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Masked repetition priming of letter-in-string identification: An ERP investigation

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Abstract

In a post-cued letter identification task, participants were presented with 7-letter nonword target stimuli that were formed of a random string of consonants (DCMFPLR) or a pronounceable sequence of consonants and vowels (DAMOPUR). Targets were preceded by briefly presented pattern-masked primes that could be the same sequence of letters as the target, composed of seven different letters, or sharing either the first or last five letters of the target. There was some evidence for repetition priming effects that were independent of target type in an early component, the N/P150, thought to reflect the mapping of visual features onto letter representations, and that is insensitive to orthographic structure. Following this, pronounceable nonwords showed significantly greater repetition priming effects than consonant strings, in line with the behavioral results. Initial versus final overlap only started to influence target processing at around 200–250 ms post-target onset, at about the same time as the effects of target type emerged. The results are in line with a model where the initial parallel mapping of visual features onto a location-specific orthographic code is followed by the subsequent activation of location-invariant orthographic and phonological codes.

Keywords

Pseudoword superiority effect; ERPs; Nonword processing; Masked priming

1. Introduction

In languages that use an alphabetic script, strings of letters that do not correspond to a real word (i.e., nonwords) can vary in terms of the amount of orthographic and phonological structure they carry. Most research investigating the processing of such nonword stimuli typically distinguishes between the extreme conditions of orthographically legal, pronounceable strings of letters on one hand, and illegal, unpronounceable consonant strings on the other. The present study follows this convention, and examines the processing of these two types of nonword, using an original combination of masked repetition priming, event-related potential (ERP) recordings, and post-cued letter-in-string identification. The task of post-cued letter-in-string identification, often referred to as the Reicher–Wheeler task (Reicher, 1969; Wheeler, 1970), is thought to provide a window on the mechanisms involved in parallel, independent letter identification, which is the very starting point of

visual word recognition in languages that use an alphabetic script. By augmenting this task with both a priming manipulation and the recording of ERPs we therefore hope to provide further insights into the very first phase of the reading process when the eyes fixate a printed word.

There is a large literature contrasting the performance of skilled readers to these two types of nonword stimuli in behavioral experiments. For example, when asked to reject these stimuli as nonwords in a lexical decision task, participants are faster and more accurate at rejecting consonant strings than pronounceable nonwords (e.g., Ratcliff et al. (2004), Holcomb and Neville (1990)). Differences are also observed even when participants only have to identify a single letter in the stimulus in a post-cued letter-in-string identification task. In studies using this paradigm, letter identification is found to be more accurate in pronounceable nonwords than consonant strings—the so-called “pseudoword superiority effect” (e.g., Baron and Thurston (1973), Grainger and Jacobs (1994, 2005), Spoehr and Smith (1975)). Although the precise mechanisms underlying the pseudoword superiority effect remain to be clarified, it is likely that pseudoword stimuli (i.e., orthographically regular and pronounceable nonwords) benefit from multiple additional sources of information that are present to a lesser extent in consonant strings. This additional information could be provided by the familiarity of letter combinations, the quality of the phonological code, or the ability to make contact with whole-word representations.

However, at least one account of printed word perception predicts that the very first phase of orthographic processing should be insensitive to such differences in orthographic, phonological, and lexical information. This is Grainger and van Heuven’s (2003) account of orthographic processing, recently integrated within a multiple-route model of visual word recognition (Grainger and Ziegler, 2011) that incorporates essential aspects of the bi-modal model of visual word recognition (Diependaele et al., 2010; Grainger and Ferrand, 1994; Grainger and Holcomb, 2009a), shown in Fig. 1. According to this account of visual word recognition, the initial mapping of visual features onto abstract letter identities should operate in parallel (see e.g., Adelman et al. (2010)) and should not depend on the internal structure of the target string of letters. At this level of processing the system knows where letters are relative to eye fixation location, but does not know where the different letters are with respect to each other. Therefore, the earliest processing point that distinguishes between consonant strings and pronounceable nonwords in this model, is in the pathway that transforms the location-specific orthographic code (O-units R) into the location-invariant sublexical code that subsequently gives rise to sublexical phonological activation (i.e., the O $\leftrightarrow$ P interface shown in Fig. 1). It is this sublexical orthographic code that is sensitive to contiguous orthographic structure—that is the frequency of co-occurrence of adjacent letters. Grainger and Ziegler (2011) referred to this as the *fine-grained orthographic code*, in order to emphasize the level of precision of letter position information that is required in order to successfully perform the sublexical mapping of orthography to phonology. The other critical point of divergence between the two types of nonword is at the level of whole-word orthographic representations (O-words) that will typically be more strongly activated by a pronounceable nonword target than a consonant string target. Fig. 1 describes these different processing stages, and provides a tentative mapping of each component process onto a hypothetical ERP difference wave in a masked repetition priming experiment.

The general aim of the present study was to use nonword stimuli in order to gain a better understanding of the mechanisms involved in processing strings of letters during the very earliest stages of visual word recognition. However, the specific starting point was some pilot work investigating masked priming effects in a letter-in-string identification task with random consonant strings. In this study it was found that participants’ ability to report the identity of a single target letter in a briefly presented (100 ms) target string of five different

consonants (e.g., BFMRG) was not influenced by whether the preceding prime stimulus (presented for 50 ms) was identical to the target string or was a completely different string of consonants. As in the present study, the position of the target letter was indicated immediately after presentation of the target string of letters, and simultaneously with the presentation of a backward masking stimulus. Given the number of experiments reporting robust orthographic priming effects in similar conditions (see Grainger (2008), for review), this absence of priming is quite striking. The lack of behavioral repetition priming effects in this pilot work could either be due to a general failure to extract information from briefly presented, pattern-masked consonant strings, or because the information that is extracted from the prime stimulus is not useful for the task of letter-in-string identification. The results of some more recent research combining masked priming and the same-different judgment task suggests that it is not because of a failure to extract information from briefly presented consonant strings. García-Orza et al. (2010) found significant priming effects with random consonant primes and targets using this paradigm. The time it took to determine that the target string was identical to a previously presented probe string of letters was reduced when the target was preceded by a masked prime stimulus composed of the same letters (repetition prime) compared with a totally unrelated prime. Furthermore, an earlier study had shown that the time to classify a set of three random consonants as all being letters (multiple alphabetic decision) was reduced by a masked prime stimulus composed of the same letters compared with different letter primes (Peressotti and Grainger, 1995). Therefore, the failure to find repetition priming effects with random consonant strings in our pilot work would be more likely related to the specific task of letter-in-string identification, and the kind of information that is required to perform this task.¹ In other words, a prime stimulus formed of a random string of consonants would generate activation in location-specific sublexical orthographic representations (see Fig. 1), but activation of such representations could not be used to infer the presence of a given letter at a given position in the string for the task of letter-in-string identification.

This explanation can be clarified using the model described in Fig. 1. According to this account, location-specific letter representations map onto different forms of higher-level representation, which would be better candidates for integrating information across prime and target stimuli in masked priming. Most important is that some of these higher-level representations, those that retain information about letter identity and precise letter position (i.e., the fine-grained orthographic code), would provide relevant information for letter-in-string identification. In this way, masked primes that are strings of consonants could activate location-specific letter representations, but would not generate significant levels of activation in higher-level representations that could inform the letter-in-string identification response. According to this explanation of why there might be no masked repetition priming with random consonant strings in post-cued letter-in-string identification, we ought to be able to find evidence for priming effects at the level of location-specific letter representations by recording ERPs. The main goals of the present study are therefore twofold. First, we test for behavioral masked repetition priming effects in the post-cued letter-in-string identification paradigm using pronounceable nonwords and consonant strings as primes and targets. Second, we seek evidence for effects of masked primes in the possible absence of behavioral effects in this paradigm, by recording ERPs as well as behavioral responses.

¹We note in passing that nonword targets in the lexical decision task tend not to be sensitive to masked orthographic priming, and this absence of priming very likely reflects specificities of the lexical decision task (Dufau et al., in press).

1.1. Nonword processing and ERPs

The masked priming technique has been successfully combined with ERP recordings in a number of recent studies performed by our group (e.g., Holcomb and Grainger (2006); see Grainger and Holcomb (2009a), for review). This combined methodology has been shown to be sensitive to early feature level processing (Chauncey et al., 2008), to location-specific orthographic processing (Dufau et al., 2008), to sublexical orthographic and phonological processing (Grainger et al., 2006), to morphological processing (Morris et al., 2007), to effects of whole-word form processing (Massol et al., 2010), and to semantic processing (Holcomb and Grainger, 2009; Midgley et al., 2009). However, most of our prior work has examined the processing of word targets in semantic categorization and lexical decision tasks, and none, except for the Massol et al. (2011) study to be described below, have focused on the processing of nonword stimuli as targets.

Furthermore, most prior work comparing the processing of word stimuli and different types of nonwords has involved a direct comparison of the ERPs generated by the different types of stimuli, as opposed to the priming manipulation to be used in the present study (Bentin et al., 1999; Coch and Mitra, 2010; Proverbio et al., 2004; Rosazza et al., 2009; Ziegler et al., 1997). The observed patterns vary from study-to-study, possibly because of the different tasks involved. For example, Bentin et al. (1999) reported a significant difference between pronounceable and unpronounceable nonword stimuli, peaking around 320 ms, with more negative-going waves for pronounceable nonwords than for consonant strings. Two studies found evidence for an earlier difference between these two types of stimulus with significant differences at around 150 ms in a study by Proverbio et al. (2004) and a study by Coch and Mitra (2010). Two other ERP studies revealed differences between these two types of nonwords emerging at around 225 ms post-target onset (Rosazza et al., 2009; Ziegler et al., 1997). Particularly relevant for the present work, is the study by Massol et al. (2011). In this work we compared processing of different types of nonwords using masked priming and measuring ERPs. Targets in the Massol et al. (2011) study were either pronounceable nonwords (e.g., STRENG) or consonant strings (e.g., STRBNG), that both differed from a real word by a single letter substitution (STRONG). These targets were preceded by masked primes that could be the same as the target (e.g., streng—STRENG, strbng-STRBNG) or the real word neighbor of the target (e.g., strong—STRENG, strong-STRBNG). Overall, priming effects were greater and more long-lasting with pronounceable nonwords than consonant strings. However, consonant string targets showed an early effect of word neighbor priming in the absence of an effect of repetition priming, whereas pronounceable nonwords showed both repetition and word neighbor priming effects in the same time window. Independently of these priming effects, pronounceable nonwords were associated with larger negativities than consonant strings, starting at 290 ms post-target onset.

Therefore, summarizing prior work using ERPs to investigate processing of different types of nonwords, overall, it appears that differences between pronounceable nonword stimuli and consonant strings become stable after about 200 ms of processing, although some studies suggest an earlier onset, and some a later onset, possibly due to the different tasks used (we return to this issue in the Discussion). The later onset reported by Massol et al. (2011) can be attributed to the ability of the consonant strings that were tested in that study to make contact with whole-word orthographic representations. In fact, it is important to keep in mind that these stimuli were very similar to real words (differing by only a single letter substitution). So, in this case, consonant strings, just like pronounceable nonwords, would have activated whole-word representations, and it is this activation that would have delayed the emergence of differences between consonant strings and pronounceable pseudowords. However, when the consonant strings do not resemble real words, as in the majority of studies, the timing estimates tend to be closer to 200 ms post-target onset. This fits with the general interpretative framework shown in Fig. 1 (Holcomb and Grainger,

2006; Grainger and Holcomb, 2009a), whereby the very first phase of visuo-orthographic processing starts at around 150 ms post-target onset. Differences between pronounceable nonwords and consonant strings should therefore only emerge after that.

1.2. The present study

In the present study, participants were presented with brief (50 ms) visual primes that were rapidly followed by a target that was a full repetition of the prime, a target that shared the five first letters with the prime, a target that shared last five letters with the prime, or a target that was unrelated to the prime. Targets were also briefly presented (150 ms) and followed by a pattern mask accompanied by two hyphens placed above and below one of the letter positions. Participants were instructed to decide which letter they had seen in the position indicated by the hyphens by typing this character on a standard keyboard positioned in front of them. ERPs were time-locked to the onset of targets and recorded for 1000 ms after that. Primes and targets were all nonwords that were either orthographically legal and pronounceable letter strings (e.g., damopur) or strings of consonants (e.g., dcmfplr). The position of overlap manipulation was designed to reveal possible sequential processing biases that according to certain accounts of orthographic processing (e.g., Whitney (2001)), should be evident in the initial mapping of feature information onto letter representations. The theoretical framework shown in Fig. 1, on the other hand, predicts that such sequential biases should appear later in processing, following an initial parallel mapping of visual features onto location-specific letter representations. In this framework, sequential processing will most likely be evident during the sublexical mapping of orthography onto phonology, and possibly at the level of syllable representations (Carreiras et al., 2005). According to our tentative mapping of component processes onto ERP effects seen in masked priming (see Fig. 1), these sequential effects should therefore only start to be visible in the N250 ERP component.

Summing up, in the present study we will use a combination of masked priming and ERP recordings in order to investigate repetition priming effects with pronounceable nonwords and consonant strings. The general aim is to provide further evidence about the precise mechanisms involved in the very earliest processes involved in recognizing printed words. One more specific aim is to improve our understanding of the mechanisms involved in performing a letter-in-string identification task under brief stimulus durations and pattern masking. This task should encourage more letter-level processing than the lexical decision task used in our prior work comparing processing of consonant strings and pronounceable nonwords (Massol et al., 2011), yet pilot behavioral research with this paradigm failed to find any evidence for repetition priming with consonant string stimuli. Longer stimuli (7-letters) were tested compared with our prior work (5-letters) with the aim to increase repetition priming effects for consonant string targets. Furthermore, contrary to the stimuli used in Massol et al. (2011), which differed from real words by a single letter substitution, here we tested 7-letter stimuli that were orthographically much less similar to real words. This was done so as to limit top-down lexical influences in order to focus on bottom-up processing. Finally, contrary to our prior work and the other studies mentioned above, participants in the present study never saw real word stimuli. This should further limit the emergence of top-down lexical influences on processing, hence providing an even stronger focus on purely bottom-up processes.

With respect to the predictions of our model of the model presented in Fig. 1 (Grainger and Holcomb, 2009a), we expect to see equivalent priming effects for the two types of nonword in an early time window (N/P150) thought to reflect the mapping of visual features onto location-specific letter identities. Greater effects of repetition priming for pronounceable nonwords compared with consonant strings should emerge just after this time window, as soon as orthographic structure and higher-level phonological and lexical processes begin to

influence processing. Finally, we expect to see an influence of the position of overlap of partially overlapping primes (first 5 letters vs. last 5 letters shared with 7-letter targets) as soon as sequential phonological processes start to kick-in, which, according to Grainger and Holcomb (2009a) should occur during the N250 epoch, at around 250 ms post-target onset (Figs. 2 and 3).

2. Results

2.1. Behavioral results

Mean accuracy for the two types of target and the different letter positions are presented in Fig. 4. The complete set of means, including the results of the two priming manipulations, are presented in Table 1. Two separate ANOVAs were performed to examine the effects of REPETITION on one hand, and OVERLAP on the other.

In the analysis with the REPETITION factor, there was a significant main effect of REPETITION ($F(1, 15) = 15.79, p = .001$), a significant main effect of TYPE-OF-TARGET ($F(1, 15) = 48.46, p < .001$), and a significant main effect of SERIAL-POSITION ($F(3, 45) = 89.96, p < .001$). Participants responded more accurately when targets were the same stimulus as the prime compared to targets following unrelated primes, and more accurately when targets were pronounceable nonwords than when targets were consonant strings. Participants were also more accurate in identifying external letters (1st and 7th positions) than internal letters (3rd and 5th positions). Analyses also revealed a significant TYPE-OF-TARGET $\times$ REPETITION interaction ($F(1, 15) = 5.02, p = .040$) and a significant TYPE-OF-TARGET $\times$ SERIAL-POSITION interaction ($F(3, 45) = 29.02, p < .001$). Follow-up analyses showed a significant effect of repetition priming only for pronounceable nonwords ($F(1, 15) = 18.95, p < .001$), and no effect for consonant strings ($p > 4.1$). Fig. 4 and Table 1 indicate that the TYPE-OF-TARGET $\times$ SERIAL-POSITION interaction was mostly driven by differences in performance at the 3rd and 5th letter positions between the different types of target. There were, however, significant effects of SERIAL-POSITION for both types of targets (pronounceable nonword targets: $F(3, 45) = 37.35, p < .001$; consonant string targets: $F(3, 45) = 133.56, p < .001$).

In the analysis including the OVERLAP factor, neither the main effect of OVERLAP nor the interaction between TYPE-OF-TARGET and OVERLAP or between SERIAL-POSITION and OVERLAP were significant ($p > 4.1$). However, in this analysis, initial overlap primes tested at the 7th position, and final overlap primes tested at the 1st position, did not contain the target letter. If priming can be obtained with partially overlapping primes when they contain the target letter, then we should see an advantage for initial overlap at position 1 and an advantage for final overlap at position 7. We therefore performed an additional analysis with OVERLAP, TYPE-OF-TARGET, and with only positions 1 and 7 of the SERIAL-POSITION factor. The critical OVERLAP $\times$ SERIAL POSITION interaction was not significant, and neither was the triple interaction between OVERLAP $\times$ POSITION $\times$ TYPE-OF-TARGET ($F_s < 1$). There was therefore no evidence for priming from partially overlapping primes that contained the target letter compared with those that did not.

2.2. Electrophysiological data

2.2.1. Visual inspection of ERPs—The ERPs time-locked to target items are plotted in Fig. 5. As can be seen in these plots, early in the waveforms there was a small negativity peaking at around 90 ms, which was followed immediately by a prominent positivity peaking near 200 ms. Up to this point the ERPs for the two types of target were quite similar. However, starting just after the peak of the first positive-going wave, there was a

negative-going waveform that appeared to reveal different priming effects for the two types of nonword. This negative-going potential peaked at around 300 ms and resembled an N400 component with an earlier onset than typically seen with word stimuli.

2.2.2. Analysis of ERP data—We first present an analysis using three time-windows that span the major processing steps outlined in our model (Fig. 1). These analyses are performed separately for the effects of full repetition (full repetition vs. unrelated primes) and overlap (initial vs. final overlap primes). We then present a more fine-grained analysis of the time-course of effects of repetition, overlap, and type of target. All trials free from muscle artifact and/or eye movement or blink activity were included in the ERP analyses, hence including trials where the target letter was not correctly identified. Given that we are interested in how processing operates across the entire string of 7 letters, this appeared to be appropriate, and in any case necessary in order to have a sufficiently high signal-to-noise ratio.²

2.2.2.1. Full repetition vs. unrelated primes: 100–170 ms (N/P150 component). In this time-window, there was a more negative-going effect in frontal electrodes and a more positive-going effect in occipital electrodes when the target was the full repetition of the prime compared with unrelated primes. Based on previous studies showing the largest N/P150 effects at frontal and occipital sites over the right hemisphere (e.g., Chauncey et al. (2008), Dufau et al. (2008)), we performed an analysis restricted to FP2 and O2 electrode sites. ANOVAs were performed on this data with TYPE-OF-TARGET (pronounceable nonword vs. consonant string), REPETITION (full repetition vs. unrelated) and ANTERIOR–POSTERIOR (FP2 vs. O2) as factors. The statistical analysis revealed a significant interaction between REPETITION $\times$ ANTERIOR–POSTERIOR, $F(1, 15) = 4.72$, $MSE = .58$, $p = .046$, $\eta^2_p = .23$, which is the hallmark of the N/P150 effect. Follow-up analyses revealed a marginal effect of REPETITION at O2, $F(1, 15) = 3.34$, $MSE = .80$, $p = .087$, $\eta^2_p = .18$ and no effect at FP2 ($F(1, 15) = .32$). This pattern can be seen in the waveforms at electrode sites FP2 and O2 in Fig. 5, panels A and B, and it takes the same form as in our previous work, with related primes generating a greater positivity in frontal electrodes and a greater negativity in occipital electrodes compared with unrelated primes. There were no interactions with the TYPE-OF-TARGET factor.

170–270 ms. In this time-window, there was a significant TYPE-OF-TARGET $\times$ REPETITION $\times$ LATERALITY interaction, $F(2, 30) = 4.32$, $MSE = .70$, $p = .029$, $\eta^2_p = .22$. A two-step set of follow-up analyses indicated that the 3-way interaction reflects the fact that the TYPE-OF-TARGET $\times$ REPETITION interaction was only significant over the right column, $F(1, 15) = 13.51$, $MSE = 1.07$, $p = .002$, $\eta^2_p = .47$ and, in turn, that this 2-way interaction was driven by the effect of REPETITION being present only for pronounceable nonword targets, $F(1, 15) = 6.92$, $MSE = 3.37$, $p = .018$, $\eta^2_p = .31$. As can be seen in Fig. 5A pronounceable nonword targets following unrelated primes produced a more negative-going wave than targets following repetition. Importantly, the effect of REPETITION for consonant strings was not significant at any of the electrode configurations in this time-window ($p > 4.1$, see Fig. 5B).

Finally, statistical analyses revealed a significant TYPE-OF-TARGET $\times$ ANTERIOR–POSTERIOR interaction ($F(4, 60) = 4.07$, $MSE = .56$, $p = .036$, $\eta^2_p = .21$) and also a significant TYPE-OF-TARGET $\times$ LATERALITY $\times$ ANTERIOR–POSTERIOR interaction

²At the request of one reviewer we nevertheless performed an analysis after removing all trials on which an incorrect response was given. This produced a pattern of average ERP waveforms per condition that perfectly mimicked the overall analysis, although some effects were no longer significant given the reduced power in this analysis. These supplementary results are available upon request from the first author.

($F(8, 120) = 3.26$, $MSE = .07$, $p = .023$, $\eta^2_p = .17$). The latter interaction reflects the fact that the effect of TYPE-OF-TARGET was only significant over the left column, $F(1, 15) = 5.97$, $MSE = .91$, $p = .027$, $\eta^2_p = .28$, with the pronounceable nonword targets producing more negative-going waveforms than the consonant string targets.

300–500 ms. In this time-window there were no significant main effects or interactions.

Summary of ERP repetition priming effects. The ERP data revealed an early and highly focal effect of repetition priming that did not interact with target type. This took the form of an interaction between the effects of priming and electrode site at the two locations typically used to examine the N/P150 (FP2 and O2), that peaked at about 150 ms post-target onset. After this early effect, the waveforms for pronounceable nonword and consonant string targets started to diverge at around 200 ms post-target onset, and at the same time more widespread repetition priming effects were seen, but only for pronounceable nonwords. ERPs generated by pronounceable nonword targets were less negative-going following repetition primes compared to unrelated primes, but even this effect was not robust in the traditional N400 time-window.

2.2.2.2. Initial overlap vs. final overlap: 100–170 ms (N/P150 component). In the overall analysis in this time window, as well as the analyses restricted to frontal and occipital sites (see analysis of Repetition priming) there were no main effects of OVERLAP or TYPE-OF-TARGET, and no significant interactions.

170–270 ms. Examination of the grand average waveforms revealed larger negativities for targets following initial overlap primes than targets following final overlap primes in frontal sites, whatever the type of target. These observations were confirmed by the presence of significant OVERLAP $\times$ ANTERIOR–POSTERIOR interaction ($F(4, 60) = 5.12$, $MSE = .48$, $p = .014$, $\eta^2_p = .25$). Follow-up analyses revealed significant effects of OVERLAP in left frontal sites (FP1 and F7), $F(1, 15) = 8.26$, $MSE = .6$, $p = .011$, $\eta^2_p = .35$ (see Fig. 5C). Over the left frontal sites, targets sharing the initial letters with the prime were associated with larger negativities than targets sharing the final letters with the prime.

300–500 ms. In this time window, there was also a significant OVERLAP $\times$ ANTERIOR–POSTERIOR interaction ($F(4, 60) = 7.73$, $MSE = .79$, $p = .002$, $\eta^2_p = .34$). As in the previous time-window, follow-up analyses revealed significant effects of OVERLAP in left frontal electrode sites, $F(1, 15) = 7.41$, $MSE = 1.43$, $p = .015$, $\eta^2_p = .33$. Again, targets following initial overlap primes were associated with larger negativities than targets following final overlap primes, whatever the type of target (see Fig. 5C).

Summary of ERP overlap priming effects. Primes that shared the first five letters with 7-letter targets compared with primes sharing the last five letters gave rise to more negative-going waveforms starting at around 200 ms post-target onset in left frontal electrode sites. These effects of position of overlap were the same for consonant strings and pronounceable nonwords.

2.2.2.3. Time-course analyses: Here we examine the time-course of effects of REPETITION, OVERLAP and TYPE-OF-TARGET (Figs. 6 and 7) using 50 ms time bins in order to provide a more fine-grained analysis of the evolution of these effects over time. We present the time-course of effects of REPETITION separately for the pronounceable nonword and consonant string targets (Fig. 6), given that there was a significant REPETITION $\times$ TYPE-OF-TARGET interaction in all but the N/P150 analysis presented above. Figs. 6 and 7 show the time-course analyses of each of these effects. The voltage maps represent voltage differences calculated by subtracting the voltage values in the full

repetition condition from the voltage values in the unrelated prime condition (Fig. 6) or by subtracting the values in the initial overlap condition from the values in the final overlap condition (Fig. 7). Each voltage map corresponds to a 50 ms time-window average, starting at 150 ms and continuing to 500 ms post-target onset. The tables represent the significant effects (corrected p -values) obtained with ANOVAs in each of the seven successive time-windows.

2.2.2.4. Summary of time-course analyses: The results of the time-course analyses confirm and extend the results obtained in the epoch-based analyses presented above. Clear effects of repetition priming were seen for pronounceable nonword targets between 200 and 250 ms post-target onset ($F(1, 15) = 4.87$, $MSE = 8.89$, $p = .043$, $\eta^2_p = .24$), and also between 400 and 450 ms post-target onset (REPETITION $\times$ LATERALITY: $F(2, 30) = 3.99$, $MSE = 1.26$, $p = .042$, $\eta^2_p = .21$), an effect that was not visible in the analysis of the N400 epoch. Effects of the overlap factor were first evident in the 200–250 ms time window (OVERLAP $\times$ ANTERIOR–POSTERIOR: $F(4, 60) = 7.25$, $MSE = .42$, $p = .001$, $\eta^2_p = .32$), and continued to have an influence up to 500 ms post-target onset. The same was true of the type-of-target factor, although the spatial distribution of the effects were not the same.

3. Discussion

In the present study we examined the processing of nonword stimuli of 7-letters in length that either formed a pronounceable string of letters (pronounceable nonwords) or a random string of consonants (consonant strings). Participants had to identify the letter that appeared at a post-cued location in briefly presented target strings. Targets were preceded by briefly presented 7-letter prime stimuli that could be the same as the target (full repetition), a completely different set of letters (unrelated prime), or shared either the first or last 5 letters with targets (initial overlap, final overlap). These manipulations were designed to shed light on the mechanisms used to process strings of letters during the very first phase of visual word recognition. The main results can be summarized as follows:

1. The behavioral results provide a replication of the well-known pseudoword superiority effect whereby letters are easier to identify when presented in a pronounceable nonword string than a random consonant string (see Grainger and Jacobs (2005), for a review). We also observed the standard outer-letter advantage whereby letters in exterior positions are easier to identify than letters in interior positions in the string (see Tydgate and Grainger (2009), for similar results). Most important is that we observed a significant repetition priming effect for pronounceable nonwords, while consonant strings were insensitive to repetition priming. Effects of the overlap manipulation (initial vs. final overlap) were not significant.
2. The ERP results revealed a difference in the waveforms generated by pronounceable nonwords and consonant strings that was significant at 200 ms post-target onset.
3. There was some evidence that repetition priming affected the ERPs generated by both pronounceable nonwords and consonant strings in an early ERP component (N/P150), whereas only pronounceable nonword targets were sensitive to repetition priming after 200 ms post-target onset. ERPs to pronounceable nonwords were less negative-going following repetition primes compared with unrelated primes.
4. Initial overlap primes led to slightly but significantly more negative-going ERP waveforms than final overlap primes for both types of target, and this effect emerged at around 200 ms post-target onset in left frontal electrode sites.

In what follows we will discuss the more general implications of our results with respect to component processes in visual word recognition and the estimated time-course of these component processes, as shown in Fig. 1. Then we examine the more specific implications of our results with respect to the mechanisms involved in performing letter-in-string identification, and finally we discuss the results of the position of overlap manipulation.

3.1. Random consonants vs. pronounceable pseudowords

Both the behavioral and the electrophysiological results of the present study revealed key differences in the way random consonant strings and pronounceable pseudowords are processed. Here, we will tentatively link these observed differences and the timing of the differences to the component processes of our model of visual word recognition shown in Fig. 1. Behaviorally, the differences took the form of the standard pseudoword superiority effect (e.g., Grainger and Jacobs (2005)), with improved accuracy in the identification of letters presented in pronounceable pseudowords than in random consonant strings, plus the differences in repetition priming effects that were discussed above. Electrophysiologically, this took the form of differences in the waveforms generated by these two types of nonword, as well as differences in the effects of repetition priming. Both the main effect of target type, and the interaction between repetition priming and target type became evident at around 200 ms post-target onset, suggesting that this is a key point in time at which the processing of consonant strings and pronounceable pseudowords diverges. We will argue that both of these effects are being driven by the fine-grained sublexical orthographic representations and associated sublexical phonological representations that are hypothesized to begin to affect processing at around 200 ms in the model described in Fig. 1. Here, we will first examine how such representations might have influenced the repetition priming effects tested in the present study, before examining their influence on the main effect of target type that we observed.

Firstly, with respect to priming effects, fine-grained orthographic representations would retain enough information about letter identities and letter positions in order to perform accurate letter-in-string identification. These representations would be less activated by consonant strings than pronounceable nonwords, and would be more resistant to masking than lower-level location-specific letter representations. As noted above, another possibility is that pronounceable nonwords partially activate whole-word representations, which would also provide the appropriate information about letter identity and letter position for accurate letter-in-string identification (Grainger and Jacobs, 1994, 2005). The pronounceable nonwords were of course more similar to real words than consonant strings, with an average “Orthographic Levenshtein Distance” (OLD20; Yarkoni et al., 2008) of 2.85 (SD = .35) for the pronounceable nonwords, and 3.99 (SD = .33) for the consonant strings (smaller values represent greater orthographic similarity). These values are much larger than the OLD20 values of the consonant strings tested in the study of Massol et al. (2011) that had a mean value of 1.84 (SD = .23), suggesting that one of the reasons for the later divergence in ERPs to the two types of nonword in that study (290 ms) is likely due to the consonant strings being highly similar to real words. We would argue that the relatively low level of similarity between the pronounceable nonword stimuli tested in the present study and real words points more to a sublexical locus of the effects of target type that we observed. The fact that in the present study the nonword stimuli produced an earlier peaking negativity than the typical N400 is in line with this reasoning.

Within the theoretical framework for orthographic processing described in the introduction (see Fig. 1), consonant strings and pronounceable nonwords should activate location-specific letter detectors to the same extent (Grainger and van Heuven, 2003; Grainger and Ziegler, 2011). The present study provides two key sources of evidence in support of this theoretical position. First, there was some evidence for a repetition priming effect on the N/

P150 component that was not sensitive to target type, as predicted by our model. This particular component is thought to reflect the mapping of visual features onto location-specific letter representations, and a large set of empirical findings are in line with such an interpretation (see Grainger and Holcomb (2009a), for a review). The fact that the effects were relatively weak in the present study, both for consonant strings and pronounceable nonwords, is likely due to the change in case between primes and targets, that would reduce the level of visual feature overlap in the repetition condition. Second, as already noted above, effects of target type only started to emerge at around 200 ms post-target onset in the present study, in line with some prior research comparing the processing of consonant strings and pronounceable nonwords (Rosazza et al., 2009; Ziegler et al., 1997). Indeed, evidence for a considerable amount of processing shared by the two types of nonword target was provided by the relatively late divergence of the waveforms associated with each target type. According to the model shown in Fig. 1, the main difference in processing associated with these two types of stimuli arises along the fine-grained orthographic processing route. This processing route requires precise information about which letters are next to which in order to extract multi-letter graphemes and affixes that play a key role in subsequent phonological and morphological processing. The point of divergence of the ERP waveforms to the two types of target suggests that such fine-grained orthographic processing is only starting to have a significant influence on target processing at around 200–250 ms post-target onset, in the testing conditions of the present experiments.

Above, we discussed how these timing estimates could be slower if the consonant string stimuli are more orthographically similar to real words (Massol et al., 2011), but we have not yet addressed why some studies found evidence for a much earlier point of divergence (e.g., Proverbio et al. (2004), Coch and Mitra (2010)). Coch and Mitra's (2010) study used an almost identical procedure to the present study, but with no priming, and with shorter (4-letter) stimuli. They reported an early difference between pronounceable pseudowords and random consonant strings on a P150 component that peaked at 150 ms post-stimulus onset, and that was most visible in left posterior sites (O1 was the site chosen to illustrate the effect). Given that the effect of target type started to emerge in left posterior electrode sites in the 200–250 ms time-window in the present study (see Fig. 7b), one possibility is that it is the presence of prime stimuli that is the cause of the difference in timing estimates across the two studies. Furthermore, it could be the presence of word stimuli in the Proverbio et al. (2004) and Coch and Mitra (2010) studies that encouraged the use of top-down lexical information when processing the pronounceable nonword stimuli. It is therefore important to note that participants never saw any word stimuli in the present study, and this should have further helped limit top-down lexical influences on orthographic processing, hence providing an arguably more direct view on purely bottom-up processing.

3.2. Masked repetition priming with random consonant strings

The starting point of the present research was the result of some pilot behavioral work showing null effects of masked repetition priming with random consonant strings in a post-cued letter identification task. This finding was replicated in the behavioral results of the present study. Most important is that the absence of a behavioral priming effect with consonant strings was found in the presence of significant repetition priming effects for pronounceable nonwords, thus demonstrating that our experiment did have the sensitivity to reveal behavioral priming. This failure to find behavioral masked repetition priming effects with consonant string targets in a post-cued letter-in-string identification task, also contrasts with prior reports of orthographic priming effects obtained with consonant strings in the masked priming version of the same-different matching task (Garcia-Orza et al., 2010) and in a masked prime alphabetic decision task (Peressotti and Grainger, 1995). As already pointed out in the Introduction, it would therefore appear that the specific demands of post-

cued letter-in-string identification are the main cause of the lack of behavioral priming effects with consonant string targets in this task.

Here we first offer an explanation for the contrast in the behavioral repetition priming seen for consonant strings and pronounceable nonwords, before discussing the effects seen in the ERP data. The explanation is couched within the framework of Grainger and Ziegler's (2011) account of orthographic processing, which forms part of the overall architecture shown in Fig. 1. There are two key ingredients to the explanation. The first is that activity in location-specific letter representations cannot be used to generate a behavioral response in post-cued letter-in-string identification. The second is that activity in location-specific letter representations must make contact with more robust higher-level representations in order to observe behavioral priming. Such higher-level representations would be less sensitive to pattern masking effects, enabling the integration of information across prime and target stimuli (when these are related), and informing the decision as to which letter was present at a particular location. In terms of providing appropriate information for letter-in-string identification, the higher-level representation must provide accurate information about positional information, and this can either be achieved at the level of whole-word orthographic representations, or at the level of the fine-grained orthographic code and its association with sublexical phonology (see Fig. 1). The absence of behavioral priming with consonant strings would therefore due to the failure of these stimuli generate significant levels of activity in either whole-word orthographic representations or fine-grained orthographic representations and sublexical phonology. The fact that behavioral priming can be obtained in other paradigms (e.g., Garcia-Orza et al. (2010), Peressotti and Grainger (1995)) would be due to the different types of information used to inform responses in these tasks.

Finally, significant behavioral priming can be obtained when primes are unpronounceable nonwords and targets are real words. This arises in the so-called relative-position priming manipulation where primes are formed of a concatenated subset of the target's letters (e.g., GRDN—GARDEN). In these conditions related primes have been shown to facilitate target word recognition compared with unrelated primes (Peressotti and Grainger, 1999; Grainger et al., 2006; Grainger and Holcomb, 2009b). This again can be interpreted in terms of the ability of these particular nonword primes to activate whole-word orthographic representations.

3.3. Effects of position of overlap

Another important result of the present study concerns effects of position of overlap across prime and target stimuli in the ERP data. This manipulation was designed to reveal possible sequential processing biases that according to certain accounts of orthographic processing (e.g., Whitney (2001)) should be evident in the initial mapping of feature information onto letter representations. According to these accounts, we expected to see an early difference between the effects of primes sharing the first five letters with targets compared with primes sharing the last five letters (the other two letters being different in both cases). This was clearly not the case in the present study, where the effects of this factor were seen to emerge after 200 ms post-target onset. The precise timing of this effect would suggest that it reflects sequential biases that arise during the processing of sublexical information. Indeed, according to the theoretical framework shown in Fig. 1, such sequential biases should appear after an initial parallel mapping of visual features onto location-specific letter representations. In this framework, sequential processing will most likely be evident during the sublexical mapping of orthography onto phonology, and possibly at the level of syllable representations (Carreiras et al., 2005). Given the polysyllabic nature of the pronounceable nonword stimuli tested in the present experiment (all trisyllabic), this remains one possible source of the effects of position of overlap that we observed with these stimuli. However,

the fact that statistically equivalent effects were found for the consonant strings would suggest, on the contrary, that position of overlap is affecting purely orthographic processes. Finally, the fact that there was no evidence for an effect of position of overlap in the behavioral data could well be due to the lack of sensitivity of our behavioral measure to this particularly subtle manipulation. Clearly more research is required to understand exactly when and where such positional biases operate during visual word recognition, and what are the most appropriate techniques to reveal them.

3.4. Summary and conclusions

The results of the present study confirmed prior observations of a divergence in the ERP waveforms generated by pronounceable nonwords and consonant strings starting at around 200 ms post-target onset. This is in line with Grainger and Holcomb's (2009a) proposal that processing up to around 200 ms post-target onset should be largely identical for these two types of stimuli given that it mostly involves parallel independent letter processing. Evidence in favor of such parallel independent letter processing was seen in the N/P150 component that was found to be equally sensitive to repetition priming in consonant strings and pronounceable nonwords. Following this early processing, the two types of nonword were found to be differentially sensitive to masked repetition priming effects, with robust effects emerging around 200 ms post-target onset only for pronounceable nonwords. This was taken as evidence for the relative fragility of location-specific letter representations in contrast with the greater robustness of higher-level sublexical and lexical representations. These higher-level representations would be more resistant to the masking effects induced by target presentation, and would be the basis of the repetition priming effects seen with pronounceable nonword stimuli. Finally, ERP amplitude differences were seen when comparing primes that shared initial letters with targets compared with final-overlap primes, and these effects of overlap only started to emerge after 200 ms post-target onset.

4. Experimental procedure

4.1. Participants

Sixteen undergraduate students (12 women, mean age = 19.8 years, SD = 2.6) recruited at the University of Provence received 15€ for participation in this experiment. All were right-handed native speakers of French with normal or corrected to normal vision.

4.2. Design and stimuli

The stimulus set for this experiment consisted of 640 letter strings of seven characters. Two different types of stimuli were used: 320 pronounceable pseudowords (constructed with alternating consonants and vowels, e.g., DAMOPUR) and 320 nonwords (containing only consonants, e.g., DCMFPLR), defining the two levels of the factor TYPE-OF-TARGET. The two types of nonword were matched in terms of which letters appeared at the 4 positions tested in the letter-in-string identification task (1st, 3rd, 5th, 7th). These four positions defined the 4 levels of the SERIAL-POSITION factor. Stimulus lists consisted of 640 trials each containing a prime—TARGET pair of items. There were 80 trials in each of four different priming conditions for each target type. In the repetition prime condition, the target was a full repetition of the prime (e.g., damopur—DAMOPUR; dcmfplr—DCMFPLR). In the unrelated prime condition the target was completely unrelated to the prime, and unrelated prime—TARGET pairs were formed by re-arranging the full repetition prime—TARGET pairs while ensuring that there was minimal orthographic overlap between primes and targets in the re-pairings (e.g. bujiton—DAMOPUR; bstgjvn—DCMFPLR). This ensures that when forming average ERPs in these two conditions, exactly the same stimuli (primes and targets) are involved in both conditions. These two conditions formed the two levels of the factor REPETITION. The third and fourth priming conditions

were two partial repetition conditions. In one condition, the initial overlap condition, the first five letters of the target and prime were identical while the last two letters differed (e.g. damopon—DAMOPUR; dcmfpvn—DCMFPLR). In the other partial repetition condition, the final overlap the first two letters of the prime and target differed while the last five letters were identical (e.g. bumopur—DAMOPUR; bsmfplr—DCMFPLR). These two conditions formed the two levels of the OVERLAP factor. Effects of REPETITION and OVERLAP were examined in separate analyses. In order to test each target stimulus in each of the 4 priming conditions and at each of the 4 target letter positions without repeating targets within participants, we created 16 experimental lists containing all 640 target stimuli (320 pronounceable nonwords, 320 consonant strings), and with 20 nonwords of each nonword category tested in each of the 16 conditions determined by the 4 levels of the SERIAL-POSITION factor and the 4 priming conditions. By rotating items across lists, each target nonword was tested in all 16 conditions across lists, with each participant tested in a different list. Note that in the ERP analyses the data were collapsed across the 4 levels of the SERIAL-POSITION factor in order to increase the signal-to-noise ratio (80 items per condition and participant).

4.3. Procedure

Stimuli were presented as white letters centered vertically and horizontally on a black background on a CRT monitor (60 Hz refresh rate), with constant brightness and contrast of the display, using an in-house stimulus presentation program. As can be seen in Fig. 2, each trial began with the presentation of a fixation cross (+) which remained on the screen for 700 ms and was followed by a forward mask composed of seven hash marks (#####) for a duration of 500 ms. The forward mask was replaced at the same location on the screen by a lowercase prime for 50 ms. The prime was replaced by the target in uppercase letters for a duration of 150 ms. The target word was then followed by a backward mask composed of seven hash marks that had hyphen marks positioned above and below the first, third, fifth or seventh hash mark. This backward mask remained on the screen until participants responded. On each trial participants were asked to decide which letter they had seen in the position indicated by the hyphens by typing this character on a standard keyboard positioned in front of them (post-cued partial report bar probe procedure). Only the behavioral data for the different serial positions were analyzed. The next trial began after 300 ms of blank screen. A short practice session was administered before the main experiment to familiarize participants with the procedure. The 640 trials of the main experiment were presented in pseudo-random order with 3 breaks. The experiment lasted approximately 40 min.

4.4. EEG recording

After completing informed consent, participants were seated in a comfortable chair in a sound attenuating room. The electroencephalogram (EEG) was recorded continuously from 29 electrodes mounted on an elastic cap (Electro-cap International—see Fig. 3 for the location of electrodes). An additional electrode placed over the left mastoid (A1) was used as an online reference. Two additional electrodes were used to monitor for eye-related artifact (blinks and vertical or horizontal eye movement); one below the left eye (VE) and one horizontally next to the right eye (HE). A final electrode was placed over the right mastoid (A2), recorded actively to monitor for differential mastoid activity. For all scalp electrodes impedances were maintained below 5 k Ω . Electrophysiological signals were amplified with an SA Bio-amplifier with a bandpass filter of .01 and 40 Hz. Continuous EEG was digitized on-line at a rate of 200 Hz and was low-pass filtered offline at 20 Hz. The signal was then re-referenced to the average of the left and the right mastoids. ERPs were time-locked to target stimulus onset. Averaging was performed offline.

4.5. ERP data analysis

ERPs were calculated by averaging the EEG time-locked to target onset and lasting until 500 ms post-target onset. A 100 ms pre-target period was used as the baseline. Any trials with muscle artifact or eye movement/blink activity were excluded from the averaging process (11.93% of trials). Trials on which participants gave an incorrect response in the forced-choice task were included in the ERP analysis, since we were interested in analyzing processing related to the complete string of letters as opposed to the processing associated with the correct identification of 1 out of 7 letters in the string. Furthermore, it should be noted that the position for letter identification was cued after stimulus presentation (see Fig. 2).

We employed an approach to data analysis in which the head is divided up into three separate parasagittal columns along the antero-posterior axis of the head (see Fig. 3). These analyses (left column, midline and right column) involved a laterality factor (left, central and right) and an anterior-posterior factor (i.e., FP vs. F vs. T/C vs. T/P vs. O). We used the columnar approach to analyze the spatial component of the ERP data because it provides a thorough analysis of the entire head breaking the scalp into regions. Separate sets of repeated measures ANOVAs were run on the data from each of three time windows (100–170 ms capturing the N/P150 component, 170–270 ms corresponding to the N250 epoch, and 300–500 ms corresponding to the N400 epoch)³ with the factors TYPE-OF-TARGET (pronounceable nonword vs. consonant string), REPETITION (full repetition vs. unrelated) and ANTERIOR-POSTERIOR and LATERALITY in one analysis, and with the REPETITION factor replaced by the OVERLAP factor (initial letter overlap vs. final letter overlap) in another analysis. In all cases, the Geisser and Greenhouse (1959) correction was applied to all repeated measures with more than one degree of freedom (corrected *p* values are reported). In order to evaluate possible lateralized ERP effects we also conducted a second ANOVA on the remaining electrodes. Relevant main effects or interactions involving the experimental factors were further evaluated by ANOVAs with the same design, comparing the conditions in a pairwise manner. Possible interactions of the experimental factors with the topographical factors were followed by post-hoc comparisons in each region of interest between condition pairs. The FDR correction was used in cases of multiple comparisons.

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³The three epochs correspond to the latency ranges of three components reported in a number of previous ERP masked priming experiments (e.g., Holcomb and Grainger (2006)): the N/P150, the N250, and the N400 components (see Fig. 1).

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Fig. 1.

ERP masked repetition priming effects mapped onto the Bi-modal Interactive Activation Model (note that we have turned the model on its side to better accommodate the temporal correspondence between the model and the ERP effects). This version of the BIAM incorporates the breakdown of sublexical orthographic representations (O-units) into a location-specific retinotopic (R) code, and a location-invariant word-centered (W) code. The connection between location-specific letters and sublexical phonology occurs via a fine-grained word-centered sublexical orthographic code ($O \rightleftharpoons P$).

Fig. 2.

A typical trial illustrated with repetition primes and pronounceable nonword targets. Note that no participant was presented with any letter string on more than one trial, and that unrelated primes were formed by re-arranging the related primes.

Fig. 3.
Electrode montage. Twenty-nine active tin electrodes were held in place by an elastic cap (Electro-Cap International, Inc., Eaton, OH).

Fig. 4. Serial position functions for pronounceable nonword and consonant string targets. Data are percentage of correct responses for post-cued letter identification.

Fig. 5. ERP effects. Left: ERPs time locked to target onset over 9 electrode sites. Repetition priming effects for pronounceable nonwords (Panel A) and for consonant strings (Panel B) in Full repetition condition (red line) and in unrelated condition (black line), and overlap priming effects for both types of target (Panel C) in final overlap condition (red line) and in initial overlap condition (black line). Right: Voltage maps centered on the two epochs used in the statistical analyses. The maps represent voltage differences at each electrode site calculated by subtracting the voltage values in the related condition from the voltage values in the corresponding unrelated prime condition.

Fig. 6.

Time-course analysis of effects of Repetition priming at 50 ms intervals from 150 to 500 ms post-target onset for pronounceable nonword (panel A) and consonant string targets (panel B). The maps represent voltage differences at each electrode site calculated by subtracting the voltage values in the full repetition condition from the voltage values in the corresponding unrelated prime condition.

Fig. 7.

Time-course analysis of the effects of Overlap (Panel A) and Type-of-Target (Panel B) at 50 ms intervals from 150 to 500 ms post-target onset. The maps represent voltage differences at each electrode site calculated by subtracting the voltage values in the initial overlap condition from the voltage values in the final overlap condition.

Table 1

Mean percentage of correct responses and standard deviations (*in italics*), to pronounceable nonword and consonant string targets preceded by different types of prime. Following the design of the present study, effects of Repetition (full repetition vs. unrelated) and Overlap (“initial overlap” letters 1–5 shared with target, “final overlap” letters 3–7 shared with target) are presented separately.

Pronounceable nonword										
Letter position										
TYPE-OF-PRIME	First	Third	Fifth	Seventh	Average					
Full repetition	94.7	7.4	63.8	24.0	41.9	28.3	71.3	25.7	67.9	21.4
Unrelated	89.4	9.5	51.9	24.8	33.1	26.3	64.1	26.9	59.6	21.9
Effect	5.3	11.9			8.8		7.2		8.3	
Initial overlap	95.6	4.4	55.0	25.8	41.6	24.2	70.3	26.7	65.6	20.3
Final overlap	92.8	5.2	53.1	26.3	38.4	26.6	69.1	22.8	63.4	20.2
Effect	2.8	1.9			3.1		1.3		2.3	
Consonant string										
Letter position										
TYPE-OF-PRIME	First	Third	Fifth	Seventh	Average					
Full repetition	92.8	7.1	23.4	12.1	15.9	14.0	61.6	24.4	48.4	14.4
Unrelated	89.4	9.1	16.6	15.5	13.4	8.3	61.6	25.7	45.2	14.6
Effect	3.4	6.9			2.5		.0		3.2	
Initial overlap	94.4	5.4	22.5	12.9	14.4	13.6	59.1	27.2	47.6	14.8
Final overlap	92.2	6.8	17.8	12.1	15.3	10.9	62.2	23.8	46.9	13.4
Effect	2.2	4.7			−9		−3.1		.7	