Multiple Session Masked Priming: Individual differences in orthographic neighbourhood effects

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Abstract

Multiple Session Masked Priming was used to investigate differences between individuals in the fine-tuning of their lexical representations. The form-priming effects were determined separately for each of the 50 participants, from the patterning of masked priming effects over three neighbourhood (N) levels. At each N level, primes varied in their orthographic similarity to the target - Identity, One-Letter-Different and All-Letters-Different. An analysis of the pooled data showed patterns of masked priming consistent with other group studies, but considered separately, an array of individual differences in the tuning of lexical representations was observed.

Inconsistent findings and conflicting evidence characterise much of the word recognition literature, and have lead to a plethora of theories on many aspects of word recognition. One explanation for the conflicting evidence regarding theories of word recognition, is the possibility that it reflects individual differences. The problem here lies in the fact that support for one model or another has generally been drawn from standard group studies, where outcomes are averaged over the sample of participants. Averaged outcomes may show what is generally true for that sample, but fail to capture the critical variations between individuals.

In order to study individual differences a task must be found that will provide reliable data concerning the processing capacities of each participant. There are two issues here. First, the task used must reflect the automatic processes of lexical access, and second, the task must generate sufficient data on each participant to enable stable conclusions to be drawn about their individual performance; that is, we need to be able to generate reliable individual profiles of lexical processing.

Although there is some debate (e.g. Bodner & Masson, 1997; Bodner & Masson, 2001), Forster and Davis' (1984) Masked Priming paradigm is widely considered to be an ideal tool for examining automatic lexical processing. In masked priming, a prime word/nonword is presented very briefly (50-60ms), forward masked (for 500ms) by a row of hash marks (######) and backward masked by an upper case target (500ms), to which a timed lexical decision response is made. The relationship between prime and target is manipulated in some way and if performance on the target is enhanced by a particular prime-target relationship, relative to a control condition, this relationship is taken to reflect the properties of written words important for lexical access. Masked priming has been argued to enable the investigation of lexical access processes free from any influence of more central and strategic processes (e.g. Forster, 1998). This is achieved in the way the prime is presented, making it typically unavailable for conscious report by participants. Critically, while the masked prime is not available for conscious report, a variety of priming effects are consistently observed. Such facilitatory priming effects include repetition-priming (e.g. Forster & Davis, 1984) where prime and target are the same word (e.g. farm – FARM) and form-priming (e.g. Forster, Davis, Schocknect & Carter, 1987; Forster & Veres, 1998) where the prime is of similar orthographic form (e.g. firm – FARM). The absence of both expectancy effects (e.g. Forster, 1998) and priming for nonwords (e.g. Forster & Davis, 1984; Forster et al., 1987; cf. Bodner & Masson, 1997), in addition to the existence of semantic- (e.g. Perea & Gotor, 1997) and cross-language translation-priming (e.g. Kim & Davis, 2003) indicate that masked priming effects reflect lexical level processing.

While the masked priming task provides a means of examining the automatic processes of lexical access, a new variant of this task was required to enable the collection of sufficient data from each participant that they could stand as an experiment in their own right. The Multiple Session Masked Priming paradigm (e.g. Byrne, Yelland, Johnston & Pratt, 2000; Yelland & Byrne, 2001) achieves this by repeatedly testing each participant on the same experiment. Since participants are unaware of the primes, the prime-target relationship cannot be realised, even over repeated test sessions. Thus, in the Multiple Session Masked Priming paradigm, the participant's experience is simply one of repeated exposure to the target items.

Used previously to reveal marked individual variation in the use of orthographic and phonological input codes for lexical access (e.g. Byrne, Yelland, Johnston & Pratt, 2000; Yelland & Byrne, 2001), the Multiple Session Masked Priming paradigm has proved useful for investigating individual differences in lexical processing. This study aims to look at the use of this new technique in other areas of the word recognition literature, namely orthographic neighbourhood effects.

The neighbourhood effect was first investigated by Coltheart, Davelaar, Jonasson and Besner (1977), who coined the term neighbourhood (N) density. A word's N density is simply the number of words that can be made from it by changing one letter. For instance, a high N word like *torn* has many neighbours – *corn, born, turn, town, tore* etc. In this way, N provides a rough index of a word's similarity to other words. The effects of such orthographic similarity have been used by researchers to model constraints on, and organisation of, the internal word-recognition system. Previous experiments looking at the effects of N density have shown form-priming effects when using word or nonword primes that are one-letter-different from their word targets, however, such effects are present for low N density words only, not high N (e.g. Forster et al., 1987). The form-priming effects seen at the low N density are reported consistently, albeit are smaller in magnitude than those observed in repetition-priming (e.g. Andrews, 1997). The lack of form-priming effects in high N words is usually described as an increased tuning of these lexical representations. Forster et al. (1987) first proposed a now commonly used explanation for this change in tuning, whereby a word's lexical representation becomes more finely tuned in response to increasing N density. A word with many neighbours needs to ensure only exact matches can activate its representation, otherwise a large number of these neighbours will need to be considered and errors in activation are more likely. In contrast, a word with only few neighbours can afford to be less stringent (i.e. it can be activated by a one-letter-different neighbour) as there are only a small number of possible lexical candidates. A range of word recognition theories and models have been provided for these results. Such accounts, however, will only prove useful if either, all readers show the same pattern of priming effects as a function of N density, or they are able to account for individual variation in sensitivity to N levels . The question addressed in this study is whether there are individual differences in the priming effects for similar form, indicating differences in the fine-tuning of lexical representations.

Method

Participants

Seventy-one undergraduates, graduates and staff from Monash University, Australia, volunteered to complete the experiment. All were aged between 18 and 33 years with normal or corrected-to-normal vision and were paid a token amount for their participation.

Seventeen participants chose not to complete all 12 sessions, and were therefore excluded from the analyses. In addition, a further four participants were excluded (three on the basis of overall error rates exceeding 20%, and one who was found to be a non-native speaker of English). In all, 50 participants contribute to the final analyses.

Materials and Design

One hundred and eight 4-letter words were used as targets. All were monosyllabic content words with a mean frequency of occurrence of 85.2 (SD=162.9) tokens per million in text (Kucera & Francis, 1967). The target words were selected from three (n=36) N levels (i.e. Low, Medium and High), with written frequency matched across these conditions. In addition, targets were chosen to ensure they did not belong in another target's neighbourhood. For each target word, primes of three types were constructed: (a) an All-Letters-Different (ALD) prime, a nonword which differed at each letter position from the target, to be used as a baseline control; (b) an Identity (ID) prime, which was the exact same word as the target, to measure the maximum priming effect; and (c) a One-Letter-Different (1-LD) prime, a nonword which differed from the target in one letter position, to examine any form-priming effects. The letter position at which the 1-LD prime differed from the target was varied evenly within the three N levels. Primes were matched to targets on N and consonant-vowel patterns within neighbourhood conditions.

An equivalent set of nonword items was constructed to act as foils in the lexical decision task. All matching procedures undertaken for the selection of word targets and primes was repeated for the nonword items, with the exception of written frequency matching. Some characteristics of the target items are shown in Table 1, while example items are shown in Table 2.

Table 1: Characteristics of the Masked Priming Target Items

	N		Frequency
	Range	Mean (SD)	Mean (SD)
Words			
Low N	1 - 3	2.1 (0.8)	84.3 (153.7)
Med N	6 - 7	6.5 (0.5)	85.3 (173.0)
High N	12 -15	13.9 (1.1)	85.9 (165.9)
Nonwords			
Low N	1 - 3	2.3 (0.8)	N/A
Med N	6 - 7	6.5 (0.5)	N/A
High N	10 -15	11.9 (1.5)	N/A

Note. N = Neighbourhood size

Table 2: Example Targets and Primes

	Target	ID Prime	1-LD Prime	ALD Prime
Words				
Low N	FREE	Free	frue	merp
Med N	HELP	Help	hulp	vand
High N	WIDE	Wide	kide	barp
Nonwords				
Low N	NORL	Norl	norf	vube
Med N	PALD	Pald	peld	bist
High N	BAFE	Bafe	bape	fook

Note. N = Neighbourhood size; ID = Identity; 1-LD = One-Letter-Different; ALD = All-Letters-Different

All targets were presented as UPPER CASE letter strings, while primes were presented in lower case. This reduced the possibility that any observed priming effects could be the result of priming by virtue of visual features rather than orthographic form. Three different, counterbalanced versions of the experiment were constructed so that all targets appeared with each of their primes, but only once in each version. Practice items (one exemplar of each word and nonword condition) were constructed and placed at the beginning of each version.

Procedure

For each of the 12 masked priming sessions, participants were seated in a sound attenuated booth where items were displayed on a 15" flat screen, fast decay monitor, controlled by an IBM compatible computer operating DMDX presentation software (developed at Monash University and at the University of Arizona by K.I. Forster and J.C. Forster). Participants began the experiment by pressing a foot pedal, which initiated the presentation of the instructions in the centre of the screen. The practice items were then shown, followed by the experimental items. Progress through the experiment was self-paced with a press of the foot pedal initiating each item. Participants took approximately 10 minutes to complete each session.

Each item was presented in the centre of the screen in the following sequence. First, the forward mask, a row of six hash marks (e.g. ######) was presented for 500ms. This was replaced by the 54ms presentation of the lower case prime, which was in turn replaced by the upper case target for 500ms. Participants made a timed lexical decision response to each target, pressing a blue button with their preferred hand if the target was a word of English and a red button with their other hand if it was not. Participants received response time (RT) and accuracy feedback after each response. RT was measured from the onset of the target display to the button-press response. Both response latencies and errors were recorded for each item by the computer.

Participants were asked to complete 12 masked priming sessions to ensure that each prime-target pair were tested enough to gain sufficient data for every item. Therefore, the three counterbalanced versions were completed four times each. The participants completed the sessions on a roughly daily basis, according to their availability.

Results and Discussion

In order to determine whether the group study approach was masking quite disparate patterns of individual difference amongst participants, analysis of the patterning of the group data was needed to provide a baseline against which the individual differences could be examined.

Group Analyses

The data entered into the group analyses were the condition means for both session and item based data for each of the 50 participants. Analyses of the data from word targets comprised three planned comparison ANOVAs at each of the three N levels, conducted over both participant (F_1) and item (F_2) based data. The first compared the ID and ALD prime conditions, to confirm the existence of a repetition-priming effect. The subsequent analyses looked for orthographic form-priming (1-LD vs ALD) and whether form-priming was equal in magnitude to the repetition-priming effect (ID vs 1-LD)[1]. In the interests of brevity, only the significance level of F_1 and F_2 will be reported. The group mean RTs and error data obtained from participant-based data for word targets are shown in Table 3.

Table 3: Group mean response time (RT), percentage error rate (+/- SE) and priming effects (Δ), as a function of prime type and neighbourhood (N) level for word targets.

N level	Prime	RT (ms)	Δ	% Error	Δ
Low	ID	418 (7.1)	56	3.0 (0.02)	6.8
	1-LD	448 (8.1)	26	7.4 (0.52)	2.4
	ALD	474 (7.3)	-	9.8 (0.40)	-
Medium	ID	419 (7.5)	52	3.9 (0.35)	5.6
	1-LD	449 (8.3)	22	7.7 (0.46)	1.8
	ALD	471 (7.8)	-	9.5 (0.55)	-
High	ID	432 (7.4)	41	6.2 (0.66)	5.7
	1-LD	469 (8.9)	4	12.6 (1.02)	-0.7
	ALD	473 (7.6)	-	11.9 (1.00)	-

Note. ID = Identity; 1-LD = One-Letter-Different; ALD = All-Letters-Different

As can be seen in the summary of RT data (Table 3), participants responded more rapidly to word targets preceded by their ID prime than their ALD prime, yielding significant repetition-priming effects at each of the N levels [F_1 & F_2, $p < 0.01$]. Repetition effects were found in the error data also [F_1 & F_2, $p < 0.01$]. These results indicate that the ID primes facilitate faster and more accurate lexical access for their targets at each N level.

A comparison between the mean RT for the 1-LD and ALD prime conditions showed significant orthographic form-priming effects at the Low and Medium N levels [F_1 & F_2, $p < 0.01$], while at the High N level this comparison was not significant [F_1 & F_2, $p > 0.05$]. This pattern was mirrored in the error data, with a significant decrease in errors for 1-LD primes over ALD primes for Low and Medium N targets [F_1 & F_2, $p < 0.01$], but not for High N targets [F_1 & F_2, $p > 0.05$].

As expected for masked priming studies with group data, the orthographic form-priming effects, seen in the Medium and Low N conditions, were significantly reduced in magnitude relative to those seen with repetition-priming, for both RT [F_1 & F_2, $p < 0.01$] and accuracy [F_1 & F_2, $p < 0.01$] (i.e. ID vs 1-LD). For the High N targets, this

[1] While not orthogonal, these comparisons are meaningful, an attribute Keppel (1991) believes is more important than a set of purely orthogonal comparisons without such meaning.

comparison was also significant [F_1 & F_2, $p < 0.01$], however, this was in the absence of a 1-LD prime advantage.

Overall, the group analyses for the word targets provide results which are comparable with other masked priming studies in this area. It would seem from these results that, on average, only words with High N density become finely tuned, while words without such neighbourhoods (i.e. Low and Medium) are open to activation by close relatives.

In order to complete the traditional group analyses, an investigation of nonword effects was undertaken. An omnibus analysis of the group nonword data revealed significant main effects of N Level [F_1 & F_2, $p < 0.01$] and Prime Type [F_1 & F_2, $p < 0.01$] but no interaction between them [F_1 & F_2, $p > 0.05$]. Subanalyses were then conducted to examine the within factor effects, separately for N level and Prime Type. The group mean RTs and error data, obtained from participant-based analyses of the nonwords, are shown in Table 4 for the three N levels (collapsed over prime type) and the three prime types (collapsed over N level).

Table 4: Group mean response time (RT) and percentage error rate (+/- SE) by prime type and neighbourhood (N) level for nonword targets.

		RT (ms)	% Error
N Level			
	Low	471 (8.4)	4.2 (0.42)
	Medium	493 (10.1)	9.5 (0.52)
	High	500 (11.7)	9.7 (0.78)
Prime Type			
	ID	483 (10.9)	7.9 (0.95)
	1-LD	486 (10.4)	7.5 (0.93)
	ALD	495 (10.7)	8.0 (1.00)

Note. ID = Identity; 1-LD = One-Letter-Different; ALD = All-Letters-Different

As seen in Table 4, the Low N nonword targets were responded to significantly faster and more accurately than both the High N [RT: F_1 & F_2, $p < 0.01$; % Error: F_1 & F_2, $p < 0.01$] and Medium N targets [RT: F_1 & F_2, $p < 0.01$; % Error: F_1 & F_2, $p < 0.01$]. This difference was also evident between the Low and Medium N targets [RT F_1 & F_2, $p < 0.01$; % Error: F_1 & F_2, $p < 0.01$]. However, no such differences were found between the Medium and High N targets [RT: F_1, $p < 0.05$, F_2, $p > 0.05$; % Error: F_1 & F_2, $p > 0.05$]. These results show that only the Low N words had an RT and accuracy advantage, an expected effect in nonwords, as a nonword with more neighbours has a larger number of words to eliminate before concluding that the target is in fact not a word.

Somewhat surprising were nonword priming effects in the group RT data. From Table 4 it can be seen that the ID primed target has a small, but secure, 12ms facilitation relative to the ALD baseline [F_1 & F_2, $p < 0.01$]. A similar sized (9ms) significant facilitation effect was afforded the 1-LD over ALD primes [F_1 & F_2, $p < 0.01$]. Indeed, the 3ms advantage ID primes have over 1-LD primes proved to be significant [F_1 & F_2, $p < 0.01$]. Nonword effects of these magnitudes are not uncommon in group studies; however, they rarely prove significant (Forster, 1998). They do so here due to the power afforded the group analyses with 7,200 data points per condition. Although the absence of nonword effects is usually taken to indicate that masked priming effects for words are showing lexical level processes, the nonword priming effects found here do not contradict this conclusion. As only a lexical representation can be tuned by its N density, the modulation of priming effects by N density shown for words, but not nonwords, would indicate that the word priming effects are lexical in nature. In additon, the large reduction in magnitude of the nonword priming, compared to the word priming, would also indicate different mechanisms were involved in priming for these targets. Taken together, these findings suggest that the priming effects seen for word targets can still be considered lexical in nature, but may contain a small pre-lexical, graphemic priming component.

The critical issue, however, is whether these patterns of outcomes for the group data are an accurate characterisation of the lexical processes of all skilled readers, or the average of individual differences in the nature of lexical tuning across skilled readers.

Individual Analyses

The Multiple Session Masked Priming procedure yields sufficient data for each participant to be considered an experiment in their own right. That is, each of the 50 participants were the equivalent of an experiment, where test sessions replace participants. This gives a fully repeated measures design that provides 2,592 points of data for every individual (12 sessions over 18 conditions of 12 items each). Critically, this provides sufficient data for any one person, that the analyses of the type performed on the group data can be carried out for each participant separately. From this, reliable statements can be made for *each* participant about changes in orthographic form-priming as a function of N level.

Words

Each participant's data were analysed in the same way as the group data. A true appreciation of the subtleties of individual differences found within the data would require consideration of the priming outcomes at each N level, separately for each of the 50 participants. Unfortunately, space does not permit this. Instead, participants were classified according to their pattern of significant priming effects, as a function of N level. Priming effects fell into four categories. Three represent different patterns of priming effects between the ID, 1-LD and ALD conditions that are statistically distinguishable, (a) ALD>1-LD=ID, significant orthographic form-priming of the same magnitude as the repetition-priming effect; (b) ALD>1-LD>ID, orthographic form-priming which was significantly greater than the baseline, but significantly less than the repetition-priming effect; and (c) ALD=1-LD>ID, no orthographic form-priming, in the presence of secure repetition-priming. These patterns of secure priming effects are illustrated in Figure 1. The fourth category contained cases where the pattern of priming effects was not secure. Each was of the form of (a), (b) or (c) but variability in the participants was such that the pattern of effects could not be statistically distinguished. This fourth group will not be reported on any further here.

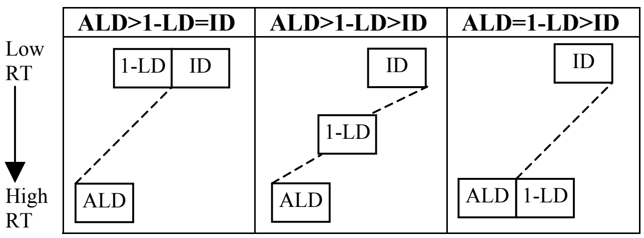

Figure 1: Depiction of the three secure priming patterns found within the data. Dashed lines indicate significant differences in response time (RT) between prime conditions.

Table 5 reports the number of participants displaying each particular priming pattern as a function of N level. The obvious feature of this data is that at Low and Medium N, participants are showing distinctly different patterns of performance; that is, the individual data differs from the grouped data.

Table 5: Number of participants as a function of priming pattern and neighbourhood (N) level.

Priming Pattern	Low N	Med N	High N
ALD>1-LD=ID	3	4	0
ALD>1-LD>ID	28	21	1
ALD=1-LD>ID	14	22	39

Note. ID = Identity; 1-LD = One-Letter-Different; ALD = All-Letters-different

At Low N, a small number of participants displayed a pattern of priming that would indicate their lexical entries for these words were poorly tuned (i.e. ALD>1-LD=ID). For these participants, the priming effects of the 1-LD and ID primes were of the same magnitude, indicating that these words were able to be accessed equally as well by a neighbour as the word itself. The majority of participants showed the priming pattern commonly found in group studies at similar N densities (i.e. ALD>1-LD>ID) (e.g. Andrews, 1997). These participants have slightly better lexical tuning than the former group, with lexical entries showing sharper but not perfect tuning for the target word. In contrast, 14 of the participants at this N level showed a finely tuned processor, which would only activate entries for an exact word match. Here the pattern shows no form-priming, even though repetition-priming was still present (i.e. ALD=1-LD>ID).

For Medium N level words there was a small shift towards increased specificity of lexical tuning, with an increase in the number of participants showing the highest level of tuning (i.e. ALD=1-LD>ID). More importantly though, there were still considerable differences between participants in the specificity of their lexical processes. This changed for High N words, with almost all the participants displaying finely tuned lexical entries for these targets (i.e. ALD=1-LD>ID).

Overall, the results shown in Table 5 indicate a general shift towards more finely tuned lexical processing with increasing N densities; a result which ties in with previous research (e.g. Forster, 1987). More importantly, however, these results demonstrate the variability between subjects in their tuning level, especially at the Low and Medium N densities; illustrated by the variation in priming patterns at these levels.

In addition to demonstrating an overall shift to fine tuning as N increases, the data obtained in this study allowed for investigation into the nature of this shift within each participant, by looking at their individual patterns of effects across N levels. Although space does not permit a full account of this data, three groups accounted for the majority of participants. The largest of these (n=16) followed the priming pattern shown in the overall group analyses. That is, these participants showed finely tuned entries for High N level targets (i.e. ALD=1-LD>ID) but slightly less tuned entries for Medium and Low N words (i.e. ALD>1-LD>ID). The second largest group (n=10) showed fine tuning (i.e. ALD=1-LD>ID) which was unaffected by changes in N level, while the third (n=6) differed from this only by having less tuning for entries at Low N densities (i.e. ALD>1-LD>ID). The remaining participants showed variations upon these themes.

Nonwords

Each participant's nonword data was analysed in the same manner as the group data, beginning with a single omnibus analysis. As with the group analyses; none of the 50 participants showed an interaction between the N Level and Prime Type factors, which was expected given that N density only tunes *lexical* representations. Forty-six participants showed a main effect of N Level and 30 showed a main effect of Prime Type. Again these effects were investigated with separate subsequent analyses.

Forty of the participants' N level effects followed the same pattern as seen in the group analyses, that is, RTs to Low N targets were significantly faster than those of the Medium or High N targets. However, there seemed to be at least some variation being masked by the group study approach. One participant's Low *and* Medium N nonword targets showed a response time advantage over High N targets, while two further participants showed RT differences between each N level (i.e. RTs increasing with N level). In addition, two participants had non-secure N level effects. Each of these variations of N level effects could be explained by the fact that with increasing N density, lexical processes have more competing entries to eliminate before concluding a nonword. Perhaps the individual pattern variation could be accounted for by variations in sensitivity to these competitors.

Half of the participants with Prime Type effects showed a similar pattern to that seen with the group analyses; that is, an equivalent RT advantage for both the 1-LD and ID conditions. Three participants showed an RT advantage for the ID condition only, while a further 12 had non-secure effects. For these 30 participants, differences between the repetition-priming effects for nonwords overall and words at each N level were calculated (Low: M=41, SE=3.3; Medium: M=36, SE=3.2; High: M=27, SE=3.4). Consistent with the group analyses, these mean differences indicate large reductions in the magnitude of nonword priming effects, compared to word priming, for these participants. It would seem that individual differences in performance are not restricted to lexical processing, but also extend to the level of graphemic priming induced by orthographically related prime-target pairs.

Conclusions

Although space constraints precluded the reporting and interpretation of the full data from this study, one major conclusion can be drawn. Although the group data were consistent with previous studies of neighbourhood density, the Multiple Session Masked Priming results revealed the group approach was masking an array of individual differences in lexical tuning. Indeed, individual variation was also evident in the existence of pre-lexical, graphemic processing.

A simple explanation of the source of such variation may be that the internal coding of representations are handled differently between the lexical processors of individuals. This may be due to some predisposition and/or individualised set of experiences, but at this stage far more would need to be known about individual differences in other aspects of written word recognition in order to make a more specific claim.

The results of this study suggest that future research should consider the Multiple Session Masked Priming paradigm and look more carefully at other fundamental claims about lexical processing drawing solely on group outcomes, in the hope of developing more sensitive models of lexical access and written word recognition.

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