Healy, A.F. (1985). Order-relevant and order-irrelevant decision rules in multiletter matching. *Journal of Experimental Psychology: Learning, Memory and Cognition, 11*, 519-537.

Ratcliff, R. (1981). A theory of order relations in perceptual matching. *Psychological Review, 88*, 552-572.

Schoonbaert, S., & Grainger, J. (2004). Letter position coding in printed word perception: Effects of repeated and transposed letters. *Language and Cognitive Processes, 19*, 333-367.

Van Assche, E. & Grainger, J. (2006). A study of relative-position priming with superset primes. *Journal of Experimental Psychology: Learning, Memory and Cognition, 32*, 399-415.

Whitney, C. (2001).  How the brain encodes the order of letters in a printed word: The SERIOL model and selective literature review. *Psychonomic Bulletin & Review, 8*, 221-243.

Whitney, C. (2007).  Comparison of the SERIOL and SOLAR theories of letter-position encoding.  *Brain and Language*, available online September 21, 2007.

Whitney, C. & Cornelissen, P. (2005).  Letter-position encoding and dyslexia. *Journal of Research in Reading, 28*, 274-301.

Whitney, C. & Cornelissen, P. (2008).  SERIOL reading.  *Language and Cognitive Processes, 23*, 143-164.

Appendix

Stimuli used in Experiment 4

Words
Stimuli are listed in the order: Word target, TL prime, 2SL prime, Scrambled prime and ALD prime.

| | | | | |
|---|---|---|---|---|
| FAITH | fiath | fouth | ifhat | agent |
| REPLY | relpy | redmy | pryel | focus |
| CHAIN | chian | choen | acnhi | elite |
| SIXTY | sitxy | sibky | xsyit | crude |
| ALOUD | aluod | aleid | oadlu | crude |
| GRIEF | greif | grouf | igfre | elite |
| MIDST | misdt | mirct | dmtis | enemy |
| ANGEL | agnel | ampel | galne | focus |
| PULSE | pusle | punbe | lpeus | frame |
| MAIZE | miaze | mouze | imeaz | knock |
| OUNCE | oucne | oulfe | noeuc | media |
| QUOTA | qouta | qeata | oqaut | panel |
| GIPSY | gispy | gilny | pgyis | panel |
| FLAIR | fliar | fluer | afrli | panel |
| SNAIL | snial | snoul | aslni | relax |
| ENVOY | evnoy | eldoy | veyno | thumb |
| FALSE | fasle | fadge | lfeas | agent |
| DIRTY | ditry | dinsy | rdyit | alert |
| OWNER | onwer | orler | norwe | crazy |
| ANGLE | agnle | arble | gaenl | crazy |
| HARSH | hasrh | halch | rhhas | drift |
| MERCY | mecry | meldy | rmyec | knock |
| NOISY | niosy | nausy | inyos | frame |
| ANKLE | aknle | ardle | kaenl | focus |
| AISLE | ailse | aigre | saeil | grasp |
| RISKY | riksy | rimpy | sryik | knock |
| FIERY | feiry | foary | efyir | magic |
| RAINY | riany | roeny | iryan | media |
| JUICY | jiucy | joacy | ijyuc | panic |
| NYMPH | nypmh | nyrch | mnhyp | phase |
| OPIUM | opuim | opoem | iompu | smart |
| METRO | merto | meglo | tmoer | smart |
| IDEAL | idael | idoul | eilda | agent |
| FAULT | fualt | foilt | uftal | elite |
| FANCY | facny | faldy | nfyac | climb |
| SOLVE | sovle | sorfe | lseov | crude |
| ALIEN | alein | aloun | ianle | drift |
| EDGES | egdes | eskes | gesde | climb |

| RIDGE | rigde | ricke | dreig | enemy |
|-------|-------|-------|-------|-------|
| SPOIL | spiol | speul | oslpi | frame |
| THIEF | theif | thoif | itfhe | grasp |
| PEARL | paerl | poerl | apler | magic |
| GLEAM | glaem | gloum | egmla | magic |
| FARCE | facre | falme | rfeac | thumb |
| VAULT | vualt | voilt | uvtal | media |
| IDIOM | idoim | idaum | iimdo | phase |
| MOURN | muorn | maern | umnor | relax |
| SPRIG | srpig | stlig | rsgpi | thumb |
| BRIEF | breif | broaf | ibfre | alert |
| GIANT | gaint | gount | agtin | alert |
| WHEAT | whaet | whoit | ewtha | crazy |
| DEALT | daelt | doult | adtel | crude |
| SIXTH | sitxh | silch | xshit | climb |
| SAUCE | suace | soice | useac | elite |
| IMPLY | ipmly | idsly | piyml | alert |
| IDIOT | idoit | idaut | iitdo | frame |
| CHOIR | chior | chaur | ocrhi | enemy |
| RANCH | racnh | ravdh | nrhac | knock |
| NIECE | neice | naoce | eneic | media |
| ONSET | osnet | ocdet | sotne | panic |
| SUEDE | seude | saide | eseud | relax |
| LIMBO | libmo | lindo | mloib | phase |
| EXPEL | epxel | endel | pelxe | smart |
| NOTCH | nocth | nolth | tnhoc | phase |
| CHEAP | chaep | choip | ecpha | agent |
| TITLE | tilte | tighe | tteil | climb |
| DEPTH | detph | degch | pdhet | crazy |
| JUICE | jiuce | jeace | ijeuc | drift |
| NOBLE | nolbe | nofre | bneol | drift |
| REACT | raect | rouct | artec | enemy |
| NYLON | nlyon | nadon | lnnyo | focus |
| ONION | onoin | onean | ionno | grasp |
| QUEST | qeust | qaist | eqtus | grasp |
| DISCO | dicso | dilgo | sdoic | magic |
| SHRUG | srhug | scmug | rsghu | panic |
| BERTH | betrh | belgh | rbhet | panel |
| QUART | qaurt | qeirt | aqtur | panic |
| SIEVE | seive | soave | eseiv | relax |
| THROB | trhob | tcmob | rtbho | smart |
| ARSON | asron | andon | sanro | thumb |

Nonwords
Stimuli are listed in the order: Nonword target, TL prime, 2SL prime, Scrambled prime and ALD prime.

| | | | |
|---|---|---|---|
| BAITH | biath | bouth | ibhat | olert |
| MUICE | miuce | meace | imeuc | crift |
| ANION | anoin | anean | ianno | frasp |
| ANSET | asnet | acdet | satne | phumb |
| GHEAP | ghaep | ghoip | egpha | srude |
| SOBLE | solbe | sofre | bseol | crift |
| QUIST | qiust | qaest | iqtus | frasp |
| QUERT | qeurt | qiart | eqtur | banic |
| YALSE | yasle | yadge | lyeas | igent |
| GARSH | gasrh | galch | rghas | crift |
| OISLE | oilse | oigre | soeil | frasp |
| FUICY | fiucy | foacy | ifyuc | banic |
| ODEAL | odael | odoul | eolda | srude |
| OLIEN | olein | oloan | ionle | banic |
| PHIEF | pheif | phoif | ipfhe | frasp |
| BAULT | bualt | boilt | ubtal | olite |
| DRIEF | dreif | droaf | idfre | docus |
| NIXTH | nitxh | nilch | xnhit | olite |
| PHOIR | phior | phear | oprhi | nagic |
| FUEDE | feude | faide | efeud | banic |
| VIANT | vaint | viunt | avtin | olert |
| NAUCE | nuace | noice | uneac | glimb |
| DANCH | dacnh | davdh | ndhac | nedia |
| RIMBO | ribmo | rindo | mroib | thase |
| FEPLY | felpy | fedmy | pfyel | olert |
| SRIEF | sreif | srouf | isfre | docus |
| NAIZE | niaze | nouze | ineaz | gnock |
| SLAIR | sliar | sluer | asrli | igent |
| VIRTY | vitry | vinsy | rvyit | olert |
| ODGES | ogdes | oskes | gosde | inemy |
| DISKY | diksy | dimpy | sdyik | gnock |
| SYMPH | sypmh | syrch | mshyp | thase |
| SAULT | sualt | soilt | ustal | glimb |
| NERCY | necry | neldy | rnyec | inemy |
| BEARL | baerl | boerl | abler | gnock |
| EDIUM | edoim | edaum | iemdu | delax |
| GANCY | gacny | galdy | ngyac | olite |
| LIDGE | ligde | licke | dleig | inemy |
| CLEAM | claem | cloum | ecmla | nagic |
| NOURN | nuorn | naern | unnor | delax |
| DITLE | dilte | dighe | tdeil | glimb |
| BEACT | baect | bouct | abtec | inemy |
| FISCO | ficso | filgo | sfoic | nagic |
| FIEVE | feive | foave | efeiv | delax |
| SHAIN | shian | shoen | asnhi | olite |

| | | | | |
|---|---|---|---|---|
| NIDST | nisdt | nirct | dntis | docus |
| BIERY | beiry | boary | ebyir | nagic |
| SMAIL | smial | smoul | aslmi | delax |
| AWNER | anwer | arler | narwe | drazy |
| GOISY | giosy | gausy | igyos | igent |
| AUNCE | aucne | aulfe | naeuc | nedia |
| EPIUM | epuim | epoem | iempu | sgart |
| INGLE | ignle | irble | gienl | drazy |
| ENKLE | eknle | erdle | keenl | docus |
| LAINY | liany | loeny | ilyan | srame |
| NETRO | nerto | neglo | tnoer | sgart |
| PHEAT | phaet | phoit | eptha | drazy |
| OMPLY | opmly | odsly | poyml | srame |
| MIECE | meice | maoce | emeic | nedia |
| IXPEL | ipxel | indel | pilxe | sgart |
| TEPTH | tetph | tegch | pthet | drazy |
| MYLON | mlyon | madon | lmnyo | crift |
| CHRUG | crhug | crmug | rcghu | nedia |
| PHROB | prhob | pcmob | rpbho | sgart |
| JIXTY | jitxy | jibky | xjyit | srude |
| ONGEL | ognel | ompel | golne | srame |
| QUITA | qiuta | qeata | iqaut | banel |
| ONVOY | ovnoy | oldoy | voyno | thase |
| ELOUD | eluod | eleid | oedlu | igent |
| BULSE | busle | bunbe | lbeus | gnock |
| MIPSY | mispy | milny | pmyis | banel |
| STRIG | srtig | smlig | rsgti | phumb |
| COLVE | covle | corfe | lceov | banel |
| SCOIL | sciol | sceul | oslci | thase |
| JARCE | jacre | jalme | rjeac | phumb |
| DOTCH | docth | dolth | tdhoc | glimb |
| KEALT | kaelt | koult | aktel | srude |
| EDIOT | edoit | edaut | ietdo | srame |
| VERTH | vetrh | velgh | rvhet | banel |
| URSON | usron | undon | sunro | phumb |

*Table 1.*

*Mean Decision Latencies (RT, in ms), Standard Errors (in parentheses) and Percent*

*Error Rates (%E) in Experiment 1*

----------------------------------------------------------------------------------------------------

Target type

----------------------------------------------------------------------------------------------------

|                          | Word      |     | Nonword   |      |
|--------------------------|-----------|-----|-----------|------|
|                          | Word      |     | Nonword   |      |
| Response type            | RT        | %E  | RT        | %E   |
| and prime type           |           |     |           |      |

----------------------------------------------------------------------------------------------------

| Same           |           |     |           |      |
|----------------|-----------|-----|-----------|------|
| Identity       | 512 (31)  | 4.2 | 545 (33)  | 6.7  |
| Control        | 578 (24)  | 8.6 | 607 (34)  | 8.6  |
| Priming effect | 66        | 4.4 | 62        | 1.9  |

----------------------------------------------------------------------------------------------------

| Different      |           |     |           |      |
|----------------|-----------|-----|-----------|------|
| Identity       | 584 (25)  | 5.3 | 602 (27)  | 7.7  |
| Control        | 597 (28)  | 5.3 | 616 (29)  | 5.1  |
| Priming effect | 13        | 0   | 14        | -2.6 |

----------------------------------------------------------------------------------------------------

*Table 2.*

*Mean Decision Latencies (RT, in ms), Standard Errors (in parentheses) and Percent*

*Error Rates (%E) in Experiment 2*

----------------------------------------------------------------------------------------------------

|  | Letter type | | | |
| --- | --- | --- | --- | --- |
|  | Similar | | Dissimilar | |
| Response type, | RT | %E | RT | %E |
| Frequency and |  |  |  |  |
| Prime type |  |  |  |  |

----------------------------------------------------------------------------------------------------

**Same**

High-frequency word

| | | | | |
| --- | --- | --- | --- | --- |
| Identity | 444 (19) | 3.1 | 450 (16) | 5.5 |
| Control | 521 (15) | 13.6 | 549 (18) | 13.8 |
| Priming effect | 77 | 10.5 | 99 | 8.3 |

Low-frequency word

| | | | | |
| --- | --- | --- | --- | --- |
| Identity | 443 (16) | 5.5 | 463 (16) | 6.5 |
| Control | 533 (18) | 11.5 | 556 (15) | 15.9 |
| Priming effect | 90 | 6.0 | 93 | 9.4 |

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**Different**

High-frequency word

| | | | | |
|---|---|---|---|---|
| Identity | 531 (21) | 8.4 | 534 (18) | 3.4 |
| Control | 528 (19) | 8.9 | 557 (21) | 4.2 |
| Priming effect | -3 | 0.5 | 23 | 0.8 |
| Low-frequency word | | | | |
| Identity | 520 (16) | 3.7 | 533 (17) | 6.3 |
| Control | 524 (16) | 5.0 | 532 (16) | 4.7 |
| Priming effect | 4 | 1.3 | -1 | 1.6 |

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*Table 3.*

*Mean Decision Latencies (RT, in ms), Standard Errors (in parentheses) and Percent*

*Error Rates (%E) in Experiment 3*

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<div align="center">Response type</div>

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| Response type and Prime type | Example Prime-Target | RT | %E |
|---|---|---|---|
| Same response | (Reference – *score*) | | |
| Identity | *score-SCORE* | 428 (18) | 5.3 |
| Pseudohomophone | *skore-SCORE* | 454 (19) | 6.0 |
| 1LD | *smore-SCORE* | 456 (18) | 5.6 |
| Different response | (Reference – *flair*) | | |
| Identity | *scout-SCOUT* | 487 (19) | 4.6 |
| Pseudohomophone | *skout-SCOUT* | 486 (19) | 4.9 |
| 1LD | *smout-SCOUT* | 491 (17) | 6.0 |

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*Table 4.*

*Mean Decision Latencies (RT, in ms), Standard Errors (in parentheses) and Percent*

*Error Rates (%E) in Experiment 4*

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Response type

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| Response, Item and Prime type | Example Prime-Target | RT | %E |
|---|---|---|---|
| Same response | | | |
| Words | (Reference – *faith*) | | |
| Identity | *faith-FAITH* | 391 (14) | 4.4 |
| TL | *fiath-FAITH* | 392 (15) | 4.1 |
| 2SL | *fouth-FAITH* | 403 (13) | 7.5 |
| Scrambled | *ifhat-FAITH* | 429 (13) | 5.3 |
| ALD | *agent-FAITH* | 473 (18) | 19.4 |
| Nonwords | (reference – *baith*) | | |
| Identity | *baith-BAITH* | 404 (14) | 4.1 |
| TL | *biath-BAITH* | 407 (16) | 5.0 |
| 2SL | *bouth-BAITH* | 420 (15) | 5.0 |
| Scrambled | *ibhat-BAITH* | 462 (19) | 9.1 |
| ALD | *igent-BAITH* | 474 (16) | 15.6 |

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Different response

| Words | (Reference – *anger*) | | |
|---|---|---|---|
| Identity | *month-MONTH* | 457 (14) | 3.8 |
| TL | *motnh-MONTH* | 456 (14) | 2.5 |
| 2SL | *morch-MONTH* | 449 (15) | 4.1 |
| Scrambled | *nmhot-MONTH* | 457 (17) | 1.9 |
| ALD | *rhyme-MONTH* | 455 (16) | 2.8 |
| Nonwords | (reference – *enger*) | | |
| Identity | *fonth-FONTH* | 462 (16) | 4.7 |
| TL | *fotnh-FONTH* | 468 (15) | 6.3 |
| 2SL | *forch-FONTH* | 473 (21) | 2.8 |
| Scrambled | *nfhot-FONTH* | 470 (17) | 2.8 |
| ALD | *dipsy-FONTH* | 459 (13) | 4.7 |

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*Table 5.*

*Mean match scores for word and nonword stimuli used in Experiments 4*

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|  | Model | | | |
| --- | --- | --- | --- | --- |

| Prime type | Slot-code | SOLAR | COB | SERIOL |
| --- | --- | --- | --- | --- |
| Words | | | | |
| Identity | 1.00 | 1.00 | 1.00 | 1.00 |
| TL | 0.60 | 0.87 | 0.90 | 0.86 |
| 2SL | 0.60 | 0.60 | 0.23 | 0.39 |
| Scrambled | 0.60 | 0.60 | 0.47 | 0.32 |
| ALD | 0.04 | 0.18 | 0.02 | 0.02 |
| | | | | |
| Nonwords | | | | |
| Identity | 1.00 | 1.00 | 1.00 | 1.00 |
| TL | 0.60 | 0.87 | 0.90 | 0.86 |
| 2SL | 0.60 | 0.60 | 0.23 | 0.39 |
| Scrambled | 0.60 | 0.60 | 0.47 | 0.32 |
| ALD | 0.06 | 0.19 | 0.02 | 0.02 |

Author notes

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Footnotes

1. TL similarity effects have been found with nonwords in the unprimed lexical

   decision task (e.g., Perea & Lupker, 2004; Lupker, Perea, & Davis, 2007). These

   studies showed that TL nonwords (e.g., *JUGDE*) are more difficult to reject than

   2SL nonwords (e.g., *JUNPE*). Note that this finding is interpreted in terms of

   activation of baseword (e.g., *JUDGE*) by the TL nonword - hence it does not

   constitute evidence that the effect is pre-lexical in origin.

2. It has been suggested to us that priming in the same-different task may be

   alternatively interpreted in terms of "response priming". At a general level, it is

   unclear how the notion of "response" is intended to be distinguished from

   "decision" in the way the Bayesian Reader explains masked priming in terms of

   evidence contributed by the prime towards the decision required to the target.

   Both accounts predict, for example, that the prime which is the same as the

   reference would interfere with *Different* responses (e.g., reference-a, prime-A,

   target-B), and this prediction has been corroborated by Kinoshita and Kaplan

   (2008, Experiment 3) in a cross-case letter match task. A more specific proposal

   (suggested by a reviewer) is that participants are using the reference-prime

   relationship to predict the response required to the target (*Same* vs. *Different*)

   before the target appears. The idea is that in the same-different task, for the *Same*

   trials, an "identity prime" (a prime that is identical to the *target*) is also the same

   as the reference (e.g., a-a-A), but for the *Different* trials, an identity prime is

   different from the reference (e.g., a-b-B), and hence the response to the target is

   completely predictable for the prime. This view that the prime is used to predict

the response before the target appears differs from the Bayesian account which assumes that the evidence contributed by the prime is combined with the evidence accumulated from the target. We note two points against the response priming view. One is the theoretical implausibility of strategically using the prime to predict the response when it is masked and hence its identity is veiled from awareness. The second is empirical. The response priming view predicts that when the reference-prime relationship is not predictive of the response to the target, priming should be reduced or eliminated. Contrary to the prediction, Kinoshita and Kaplan (2008, Experiments 2 and 3) observed an equally robust priming for the *Same* trials when the *Different* trials did and did not include the primes which were the same as the reference but different from the target (e.g., a-A-B). Thus, there is no evidence that the reference-prime relationship is used strategically to prepare the response to the target, as suggested by the response priming view.

3. The match scores were calculated using the Matchcalculator available at Colin Davis' website http://www.pc.rhul.ac.uk/staff/c.davis/Utilities/. The match scores for the "Open Bigram" scheme here is the more recent Constrained OB (Schoonbaert & Grainger, 2004), which limits the number of intervening letters within a bigram to two, not the Unconstrained OB (Grainger & van Heuven, 2003), which has no limit to the number of intervening letters that a bigram can span. Calculation of match scores for SERIOL is also based on the more recent version (Whitney, 2007; Whitney & Cornelissen, 2008) which supercedes the earlier SERIOL model described in Whitney (2001), and followed the procedure

and the parameters described in Whitney (2007), where an edge or contiguous bigram gives an activation value of 1.0, a one-letter separation gives 0.8, a two-letter-separation gives 0.4. Note that some of the targets contained repeated letters (e.g., SI<u>EV</u>E) which affect match scores for schemes other than slot-coding.

4. The use of plural here is deliberate, as models of lexical decision such as MROM (Grainger & Jacobs, 1996), DRC (Coltheart et al., 2001), SOLAR (Davis, 1999) and the Bayesian Reader (Norris, 2006) specifically allow the possibility that lexical decision may be based on multiple lexical representations activated simultaneously ("global activation") by the orthographic input. Consistent with this, Kinoshita, Castles and Davis (in press) found that neighborhood density facilitated lexical decisions and modulated priming in the lexical decision task but had no effect on the same-different match task.

5. It is relevant to note that in a separate experiment from those reported here, we used the primes used in Experiment 4 as clearly visible targets requiring a *Different* response in an unprimed cross-case same-different match task. Participants (N = 24) reliably responded to the TL stimuli (e.g., *FIATH*) as being different from the reference (*faith*). The error rates to the TL, 2SL and ALD items requiring a *Different* response were 34.6%, 5.0%, 4.8%, and the RTs, 752 ms, 590 ms and 550 ms, respectively; and for identity items requiring a *Same* response, 5.6% and 574 ms.
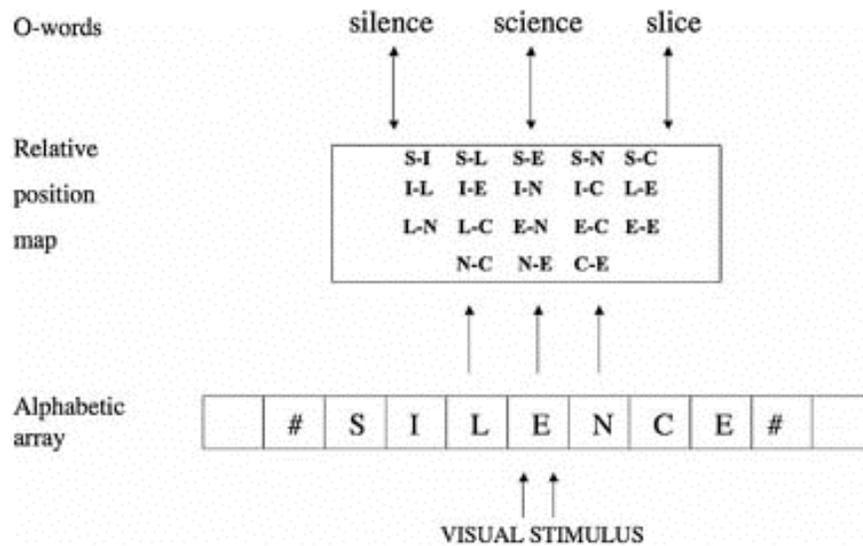
List of Figures

*Figure 1*. Grainger and Van Heuven's (2003) open-bigram model. A letter string is first processed by a bank of alphabetic character detectors (the alphabetic array). The next level of processing extracts open-bigrams from the alphabetic array to construct a relative-position map which, in turn, activates whole-word orthographic representations (O-words) via bidirectional excitatory connections with all units at the relative position level.
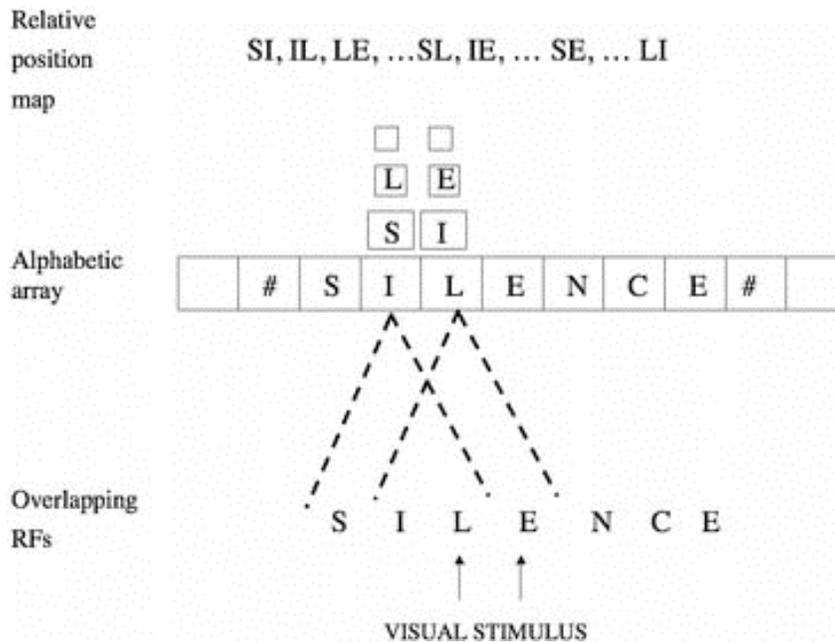
*Figure 2.* The overlap open-bigram model of Grainger, Granier, Farioli, Van Assche & van Heuven (2006). Letter detectors in the alphabetic array have large overlapping receptive fields (RFs) such that for a given letter at a given retinal location one letter identity will be maximally activated, and other letter identities falling within the receptive field of the letter detector will also receive some activation. Bigrams are computed across adjacent locations in the alphabetic array on the basis of all letter identities (several at any given location) activated above a criterion value. Thus bigrams are formed from contiguous letters in the correct order, noncontiguous letters in the correct order (open bigrams), and contiguous letters in the incorrect order (transposed bigrams).