Psychophysiology, 43 (2006), 21–30. Blackwell Publishing Inc. Printed in the USA.

DOI: 10.1111/j.1469-8986.2006.00383.x

Relatedness proportion effects on masked associative priming: An ERP study

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Abstract

The effect of relatedness proportion (the percentage of related words in a list) on associative priming was investigated in two masked priming experiments. In Experiment 1, subjects were randomly assigned to either a high (80%) or low (20%) relatedness proportion condition and performed a lexical decision task. Semantically related and unrelated primes were briefly flashed (50 ms) before the targets and were preceded by a mask that prevented their overt identification. In Experiment 2, subjects were tested in both relatedness proportion conditions in a categorization task; the N400, an electrophysiological index of lexical and semantic priming, was measured in trials that did not require a button press. Behavioral and electrophysiological priming effects were observed in both high and low relatedness proportion conditions. The observed priming effects were not modulated by relatedness proportion. The results are discussed in terms of current theories of associative priming.

Descriptors: Event-related potentials, Masked priming, Associative priming, N400, Relatedness proportion

It is well known that target words are recognized faster when they are preceded by related words, or primes, than when they are preceded by unrelated words (e.g., Meyer & Schvaneveldt, 1971). This phenomenon, called associative priming, has also been observed when the prime is presented very briefly and masked, a procedure that prevents its overt identification (masked priming; Carr & Dagenback, 1990; Marcel, 1983; Perea & Gotor, 1997; Perea & Rosa, 2002; Sereno, 1991).

Masked priming effects have generally been explained in terms of automatic spreading activation mechanisms operating within the lexicon (e.g., Collins & Loftus, 1975). According to automatic spreading activation theories, the prime automatically activates semantically or associatively related words (Logan, 1992; Posner & Snyder, 1975), and the priming effect occurs if the target is among the words preactivated by the prime such that its identification will be facilitated in terms of reaction time (RT) when compared to unprimed targets. Because subjects are unaware of the presence or the identity of the prime, controlled processes such as expectancy (strategic generation of potential targets after prime presentation) and postlexical matching (integration of prime and target in a semantic relationship that is used to influence lexical decisions) are not expected to play any role in facilitating the response to related targets (see Neely, 1991, for an in-depth review).

Retrospective Theories of Priming

Prospective theories of priming such as the automatic spreading activation account (primes create changes in long-term memory that might be advantageous for subsequently presented targets) have recently been challenged by retrospective theories of priming, according to which the prime creates an episodic representation, even when not overtly identified, that can be recruited to assist in the encoding of the target (Bodner & Masson, 1997, 2001, 2003; Masson & Bodner, 2003; Whittlesea & Jacoby, 1990). The retrospective account, so called because information about the prime is recruited after the target has been processed, was inspired by the work of authors such as Kolers and Roediger (1984) and Jacoby (1983), who proposed that perception is based on the activation of memories of previous episodes, even for stimuli that are not consciously identified. In this view, priming is not based on the temporary activation of a stable memory representation, but on the activation of an internal representation that is seen as "a summary statistic reflecting the number and similarity of memories for episodes recruited by the current stimulus configuration" (Masson & Bodner, 2003, p. 63). Therefore, according to this view, long-term priming and masked priming rely on similar mechanisms: the recruitment of an episode (see Masson & Bodner, 2003, for a discussion of the dissociations of these two forms of priming).

Evidence for prime recruitment in masked conditions has been presented by Whittlesea and Jacoby (1990). In their paradigm, participants were presented with three stimuli in a row.

Many thanks to Keith Rico, Teressa DelSanto, Joanna Doerfer, Amertah Perman, Stella Quinn, and Michael Reisner for helping with data collection. I also thank Donna Coch for her invaluable comments and suggestions, Glen Bodner for his helpful comments on an earlier version of the manuscript, and the three anonymous reviewers for their insightful comments and suggestions.

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The first stimulus (prime) was a masked word (e.g., GREEN, presented for 60 ms), the second was an interpolated word (e.g., PLANT, presented for 150 ms), and the third was the target (e.g., GREEN). The task was to name the target and report on the identity of the interpolated word. The manipulation concerned the appearance of the second word: It was presented in uppercase letters in 50% of the trials and in mixed cases (e.g., plANt) in the other 50% of the trials (degraded condition). Whittlesea and Jacoby hypothesized that if the interpolated word were degraded, participants would rely more on the first word in order to identify the interpolated word. If so, this retrospective use of the prime would make it more available to assist with the naming of the target (larger priming effect). Therefore, the authors predicted a larger priming effect in the degraded condition when compared to the nondegraded condition. The results confirmed their hypothesis. Because participants did not know whether the interpolated word would be degraded or not while processing the prime, degradation effects were interpreted as retroactive.

The retrospective account differs from the automatic spreading activation account in three important aspects (see Masson & Bodner, 2003, for an in-depth discussion). First, whereas automatic spreading activation theories rely on the distinction between semantic and episodic memory (traditionally, episodic representations have been associated with conscious perception; e.g., Kanwisher, 2001), retrospective theories purport that an episodic representation of a stimulus is created even if that stimulus is not consciously processed. Second, priming effects do not reflect changes in connection strengths in semantic networks in long-term memory, but rather the recruitment of a memory resource. Third, retrospective theories but not automatic spreading activation theories predict that the priming effect will be influenced by contextual factors, such as the proportion of related items in a list (relatedness proportion; Bodner & Masson, 2001, 2003). Relatedness proportion is known to modulate the priming effect in unmasked conditions when the time interval between the presentation of the prime and the target (stimulus onset asynchrony, SOA) is long enough to allow subjects to generate potential targets (e.g., Henik, Friederich, Tzelgov, & Tramer, 1994; Neely, Keefe, & Ross, 1989; Pecher, Zeelenberg, & Raaijmakers, 2002). Given this pattern, relatedness proportion effects have generally been associated with attention-controlled and strategic processes (Neely, 1977, 1991).

Bodner and Masson (2001, 2003) found relatedness proportion effects in masked repetition and associative priming paradigms at a very short SOA (50 ms) in the form of larger priming effects in high relatedness proportion conditions (e.g., 80% related pairs) compared to low relatedness proportion conditions (e.g., 20% related pairs). An interpretation of this pattern of results based on the more successful use of an anticipation strategy in the high relatedness proportion lists cannot be adopted in this case, because participants did not consciously process the primes. Instead, Bodner and Masson proposed that this pattern reflects subjects' reliance on the recruitment of the prime when such recruitment is particularly advantageous for the processing of the corresponding target—that is, in the high relatedness proportion conditions. Therefore, increasing the number of related trials in a list would increase the magnitude of the priming effect because the related primes would be recruited during target processing more often.

Purpose of the Present Study

Bodner and Masson's (2003) results still await replication. Relatedness proportion effects in masked associative priming tasks have not been found consistently (for null effects, see Pecher et al., 2002; Perea & Rosa, 2002). When they have been found, these effects have been interpreted as reflecting types of decisional processes other than the recruitment process espoused by Bodner and Masson (2003). For example, Forster, Mohan, and Hector (2003) likened the relatedness proportion effect in masked conditions to the time criterion effect in naming tasks (Lupker, Brown, & Colombo, 1997). Lupker et al. proposed that subjects set a time criterion for responding and that the RT to a given item is influenced by the difficulty of the surrounding items. If the difficulty of the task increases, the time criterion is extended. According to this interpretation, subjects respond more slowly to related targets in a low relatedness proportion list compared to a high relatedness proportion list because most of the word pairs are unrelated and therefore difficult items (Forster et al., 2003).

Because RT constitutes a composite behavioral measure and reflects the activation of multiple representations and levels of analysis, it is not always clear what cognitive stages are affected by a behavioral experimental manipulation, as Forster et al.'s (2003) alternative interpretation suggests. The purpose of the present study is twofold: to determine whether behavioral relatedness proportion effects in masked associative priming can be replicated (Experiment 1) and to further investigate the nature of masked associative priming effects by employing the event-related potential (ERP) technique (Experiment 2). ERPs are voltage fluctuations in the electroencephalogram (EEG) elicited by the presentation of a controlled stimulus (Hillyard & Picton, 1987). The different positive and negative components in an ERP waveform reflect the activation of the neuronal populations that are recruited during the processing of the stimulus regardless of whether the stimulus is consciously perceived or not (e.g., Dehaene et al., 1998). This technique allows for the identification of components associated with semantic and response-related processes and allows for determination of what components are sensitive to specific experimental manipulations. Therefore, ERPs are well suited to determining whether or not relatedness proportion modulates semantic processes in masked conditions.

EXPERIMENT 1

Experiment 1 followed the procedure employed by Bodner and Masson (2003). In Experiment 1a, two groups of participants (high and low relatedness proportion conditions) were tested in a behavioral lexical decision task under masked priming conditions. According to automatic spreading activation theories (Neely, 1991; Perea & Rosa, 2002), the size of the priming effect would be predicted to be similar in high and low relatedness proportion conditions. According to the retrospective theory (Bodner & Masson, 2003), a larger priming effect in the high relatedness proportion condition when compared to the low relatedness proportion condition would be predicted. In Experiment 1b, two groups of participants (high and low relatedness proportion conditions) were tested in a behavioral lexical decision task in which primes were fully visible. This control experiment served to confirm the sensitivity of the experimental design and materials in relation to the findings from Experiment 1a.

Methods

Experiment 1a (Masked Experiment, SOA = 50 ms)

Participants. Forty participants from the State University of New York (SUNY) at New Paltz participated in the study after signing informed consent. Participants (27 women, mean age = 21 years, range = 18–33) were right-handed (Edinburgh Handedness Inventory; Oldfield, 1971) and native English speakers. All participants had normal or corrected-to-normal vision and participated for class credit or as part of a course requirement.

Stimuli. Two hundred words and 200 nonwords served as target stimuli. Two types of primes were associated with each target word: related and unrelated primes. The related prime words were chosen through the Edinburgh Association Thesaurus (ETA, http://www.eat.rl.ac.uk/), a set of word association norms. The mean association between related primes and targets was 29.27 (*SD* 18.2). Related prime–target pairs included both associative (e.g., sad–happy, soup–spoon, alarm–clock, hair–comb) and associative/semantic (e.g., nurse–doctor, weird–strange, pear–apple, tiger–lion) relations. The proportion of associative and associative/semantic relations across related prime–target pairs was approximately equal (48% and 52%, respectively).

To create the unrelated prime–target pairs, for each related prime–target pair, an unrelated prime word was chosen that matched the related prime by frequency and length but bore no associative or semantic relationship with the target word. Target words had a mean frequency of 123.14 (*SD* 174.8) as based on the Francis and Kucera corpus (Kucera & Francis, 1967) and a mean length of 4.54 letters (*SD* 0.96). Related primes had a mean frequency of 105.4 (*SD* 162.4) and a mean length of 4.38 letters (*SD* 0.98). Unrelated primes had a mean frequency of 105.3 (*SD* 161.8) and a mean length of 4.48 letters (*SD* 1.03). The difference in frequency and length between related and unrelated primes was not significant, $p = .99$ and $p = .32$, two-tailed, respectively.

Nonword targets were created by changing one or two letters of real words (some included in the experiment, some not) and had a mean length of 4.53 letters (*SD* 0.96). Nonword targets were preceded by word primes ($n = 200$); word primes preceding nonwords had a mean length of 4.53 letters (*SD* 0.96) and mean frequency of 59.8 (*SD* 140).

The 200 target words were divided into 5 sublists of 40 words each. These sublists were then combined into 10 lists, 5 for each relatedness proportion condition. Each high relatedness proportion list was comprised of 4 sublists of related trials ($n = 160$, 80% relatedness proportion), 1 sublist of unrelated trials ($n = 40$, 20% unrelatedness), plus 200 word–nonword pairs. Each low relatedness proportion list was comprised of 4 sublists of unrelated trials ($n = 160$, 80% unrelatedness), 1 sublist of related trials ($n = 40$, 20% relatedness proportion), plus 200 word–nonword pairs. Therefore, for each relatedness proportion list, the combination of related and unrelated word pairs was different, whereas the word–nonword pairs remained identical across lists. For example, the first high relatedness proportion list was comprised of 4 sublists of related pairs (e.g., 1, 2, 3, 4) and 1 sublist of unrelated pairs (e.g., 5). The second high relatedness proportion list was comprised of 4 sublists of related pairs (e.g., 2, 3, 4, 5) and 1 sublist of unrelated pairs (e.g., 1). The first low relatedness proportion list was comprised of 4 sublists of unrelated pairs (e.g., 1, 2, 3, 4) and 1 sublist of related pairs (e.g., 5). And so on. Targets and primes in each list were matched on frequency (words) and length (words and nonwords).

Within each relatedness proportion condition, the lists were counterbalanced across participants through random assignment so that each subject saw a particular stimulus only once, allowing for comparison of the same target preceded by different types of primes across participants. Thus, it was possible to protect against any uncontrolled target-related factors and to compare the same targets preceded by different types of primes across subjects.

Procedure. After being randomly assigned to either the high or low relatedness proportion condition and, within each condition, to a particular stimulus list, participants were tested in a sound-attenuated and dimly lit booth; they were seated 100 cm directly in front of a 19-in. monitor on which stimuli were presented, such that each stimulus subtended 0.5–3.5° of horizontal visual angle and 1° of vertical visual angle. The sequence of events (see Figure 1) was the following: A white rectangle appeared at the center of the screen and served as a warning signal that the new trial was about to begin; 1000 ms after the presentation of the rectangle, a mask formed by 10 consecutive Xs (XXXXXXXXXX) was presented for 500 ms, replaced by the prime (50 ms) in lowercase letters and then by the target (500 ms) in uppercase letters. Targets were flanked by four ampersands (two on either side) to minimize prime perceptibility. The white rectangle disappeared 1.5 s after the target disappeared to end the trial.

The session was self-paced; that is, participants controlled when the next trial would begin by pressing a button on a response box in their laps. Participants were further instructed to press one button if the target was a real word and another button if the target was not a real word, and to respond as rapidly as possible without jeopardizing the accuracy of their responses. Response hand for word and nonword responses was counterbalanced across participants. Forty practice trials preceded the actual test session. None of the primes or targets in the practice list was included in the experimental list. The practice list was comprised of 20 word–word pairs (16 related and 4 unrelated pairs in the high relatedness proportion condition and 4 related and 16 unrelated pairs in the low relatedness proportion condition) and 20 word–nonword pairs. Neither during the practice nor during the experiment was the presence of the prime mentioned by the experimenter.

After completion of the experiment a debriefing questionnaire was administrated to assess awareness of the primes or their identity. The questionnaire included the following questions: "What did you realize about the experiment? Did you realize that there was another word flashed between the string of Xs and the

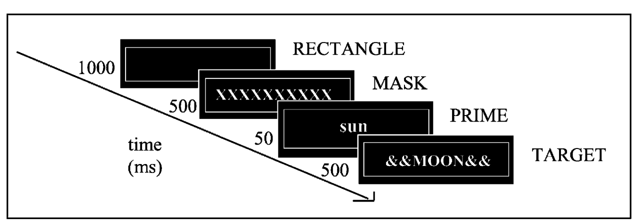

Figure 1. Illustration of the sequence of events used in Experiment 1a. Presentation time in milliseconds for each event is indicated by the number to the left of each rectangle. Interstimulus interval between events is zero.

uppercase letters? If yes, could you read it? Did you have any difficulty in performing the task? If yes, please explain."

Prime awareness experiment. Subsequently, participants performed a lexical decision task on the primes. A sequence of 50 prime–target pairs (not used in the primary experiment)[1] followed the same display sequence as the experimental lexical decision task (see Figure 1). Subjects were now required to make a lexical decision response to the masked prime. Subjects were informed that half of the primes would be words and half nonwords and were encouraged to make their best guess if they could not see the prime. For this task, accuracy was stressed over speed.

Experiment 1b (Unmasked Experiment, SOA = 1000 ms)

Participants. Twenty-three participants from SUNY at New Paltz participated in the study after signing informed consent. Participants (14 women, mean age = 21 years, range = 18–29) were all right-handed except for two left-handed participants (Edinburgh Handedness Inventory; Oldfield, 1971); all participants were native English speakers except for one fluent bilingual (Japanese–English) participant. All participants had normal or corrected-to-normal vision and participated for class credit or as part of a course requirement.

Stimuli. The stimuli were identical to those used in Experiment 1a.

Procedure. The procedure was similar to the one followed in Experiment 1a with the following exceptions. First, primes were presented for 500 ms and followed by an interstimulus interval (ISI) of 500 ms (SOA = 1000 ms); therefore, the primes were fully visible and readable. Second, participants were instructed to silently read the prime and the target and decide whether or not the target was a real word; as in Experiment 1, subjects were instructed to respond as rapidly as possible without jeopardizing the accuracy of their responses. Finally, subjects in Experiment 1b did not participate in the prime awareness experiment outlined in Experiment 1a, and no final questionnaire to assess awareness of the primes or their identity was administrated.

Results

Experiment 1a

Prime awareness. Accuracy in classifying the primes as words or nonwords was assessed by computing the proportion of word responses made to word primes (hits) and nonword primes (false alarms). These values were then transformed into *d′* values for each participant. The mean *d′* values for the high and low relatedness proportion conditions were 0.065 and 0.078, respectively. These values did not differ significantly from zero (all *p*s > .3), confirming that participants were not able to discriminate between word and nonword primes.

RTs and accuracy. Mean reaction time and accuracy for each condition are shown in Table 1. For each subject, median RT was calculated for each prime and relatedness proportion condition only for correct responses. Participants were faster when targets were preceded by related than unrelated primes, $F(1,38) = 19.13$, $p < .0001$. This priming effect was significant in both high and low relatedness proportion conditions (17 ms in the high relatedness proportion condition, t[19] = −3.63, $p = .002$, two-tailed; 14.2 ms in the low relatedness proportion condition, t[19] = −2.64, $p = .016$, two-tailed). The interaction between prime condition (related, unrelated) and relatedness proportion condition (high, low) was not significant, $F(1,38) = 0.16$, $p = .7$, n.s.

Table 1. *Behavioral Data for Experiment 1a (Masked Condition, n = 40)*

	RT		Priming effect	ACC	
	Related	Unrelated		Related	Unrelated
High relatedness proportion	558.48 (88.18)	575.48 (87.35)	17	94.94 (4.85)	92.25 (5.3)
Low relatedness proportion	569.41 (87.63)	583.59 (90.67)	14.2	95.25 (5.1)	94.38 (5.1)
Mean	563.94	579.53	15.6	95.1	93.31

Accuracy is expressed in mean proportions. Standard deviations for each condition are provided in parentheses. RT: mean reaction times; ACC: mean accuracy.

Overall, participants' accuracy was higher for related than unrelated trials, $F(1,38) = 11.09$, $p = .002$. Although differences in accuracy for related and unrelated trials tended to be greater in the high relatedness proportion than in the low relatedness proportion condition, the main effect of prime did not interact with relatedness proportion, $F(1,38) = 2.87$, $p = .1$, n.s. Finally, no differences in accuracy between the high and low relatedness proportion conditions were observed (relatedness proportion, $F[1,38] = 0.65$, $p = .43$, n.s.).

Further statistical analyses were conducted with data from the participants whose *d′* value did not exceed the upper 95% confidence level of $d' = 0$ for the present data (this value was 0.23). Eleven participants whose *d′* values were larger than 0.24 were excluded; therefore, the further analyses were performed on the remaining 29 participants (14 in the high relatedness proportion condition and 15 in the low relatedness proportion condition). Findings for this subgroup of participants mirrored the findings for all participants. Participants were faster when targets were preceded by related than unrelated primes, $F(1,27) = 15.41$, $p = .001$. The priming effect was significant in both high and low relatedness proportion conditions (20 ms in the high relatedness proportion condition, t[13] = −3.47, $p = .004$, two-tailed; 15 ms in the low relatedness proportion condition, t[14] = −2.23, $p = .04$, two-tailed). The interaction between prime and relatedness proportion was not significant, $F(1,27) = 0.3$, $p = .59$, n.s.

Experiment 1b

Mean reaction time and accuracy for each condition are shown in Table 2. For each subject, median RT was calculated for each prime and relatedness proportion condition only for correct responses. Participants were faster when targets were preceded by related than unrelated primes, F(1,21) = 73.28, $p < .0001$. This priming effect was significant in both the high and low relatedness proportion conditions (63.2 ms in the high relatedness proportion condition, $t[11] = -7.51$, $p < .0001$, two-tailed; 31.6 ms in the low relatedness proportion condition, t[10] = −4.5, $p = .001$, two-tailed). Importantly, the priming effect was larger in the high relatedness proportion than in the low relatedness

[1]Using the same stimuli in both the experimental task and the prime awareness task might have influenced the visibility of the primes in the second task and created unintended priming effects across the two tasks. For this reason, a different set of stimuli was selected.

Table 2. *Behavioral Data for Experiment 2 (n = 23)*

	RT		Priming effect	ACC	
	Related	Unrelated		Related	Unrelated
High relatedness proportion	555.62 (83.89)	618.85 (98.27)	63.23	96.15 (4.21)	92.92 (6.6)
Low relatedness proportion	605.26 (177.75)	636.90 (189.73)	31.64	96.36 (5.5)	95.11 (4.2)
Mean	580.44	627.87	47.73	96.25	93.97

Accuracy is expressed in mean proportions. Standard deviations for each condition are provided in parentheses. RT: mean reaction times; ACC: mean accuracy.

proportion condition (prime × relatedness proportion, $F[1,21] = 8.13$, $p = .01$).

Overall, participants' accuracy was higher for related than unrelated trials, $F(1,21) = 5.2$, $p = .03$. Although differences in accuracy for related and unrelated trials tended to be greater in the high relatedness proportion than in the low relatedness proportion condition, the main effect of prime did not interact with relatedness proportion, $F(1,21) = 1.02$, $p = .33$, n.s. Finally, no differences in accuracy between the high and low relatedness proportion conditions were observed, $F(1,21) = 0.38$, $p = .55$, n.s.

EXPERIMENT 2

The results of Experiment 1a failed to replicate Bodner and Masson's (2003) findings. Masked associative priming was found in both the high and low relatedness proportion conditions, but it was not modulated by relatedness proportion. Such modulation was instead found in the unmasked version of the task (Experiment 1b), in which the priming effect was significantly larger in the high compared to the low relatedness proportion condition. The results of Experiment 1b confirm that the lack of relatedness proportion modulation on the priming effect in the masked condition observed in Experiment 1a was not due to factors related to the stimuli or insensitivity of the experimental design. These results are consistent with previous work that has failed to find relatedness proportion effects on masked associative priming (Pecher et al., 2002; Perea & Rosa, 2002).

As already mentioned, RTconstitutes a composite behavioral measure that reflects multiple representations and levels of analysis. Therefore, it remains possible that relatedness proportion effects in masked conditions are present but somehow concealed by the contribution of other factors. The goal of Experiment 2 was to test retrospective theories of priming and assess relatedness proportion effects on masked associative priming by employing a more sensitive measure of lexical and semantic processing, that is, the ERP N400 effect.

The N400 is a negative-going deflection in the ERP waveform peaking around 400 ms (300–500-ms time window) that has consistently been found to be larger following unrelated than related targets (Kutas & Hillyard, 1980). This N400 effect, somewhat greater over central and parietal sites and over the right hemisphere, has been observed in a variety of paradigms, including sentence processing (Kutas & Hillyard, 1984; Neville, Nicol, & Barss, 1991), lexical decision (Bentin, McCarthy, & Wood, 1985; Brown & Hagoort, 1993; Chwilla, Brown, & Hagoort, 1995; Holcomb & Neville, 1990), and categorization (e.g., Holcomb, Reder, Misra, & Grainger, 2005) paradigms. Importantly, a reduced N400 effect has also been observed in a number of masked associative priming studies (Kiefer, 2002; Kiefer & Spitzer, 2000) and in attentional blink studies (Luck, Vogel, & Shapiro, 1996; Rolke, Heil, Streb, & Hennighausen, 2001). Given that expectation strategies and postlexical matching mechanisms can be ruled out in masked priming paradigms (participants consciously process only the targets), the N400 effect might be considered an automatic index of semantic priming, and thus primarily associated with automatic spreading activation mechanisms within the lexicon (Kiefer, 2002; Luck et al., 1996). However, the nature of the N400 effect in masked conditions is under debate (e.g., Heil, Rolke, & Pecchinenda, 2004; Holcomb et al., 2005; Kiefer, 2002; see the final Discussion) and retrospective theories of relatedness proportion also predict masked priming effects (based on episodic memory processes; Bodner & Masson, 2003). Although the present study does not focus on the nature of the N400 effect itself, it will allow for valuable insight into whether relatedness proportion modulates the N400 masked priming effect.

Experiment 2 differed from Experiment 1 in two respects: (1) to increase power (because ERP masked priming effects are generally quite small), each subject was tested in both relatedness proportion conditions; (2) to measure the N400 effect uncontaminated by motor-related potentials, subjects were required to perform a categorization task and press a button only when a proper name was presented as a target.[2] Only trials that did not required a button press (i.e., were free of potential contamination from motor responses) were analyzed. Previous studies have shown that the N400 effect is present in categorization tasks, even when the prime is masked (e.g., Holcomb et al., 2005; Misra & Holcomb, 2003).

Based on previous studies (e.g., Kiefer, 2002), an N400 effect was predicted in both relatedness proportion conditions. However, automatic spreading activation and retrospective theories of priming make different predictions regarding the influence of relatedness proportion on the N400 effect. If masked associative priming effects reflect automatic facilitatory mechanisms within the lexicon, then relatedness proportion should not modulate the size of the N400 effect. According to this theory, such facilitation would reflect automatic mechanisms of spreading activation that are not sensitive to contextual factors. In contrast, if, as purported by retrospective theories of priming, priming reflects the episodic recruitment of the prime, then a larger priming effect in the form of a larger N400 effect should occur in high relatedness proportion conditions as compared to low relatedness proportion conditions. This pattern has been demonstrated in unmasked priming experiments (e.g., Chwilla et al., 1995; Holcomb, 1988) and is thought to be due to a greater reliance on the prime in conditions in which the prime is highly predictive of the target (i.e., in high relatedness proportion lists).

[2]In typical masked priming experiments, the size of the N400 effect is generally very small and the effect overlaps with the P300. Therefore, it can be unclear whether the N400 effect is a real N400 effect or just a consequence of a later P300 to unrelated trials. For this reason, a categorization task has been employed in Experiment 2 and relatedness proportion effects were measured on trials that did not require a button press.

Methods

Participants

Forty-one participants from SUNY at New Paltz participated in the study after signing informed consent. Participants (31 women, mean age = 21.8 years, range = 18–33) were all right-handed except for one ambidextrous person (Edinburgh Handedness Inventory; Oldfield, 1971) and all were native English speakers. All participants had normal or corrected-to-normal vision and participated for extra credit or as part of a course requirement. No participant from Experiment 1 was included in Experiment 2.

Materials

The 200 pairs of related words and 200 unrelated primes used in Experiment 1 were used in Experiment 2. One hundred proper nouns were added to the master list of stimuli (e.g., Alice, David, Helen, George). Proper nouns were chosen based on familiarity and lack of lexical ambiguity (e.g., nouns such as Grace were not included). Each high relatedness proportion list was comprised of 160 pairs of related words, 40 pairs of unrelated words, and 50 word–proper noun pairs. Each low relatedness proportion list was comprised of 160 pairs of unrelated words, 40 pairs of related words, and 50 word–proper noun pairs. All word–proper noun pairs were comprised of unrelated pairs (e.g., trap–Paul). Proper nouns had a mean frequency of 19.25 (*SD* 25.37) and a mean length of 4.52 letters (*SD* 1.01). Proper nouns in the two lists were matched by frequency and length.

Within each relatedness proportion condition, the lists were counterbalanced across participants through random assignment so that each subject saw a particular stimulus only once, allowing for comparison of the same target preceded by different types of primes across participants. Thus, it was possible to protect against any uncontrolled target-related factors and to compare the same targets preceded by different primes across subjects.

Procedure

The procedure was identical to the one adopted in Experiment 1 with the following exceptions. Participants were instructed to press either the left or the right button of a response box in their laps if the target was a proper noun and to respond as rapidly as possible without jeopardizing the accuracy of their responses. No button press was required if the target was a common noun. To minimize eye movement artifacts, participants were instructed not to blink when the white rectangle was present on the screen.

Twenty-five practice trials preceded the actual test session. The practice list was comprised of 20 word–word pairs (10 related and 10 unrelated pairs) and 5 word–proper noun pairs, none of which was included in the experimental list. Neither during the practice nor during the experiment was the presence of the prime mentioned by the experimenter.

After completion of the experiment, a debriefing questionnaire identical to the one employed in Experiment 1 was administrated to assess awareness of the primes. Participants then performed the prime awareness task as described in Experiment 1a.

ERP Materials and Recording

The EEG was recorded from 29 electrodes mounted in an elastic cap (Electro-Cap) according to a standard extended International 10–20 configuration. In addition, electrodes were placed beneath one eye to monitor blinking and vertical eye movements and at the outer canthus of each eye to monitor horizontal eye movements. Online recordings were referenced to the right mastoid and re-referenced to averaged mastoids in the final data averaging. Impedances were kept under 2 kΩ for the mastoids and scalp electrodes, under 5 kΩ for horizontal and vertical eye channels, and under 8 kΩ for the isoground channel.

The EEG was amplified with SA amplifiers (bandpass of 0.01 to 100 Hz) and digitized online at a sampling rate of 250 Hz. A 60 Hz filter was applied to the data off-line. Trials characterized by eye movements, muscular activity, and electrical noise were rejected by automatized programs and were not included in the analyses. Blinks, eye movements, and drift were detected through a "peak-to-peak amplitude" function: Trials were rejected if the amplitude value between the maximum and minimum data points in the specified time window was larger or smaller than a priori established thresholds (these thresholds were 17, 20, and 30 μV for blinks, eye movements, and drift, respectively[3]). Amplifier blocking was detected through similar routines identifying the number of data points within the minimum and maximum values within a given search window; trials outside an experimenter-established a priori threshold (20 points) were rejected. Only common noun targets not followed by a button press were included in analyses.

ERPs to targets were averaged over an epoch of 1000 ms, using a 200-ms prestimulus baseline. The N400 effect was quantified as the mean voltage of the interval between 300 and 500 ms after target presentation. Factors for ANOVAs were the following: block order (between-subjects factor, 2 levels; high relatedness proportion condition first and low relatedness proportion condition first), relatedness proportion (2 levels; high and low), prime type (2 levels; related and unrelated), hemisphere (2 levels; left and right), anterior/posterior (ant/post, 6 possible levels), lateral/medial (lat/med, 2 possible levels). Electrode sites included in the anterior/posterior factor were: F7/8 and F3/4 (frontal), FT7/8 and FC5/6 (fronto-temporal), T7/8 and C5/6 (temporal), CP5/6 and C3/4 (centro-temporal), P7/8 and P3/4 (temporo-parietal), and PO7/8 and O1/2 (parietal-occipital). Sites included in the lateral/medial factor were: F7/8, FT7/8, T7/8, CP5/6, P7/8, PO7/8 (lateral) and F3/4, FC5/6, C5/6, C3/4, P3/4, O1/2 (medial). Adjusted p and epsilon values (Geisser–Greenhouse correction) are reported for all within-subject measures with more than one degree of freedom. Significant interactions involving condition effects were followed up by simple effects analyses. To calculate scalp voltage maps for the N400 effect, a spherical spline interpolation (Perrin, Pernier, Bertrand, & Echallier, 1989) was used to interpolate the potential on the surface of an idealized, spherical head based on the voltages measured at each electrode location.

Results

Subject Inclusion

Five subjects were excluded from the analyses because of low accuracy ($n = 1$) or because the prime awareness data were lost due to technical issues ($n = 4$). Therefore, the following analyses were performed on 36 participants.

[3]The software program used to analyze the ERP data was ERPSS (http://www.erpss.com). In this program, artifact rejection is carried out prior to normalization. Therefore, thresholds for artifact rejection are specified in terms of arbitrary units used in the raw data file. The provided values have been obtained by converting these units based on values obtained with the calibration process.

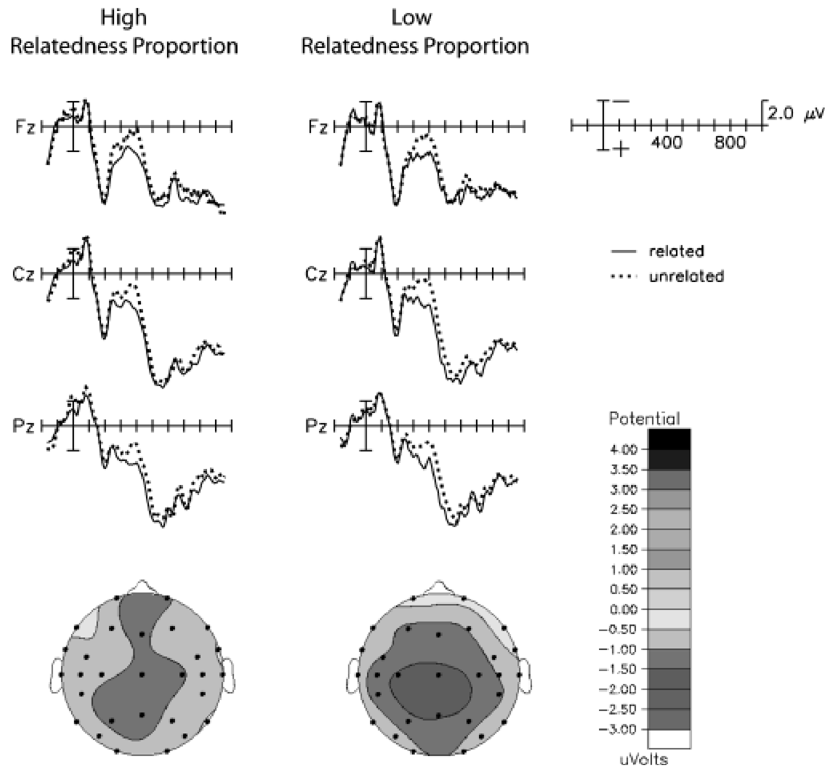

Figure 2. ERP waveforms to word targets preceded by related and unrelated primes at midline recording sites in the high and low relatedness proportion conditions (negative is plotted up). The voltage maps show the distributions of the N400 effect in the two conditions (300–500 ms; ERP to targets preceded by related primes subtracted from ERP to targets preceded by unrelated primes).

Prime Awareness

Hit and false alarms rates were transformed into d' values for each participant. The mean d' value was 0.05, which was not significantly different from zero ($p = .57$, two-tailed), confirming that subjects were not able to discriminate between word and nonword primes. Subsequent behavioral and electrophysiological analyses were performed on the participants whose d' values were below the upper 95% confidence level of $d' = 0$ for the present data (this value was 0.21). Eight participants with d' values larger than 0.21 were excluded; therefore, the following analyses were performed on the remaining 28 participants (14 received the high relatedness proportion condition first and 14 received the low relatedness proportion condition first).

Behavioral Data

An omnibus ANOVA was performed with relatedness proportion as the within-subjects factor and block order as the between-subjects factor. Mean reaction times for proper nouns (calculated for correct responses only) were 547.24 ms (*SD* 64.51) for the high relatedness proportion condition and 545 ms (*SD* 65.48) for the low relatedness proportion condition. The difference between the two conditions was not significant, $F(1,26) = 0.1$, $p = .75$. For the RT data, block order was not significant, $F(1,26) = 1.38$, $p = .25$, and did not interact with relatedness proportion, $F(1,26) = 1.47$, $p = .24$. Accuracy was 97.36% (*SD* 3.13) in the high relatedness proportion condition and 96.64% (*SD* 4.87) in the low relatedness proportion condition. The difference between the two conditions was not significant, $F(1,26) = 0.77$, $p = .39$. For the accuracy data as well, block order was not significant, $F(1,26) = 0.56$, $p = .46$, and did not interact with relatedness proportion, $F(1,26) = 0.000$, $p = .999$.

ERP Data

ERPs to targets preceded by related and unrelated primes for both high and low relatedness proportion conditions are shown in Figure 2. An omnibus ANOVA was performed with prime type and relatedness proportion as the within-subjects factors and block order as the between-subjects factor. No interaction between prime and block order was significant (all $p\text{s} > .07$[4]). Therefore, follow-up analyses were performed on mean amplitudes collapsed across block order conditions. The N400 effect was significant (prime, $F[1,26] = 14.54$, $p = .001$): ERPs to targets were more negative when targets were preceded by unrelated than related primes. This effect was largest over centro-parietal and medial sites (prime × ant/post, $F[5,130] = 3.1$, $p = .06$, $\varepsilon = .36$; prime × lat/med, $F[1,26] = 11.15$, $p = .003$; prime × ant/post × lat/med, $F[1,26] = 3.0$, $p = .04$, $\varepsilon = .61$). Analyses performed for the two relatedness proportion conditions separately revealed that the N400 effect—the main effect of prime—was significant in both conditions (high relatedness proportion, $F[1,26] = 7.79$, $p < .01$; low relatedness proportion, $F[1,26] = 12.38$, $p = .002$; see Figure 3). Although the N400 effect was numerically larger in the low than in the high relatedness proportion condition, no interactions between the priming effect and relatedness proportion were significant (all $p\text{s} > .07$[5]).

[4]There was a nonsignificant, weak interaction between relatedness proportion, prime, ant/post, and block order, $F(5,130) = 2.99$, $p = .07$, $\varepsilon = .41$, n.s., and all other interactions between prime and block order were also not significant (all $p\text{s} > .12$).

[5]There was a weak, nonsignificant five-way interaction between relatedness proportion, prime, hem, ant/post, and lat/med, $F(5,130) = 2.79$, $p = .07$, $\varepsilon = .43$, n.s., and all other interactions between relatedness proportion and prime were also not significant (all $p\text{s} > .22$).

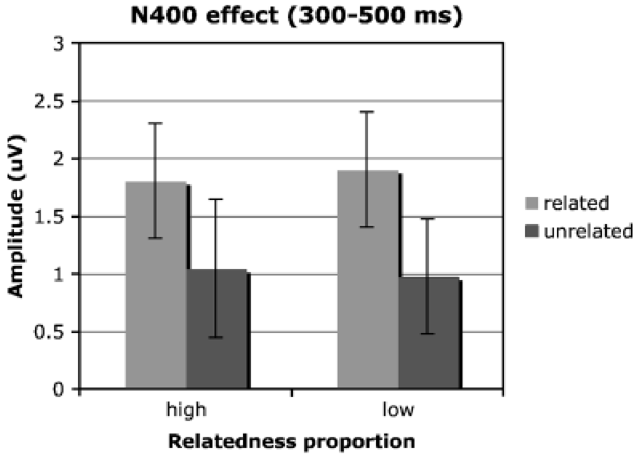

Figure 3. N400 mean amplitude (300–500 ms, in microvolts) to targets preceded by related and unrelated trials in the high and low relatedness proportion conditions. Bars indicate standard errors.

Discussion

In both Experiments 1a and 2 behavioral or electrophysiological priming effects were found in both high and low relatedness proportion conditions, but in neither experiment were these effects modulated by relatedness proportion (moreover, the N400 effect was actually numerically larger in the low compared to the high relatedness proportion condition). Therefore, the present findings do not support retrospective theories of masked associative priming. Other studies have failed to replicate relatedness proportion effects in similar masked priming experiments. Recently, Pecher and colleagues (2002) found no relatedness proportion effect in a perceptual identification task. Similarly, Perea and Rosa (2002) found no relatedness proportion effects in a series of lexical decision and naming tasks in which primes and targets were presented at several short SOAs. By employing both behavioral and more sensitive electrophysiological measures of semantic processing, the present data cast doubts on retrospective explanations of masked associative priming effects. Bodner and Masson (2003) have argued that such null effects might arise due to partial awareness of the primes. Although prime awareness was not assessed by Perea and Rosa (2002), objective measures of prime awareness (Merickle, Smilek, & Eastwood, 2001) were obtained in the present study and analyses were performed only on data from participants who could not identify the primes. Therefore, it is unlikely that prime awareness played a role in the present findings.

Results of other ERP studies have also cast doubt on the retrospective prime recruitment hypothesis. For example, Holcomb (1993) tested the effects of target degradation on the N400 effect in an unmasked priming study. According to retrospective theories of priming, the degradation of the target should increase the magnitude of the priming effect because subjects rely more on the prime in order to identity the target when the target is degraded (Whittlesea & Jacoby, 1990). Holcomb (1993) did find a larger behavioral priming effect for degraded targets compared to nondegraded targets, but the size of the N400 effect was similar in the two conditions. Interestingly, the N400 effect was delayed in the degradation condition, a finding that suggests that target degradation influenced RT at a stage of processing that preceded, and did not directly affect, the semantic priming effect.

The present data replicate findings demonstrating the presence of automatic semantic activation processes as indexed by the N400 effect in masked conditions (Kiefer, 2002; Kiefer & Spitzer, 2000) and in other paradigms such as attentional blink (Luck et al., 1996; Rolke et al., 2001) and letter-search tasks (Heil et al., 2004). Although the present results do not directly support automatic spreading activation theories of priming (as is well known, null results are difficult to interpret), they are consistent with a proactive interpretation of unconscious lexical processes in which the presentation of the prime creates a change in long-term memory that benefits the analysis of subsequently presented related targets.

Alternative interpretations of the N400 effect in masked conditions do exist. Holcomb and colleagues have argued that the role of automatic spreading activation mechanisms can be ruled out because masked semantic priming in the form of N400 modulation has been found for pictures of objects, which do not have lexical entries (McPherson & Holcomb, 1999).[6] Instead, according to Holcomb et al., the N400 effect reflects postlexical mechanisms through which a target semantic item is integrated into a context, even if that context is not consciously experienced or identified (Holcomb et al., 2005; Misra & Holcomb, 2003). In this view, some of the priming obtained in Experiment 2 might reflect backward priming from the target to the subliminal prime. Due to the short presentation time and the mask, the prime would not be able by itself to fully activate the semantic field associated with this item, but the immediately following supraliminal target would be robust enough to increase its weak activation (in the case of unrelated primes, the lack of semantic overlap would result in a larger N400). Although it is not possible to exclude the contribution of backward priming in the present findings, it is unlikely that this mechanism alone can account for the N400 effect observed in Experiment 2. According to Holcomb's hypothesis, the masking of the target instead of the prime would prevent the postlexical integration between the target and the prime from taking place and would therefore eliminate the N400 effect (Holcomb et al., 2005; Misra & Holcomb, 2003). However, data on the attentional blink (Luck et al., 1996; Rolke et al., 2001) have shown that the N400 effect is present when target words are missed and not available for conscious report. These data suggest that automatic spreading activation is sufficient to evoke an N400 amplitude modulation (Rolke et al., 2001). Therefore, an interpretation of the N400 effect in masked conditions exclusively in terms of postlexical contextual integration is not fully supported by the extant literature.

In a recent study, Holcomb et al. (2005) did find an N400 effect in a masked categorization task when primes were presented for 40 ms—but only in participants who were able to identify the primes at above chance levels. This result might cast doubt on the present findings and suggest that the observed N400 effect might be due to some residual consciousness of the prime for some of the trials (e.g., Cheesman & Merickle, 1985). Although partial consciousness is likely to be impossible to rule out, a critical difference between Holcomb et al.'s study and the present one is the much shorter SOA here (50 vs. 600 ms). It is

[6] I am indebted to one of the anonymous reviewers for noting that the presence of the N400 modulation for pictures does not rule out automatic spreading activation mechanisms because conceptual information related to objects is thought to be stored in a semantic network accessed by both pictures and words. Thus, automatic spreading activation mechanisms could be active when pictorial stimuli are used. Furthermore, lexical entries are generally associated with pictures of nameable objects. Hence, automatic spreading activation mechanisms could additionally act upon associations between lemmas within the "mental" lexicon.

unlikely that an SOA of 50 ms would constitute sufficient time to consolidate an episodic memory trace of the primes, especially considering that such consolidation would occur in parallel and in synchrony with the processing of the targets.

Interestingly, there is also some evidence to suggest that prime visibility might *negatively* affect priming effects (see Durante & Hirshman, 1994). For example, Kiefer (2002) reported a negative correlation between visibility of the primes and the behavioral priming effect at a short SOA (67 ms). Although the correlation was not significant for the N400 effect ($p = .2$), the direction of the correlation was negative for the ERP effect as well; in any case, the N400 effect did not increase with prime visibility. Finally, a number of studies that have employed an SOA longer than 200 ms have failed to demonstrate an N400 effect (e.g., Kiefer & Spitzer, 2000; Ruz, Madrid, Lupiáñez, & Tudela, 2003) or a behavioral priming effect (e.g., Greenwald, Draine, & Abrams, 1996), suggesting that at least some aspect of the automatic priming effects tapped by masked priming paradigms is short-lived. Although the lack of masked associative priming at longer SOAs is also consistent with a postlexical integration mechanism (integration of the prime after the target has been processed might be weaker due to the dissipation of prime activation), taken together, these findings suggest that it might be premature to abandon the hypothesis of proactive mechanisms of priming, despite Holcomb et al.'s (2005) recent results. Clearly, further research is needed to assess the contribution of prelexical and postlexical mechanisms in masked associative priming.

In the present experiment, different primes were used for related and unrelated trials. It is therefore possible that the obtained differences reflect not priming effects but some uncontrolled systematic differences in the two groups of words. Although primes were matched by frequency and length, other lexical/semantic variables, such as concreteness, were not controlled for. Indeed, a post hoc analysis revealed that related primes had higher concreteness levels than unrelated primes,[7] but because it was not possible to obtain concreteness levels for all words in the list, these analyses remain preliminary. Even with this potential confound, it is unlikely that the N400 effect in the present experiment reflects differences in the concreteness of the primes for two reasons. First, research has shown that concreteness and imageability effects are independent from priming effects. Concreteness effects are usually largest at anterior sites and are observed over a prolonged time window (i.e., 300–800 ms; e.g., Kounios & Holcomb, 1994; West & Holcomb, 2000; for data concerning imageability, see Swaab, Baynes, & Knight, 2002). The N400 effect in the present experiment was more robust over central and parietal sites and was observed within the typical N400 effect time window (300–500 ms). Second, concreteness effects are usually observed in the form of a larger (i.e., more negative) N400 to concrete than abstract words (e.g., Kounios & Holcomb, 1994; West & Holcomb, 2000). Therefore, if it were true that the N400 effect in the present study is due to uncontrolled concreteness effects related to the primes, a larger N400 would be expected for related as compared to unrelated trials, because related trials were primed by more concrete words. This is not the case in the present data.

It is noteworthy that most studies on concreteness effects have employed experimental conditions in which the context was fully available (e.g., sentence processing or unmasked lexical decision tasks). Further, West and Holcomb (2000) have shown that such effects are amplified in tasks requiring semantic, or deep, analysis of words. In the present task, primes were masked and participants were not aware of their identity. It remains unclear whether the concreteness of masked primes could significantly affect ERPs to targets. Future research will need to investigate this issue more directly.

Although the present results clearly do not corroborate retrospective theories of masked associative priming, these findings do not imply that contextual effects do not play any role in the subliminal or preattentive processes indexed in masked priming experiments. Contextual effects have been described in other masked priming paradigms, such as pseudohomophone and form priming (Ferrand & Grainger, 1996; Forster & Veres, 1998), repetition priming (Bodner & Masson, 1997, 2001), and visual discrimination (Jaskowski, Skalska, & Verleger, 2003). Future research will need to determine under what conditions such contextual factors play a consistent role and how automatic spreading activation processes, postlexical integration processes, and contextual factors might interact to contribute to the observed masked priming effects.

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[7]Analyses were based on the MRC database (http://www.psy.uwa.edu.au/MRCDataBase/uwa_mrc.htm). The difference in concreteness between related and unrelated primes was significant at the $p = .01$ level.

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(Received June 28, 2005; Accepted January 16, 2006)