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Is *"Blank"* a suitable neutral prime for event-related potential experiments? ☆

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Abstract

We report an experiment that evaluates whether *BLANK* or an unrelated prime is a more suitable baseline for assessing priming for an ERP study. Sixteen subjects performed a lexical decision task with a 1 s prime-target stimulus onset asynchrony. Increased amplitude for the N400 was observed for targets in the unrelated prime condition whereas targets in the *BLANK* prime condition evoked activity that was more like that in the related prime condition. Theoretically, we conclude that the N400 reflects semantic integration. Pragmatically, we conclude that the *BLANK* prime is a better neutral prime but that unrelated primes yield stronger N400 effects.

Keywords: N400; Semantic priming; Expectancy; Semantic integration; Recognition potential

1. Introduction

Semantic priming is the phenomenon wherein the semantic context established by an initial word or sentence stem (the "prime") modifies the processing efficiency for a subsequent semantically related "target" stimulus. This phenomenon is important because it provides clues as to the organization of semantic memory as well as its interaction with linguistic processing. Most priming research has been conducted with the lexical decision paradigm, a task in which the presentation of a prime influences the ability of the participant to judge whether a succeeding target is a word or a pseudo-word.

Studies of the lexical decision task have identified three semantic priming mechanisms, each with different properties (Neely, 1991). Automatic spreading activation or ASA (Collins & Loftus, 1975) is thought to be a fast-acting involuntary process in which an activated semantic node proceeds to activate linked semantically related nodes, with this activation fading away after about 400 ms (Neely, 1977). The second mechanism is expectancy priming, a slower, strategically mediated controlled process in which the participant consciously uses the prime to predict what the target word is likely to be. Expectancy-based priming takes about 700 ms to become operative (Neely, 1977) and produces facilitation (for expected/related targets) and may produce inhibition for unexpected/unrelated targets (Becker, 1980). The third mechanism is semantic matching, a slower,

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strategically mediated controlled post-lexical process that is thought to be a strategic use of a more general semantic integration process in which each word is integrated into the ongoing semantic context (de Groot, 1985). Unlike ASA or expectancy, semantic matching operates only in the lexical decision task and not in the pronunciation task. In using semantic matching, the participant capitalizes on detecting a relationship between the target and its preceding word prime so as to facilitate the lexical decision to the target. The detection of a semantic relation is a strong clue about the target's lexicality because nonwords typically do not even resemble words related to the word prime and thus evoke a minimal sense of relatedness. Thus, if the target activates a node that is related to its preceding prime, it must be a word and if it does not, it is highly likely to be a nonword. Neely, Keefe, and Ross (1989) have provided evidence for expectancy and semantic matching being separate strategically controlled priming processes in that they depend on different probability manipulations within the experimental test list. They found that expectancy depends on the relatedness proportion (RelProp here rather than Neely and associates' RP to avoid confusion with the acronym for the Recognition Potential, which will for the same reason be termed RecPot), which is the conditional probability that a prime and target are related, given that both are words. When the RelProp is high (>.50), expectancy is a fruitful strategy when the target is a strong associate of the prime and hence can be easily generated from it. Indeed, using a 1000 ms prime-target stimulus onset asynchrony (SOA) that is long enough for an expectancy to be invoked, Neely et al. (1989) showed that when category names were used as primes, priming for high dominance exemplars increased as RelProp increased. However, increases in RelProp did not increase priming for low dominance exemplars, which by definition would be unlikely to be included in the expectancy generated from the category-name prime. Semantic matching, on the other hand, depends on a different conditional probability called the nonword ratio (NWR), which is defined as the probability that a target is a nonword given that it is unrelated to the word prime that precedes it. When this ratio is high and a semantic relation between the target and prime is not detected (i.e., the target and prime are unrelated), it is highly likely the target is a nonword (and, as noted earlier, if a relation is detected, the target must be a word). Thus, Neely et al. (1989) found that as the NWR increases, priming for high-dominance exemplars increases just as it does with increases in RelProp. However, increases in the NWR also lead to an increase in priming for low-dominance exemplars (because it is easy to detect retrospectively the relation between the low-dominance exemplar *vulture* and its preceding prime *BIRD*, even though *vulture* is not likely to be prospectively included in the expectancy set of targets generated from *BIRD*) and also lead to an increase in nonword facilitation. Nonword facilitation is the finding that reaction times (RTs) to nonword targets are faster following word primes than following neutral primes. When the NWR is high and the prime is a word, if a relation between the target and prime is not detected, this provides good evidence that the target is a nonword and this biases a "nonword" response, relative to the neutral priming condition in which words and nonwords are equally likely to follow the neutral prime. This bias to respond "nonword" also facilitates "nonword" responses (the nonword facilitation effect) and slows/inhibits "word" responses to unrelated word targets (for which there is also a failure to detect a semantic relation). Because the nonword facilitation effect is presumably only produced by semantic matching it is considered to be one of the signatures of semantic matching. As it has been shown to occur only at longer SOAs (e.g., Neely, 1977), it seems that it, like the other strategic priming mechanism, expectancy, depends on completed, consciously controlled processing of the prime to operate. However, semantic matching differs from expectancy in a regard other than its ability to produce nonword facilitation and priming for low-dominance exemplars. Unlike expectancy, semantic matching does not operate in a pronunciation task. The reason it does not is that detecting whether or not a semantic relation exists between the target and its preceding prime does not by itself provide much information at all about how the target is to be pronounced. This differs from the lexical decision task in which only two responses are possible. When a relation is detected, the target is a word 100% of the time and when the NWR is high, say .80, and a relation is not detected, the target is a nonword 80% of the time. Thus, at long SOAs, when both expectancy and semantic matching could be operating in the lexical decision task, one observes nonword facilitation (Neely, 1977) and asymmetrical backward priming (Kahan, Neely, & Forsythe, 1999), which is the finding that *fly* produces priming for *fruit*. Because the forward association from *fly* to *fruit* is very weak, this effect could not be produced by expectancy. However, because the backward association from *fruit* to *fly* is strong, the semantic matching mechanism could detect this target-prime relation and produce priming. Thus, in pronunciation, in which semantic matching does not operate, asymmetrical backward priming does not occur at a long SOA, although it did happen at a short SOA for reasons that are not understood (Kahan et al., 1999). Furthermore, because expectancy does operate in pronunciation, Keefe and Neely (1990) have found that high-dominance exemplar priming increases as RelProp increases but low-dominance exemplar priming (which is produced by semantic matching) does not increase with increases in the NWR (as it does in the lexical decision task, in which semantic matching does operate, Neely et al., 1989.) Taken together, these dissociations in the behavioral priming data provide good evidence that three functionally distinct mechanisms contribute to priming.

A fundamental question regarding these priming mechanisms is whether they are facilitatory or inhibitory in nature. In a classic study, Neely (1977) found that at a short 250 ms prime-target SOA when only ASA would be operative, related primes produced facilitation relative to a neutral prime (consisting of a string of XXXs), regardless of whether or not related targets were likely to follow that prime, whereas unrelated primes did not produce inhibition. However, at longer prime-target SOAs of 700 ms or more, facilitation occurred for expected targets (even when they came from a different unrelated category from which participants expected exemplar targets to be selected) and was now accompanied by inhibition for unexpected targets (whether or not they were related to the prime.) Thus, ASA is solely facilitatory in nature whereas expectancy produces facilitation for expected targets and inhibition for unexpected targets. Note that expectancy-based inhibition occurs when only a broad expectancy set is possible, such as all metal words, and not when a specific prediction is possible, such as for antonym pairs (Becker, 1980). Because semantic matching biases the participant to respond "word" vs. "nonword" when a target-prime relationship is or is not detected, respectively, it produces facilitation for related targets, inhibition for unrelated targets, and nonword facilitation.

However, these conclusions depend on the use of a neutral prime condition to compare against, which raises the issue of whether the specific prime chosen to serve as the neutral prime is truly neutral (Jonides & Mack, 1984). If the neutral primes differ from the word primes on some factor that speeds RTs to the targets that follows the neutral primes, then facilitation will be underestimated and inhibition will be overestimated; the opposite would be so if they differ on some factor that slows the RTs to the targets that follow them. Support for the claim that not all neutral primes are the same comes from a study by de Groot, Thomassen, and Hudson (1982) who found that +++ primes, similar in nature to *XXX* primes, inhibit succeeding targets relative to the word *BLANK* used as a neutral prime. A subsequent experiment (den Heyer, Taylor, & Abate, 1986) suggested that the *XXX* type prime may produce unwanted perceptual masking effects because it only has this effect at shorter stimulus onset asynchronies, or SOAs, (e.g., 200 and 550 ms). At a long SOA (1000 ms), *XXX*, *BLANK*, and unrelated primes were equivalent. *BLANK* was therefore recommended as a neutral prime. Unfortunately, it is unclear from the description of the stimulus list whether the RTs for the unrelated primes reflected inhibition (as would be expected for category primes) or not (as would be expected for associative primes) since the stimulus list consisted of a mix of both types of stimulus pairs. It is therefore unclear whether the two putative neutral primes were indeed neutral or simply equally inhibitory as the unrelated primes.

Even if one accepts this conclusion for reaction time measures, this does not necessarily mean that the two neutral primes are equivalent for the purposes of event-related potentials (ERPs). ERPs are the brainwave activity evoked in the brain by events such as the presentation of a word. Like reaction time measures, ERPs have the strengths of being noninvasively measured and of providing millisecond time resolution. Nonetheless, ERPs and reaction time measures can diverge in a number of ways: (1) ERPs do not reflect all aspects of brain activity, only those that activate large numbers of neurons oriented such that their electrical fields summate (Nunez, 1981), so a priming effect could be visible in the RT but not in the ERPs. (2) Conversely, reaction time measures do not reflect all aspects of cognition, only those that lead directly to the response; for example, activity occurring after the response decision will not affect the reaction time measure, resulting in a priming effect in the ERP but not in the RT. (3) Two conditions may have similar reaction times but differ in their ERPs due to the use of different cognitive functions in the two conditions (cf. Sternberg, 1969). (4) In some situations either ERPs or reaction time measures may prove to be more sensitive indicators, revealing effects that are not seen with the other measure.

A case in point is an ERP component that has proven to be of considerable interest to language researchers, the N400 (Kutas, 1997; Kutas & Hillyard, 1980). The N400 is a right-lateralized negativity that is usually described as having its focus to the right of Pz (over the parietal lobe). The N400 has the interesting property that it is sensitive to semantic context effects, being larger to words that are semantically incongruous with the context that precedes them. It is therefore thought to reflect semantic priming but there is a great deal of debate regarding what mechanism is producing it. Suggestions have ranged from ASA (Deacon, Hewitt, Yang, & Nagata, 2000; Deacon, Uhm, Ritter, Hewitt, & Dynowska, 1999; Kutas, Lindamood, & Hillyard, 1984), expectancy (Kutas & Schmitt, 2003), to semantic integration (Brown & Hagoort, 1993).

In a 1000 ms SOA lexical decision experiment, the N400 could show effects not seen in the reaction time data if it reflects ASA (though ASA effects are generally accepted to last for less than 500 ms for RT data, this does not necessarily apply to ERP data) or if it reflects semantic integration in general and not the more specific semantic matching strategy that is used to facilitate decisional or response processes specific to the binary lexical decision task. Likewise, even though the choice of a neutral prime does not appear to make a difference to reaction time measures at a 1000 ms SOA (den Heyer et al., 1986), it could make a difference to ERP components such as the N400. It would therefore be wise to evaluate the appropriate neutral prime for an N400 experiment; conversely, examining how neutral prime choice affects the N400 might provide some clues as to the nature of the N400.

Furthermore, most N400 studies have not addressed the issue of what constitutes a neutral prime. One can differentiate between "baseline" conditions and "neutral" conditions. A "neutral" condition is defined as a condition that does not have the process of interest. In contrast, a "baseline" condition is defined as a condition that simply has less of the process of interest. Neuroimaging studies, including ERP studies, are often designed with the less stringent "baseline" conditions rather than "neutral" conditions. Part of the reason for this is that whereas both facilitatory and inhibitory effects are expected in RT measures, neural effects are likely to range from absent to present. Thus, a behavioral inhibitory effect is likely to take the form of a separate region of the brain being activated (cf. Liddle, Kiehl, & Smith, 2001). Furthermore, many N400 studies adopt a psychophysiological approach in which the primary interest is simply whether the mind is capable of performing semantic processing under a particular condition (such as subliminal presentation or in the presence of Alzheimer's disease) by detecting whether it can distinguish between semantically congruent or incongruent stimuli. It is therefore presently unclear whether a truly "neutral" prime would serve as a good "baseline" prime from a psychophysiological perspective.

Another ERP component that may be of interest in the context of neutral primes is the Recognition Potential or RecPot (Rudell, 1991). This ERP component has been shown to respond to the degree of orthographic regularity of letter strings (Martín-Loeches, Hinojosa, Gómez-Jarabo, & Rubia, 1999) and even some semantic properties of expectancy (Dien, Frishkoff, Cerbonne, & Tucker, 2003). Furthermore, source localization studies suggest it may emanate from the visual word form area (Dien et al., 2003; Martín-Loeches, Hinojosa, Gómez-Jarabo, & Rubia, 2001), a region that responds to repetition priming (Cohen et al., 2002); repetition priming is relevant because repetitive use of *BLANK* as a prime may affect how it is processed (de Groot et al., 1982). Thus, it may be possible that repeatedly presenting the same neutral prime could produce visual repetition effects that are unrelated to the semantic effects of interest.

A recent Dutch study has addressed the issue of a neutral prime with respect to the N400. They used a lexical decision task with a 700 ms SOA with both *BLANCO* primes (Dutch for *BLANK*) and unrelated primes (Brown, Hagoort, & Chwilla, 2000). They found that the *BLANCO* primes and the unrelated primes produced equivalent N400s. Their study was not specifically designed to evaluate the neutral prime issue and so two issues prevent any clear conclusions at this point. The first is that only 17% of the primes were *BLANCO*. It is therefore quite possible that these primes evoked N400s similar to the unrelated primes because they were rare enough that participants continued to treat them as words rather than as nonsemantic neutral stimuli. It therefore seems desirable to examine whether these findings extend to designs with higher proportions of neutral priming trials. The second is that if the N400 reflects expectancy, then inhibition effects should only occur if a broad class of possible targets are activated; when a specific prediction is possible inhibition is not seen (Becker, 1980). The stimulus list of this study was a mix of different types of priming pairs and so it was not possible to evaluate whether inhibition should be present in the case that the N400 reflects expectancy. This study also did not examine the RecPot.

In the present experiment, we will build on these results by examining the effect of *BLANK* and unrelated primes on ERPs using a lexical decision task. To encourage participants to invoke controlled priming mechanisms, a long 1000 ms SOA was used. To separate expectancy effects from semantic matching effects, both forward and backward asymmetrical priming pairs were included. To increase the likelihood that the *BLANK* prime habituates to the point of being a nonsemantic prime, it will appear on 33% of the trials. A high NWR of .60 should promote semantic matching. Unfortunately, an error in calculating the RelProp led to a low value of .33 (see Section 2), which though not optimal for encouraging the use of expectancy, could still invoke expectancy on some trials.

The present experiment will also explicitly examine associative versus semantic priming pairs. By using priming pairs where broad classes of words are primed (the semantic pairs) rather than specific words (the associative pairs), we hope to ensure that inhibition will be produced if expectancy is operating (and if the N400 reflects expectancy). Including both such pairs will also address a continuing debate in the priming literature which revolves around whether priming, whether automatic or controlled, is based on associative relatedness or semantic similarity (Hutchison, 2003; Lucas, 2000). Including both types avoids potential concerns that any null findings result from using the "wrong" type of priming pair.

The inclusion of both priming direction and priming type manipulations results in four priming pairs, the factorial combinations of priming direction and priming type. An example of a backward associative priming is "ship-space". An example of backward semantic priming is "light-lamp". Finally, a conventional prime type will be included for comparison's sake (symmetrical priming with both associative and semantic links, as in "lion" and "tiger"). Since only a minority of the stimulus pairs is appropriate for a narrow prediction set (the forward associative pairs), this stimulus set should induce a broad expectancy set which would produce inhibitory effects (cf. Becker, 1980). (Although the stimuli were obtained from Thompson-Schill, Kurtz, & Gabrieli (1998), their results cannot be directly compared to our because they used a short SOA in a naming task.)

From the theoretical standpoint of the nature of the N400, we predict that if it reflects expectancy then only the forward asymmetrical priming and symmetrical priming pairs should result in an N400 effect. If the N400 reflects general semantic integration then all types of priming pairs should produce N400 effects, whereas if it reflects the more specific semantic matching process it might not occur for the forward asymmetrical pairs (e.g., *stork* as the prime and *baby* as the target). This is so because the retrospective match from *baby* to *stork* might fail to find a relation because *baby* has only a very weak association to *stork* and is not semantically related to it. If the priming process reflected by the N400 is dependent on the same semantic network that generates ASA, then we also expect that the N400 will be strongest for the semantic similarity pairs if ASA is based on semantics (Lucas, 2000) and strongest for associative pairs if ASA is based on associations (Hutchison, 2003).

From the pragmatic standpoint of determining the best neutral prime for ERP experiments, if *BLANK* is treated as a semantically neutral word when it constitutes a third of the trials as opposed to an unrelated prime, it should produce an N400 effect intermediate to the N400 effects produced by the related and unrelated priming conditions. However, if the repetition of *BLANK* affects nonsemantic processes that affect the N400, the N400 effects for *BLANK* might be indistinguishable from the related priming or the unrelated priming condition or might even fall outside the range of N400 effects produced by these two kinds of primes. However, from the psychophysiological perspective, whichever prime yields the greatest contrast with the related prime condition is the best baseline condition, regardless of how neutral it is.

2. Methods

2.1. Participants

Data were collected from 32 Tulane University undergraduates who participated for extra credit. The data from three participants were dropped due to excessive artifacts. Data from two participants accidentally erased. Data from four subjects lost due to computer problems. Data from seven subjects were lost due to incorrectly applied electrode nets. Hence, the data from 16 subjects were retained for analysis (mean age 20).

2.2. Stimuli

The stimulus list was obtained from Experiment 3 of a prior study (Thompson-Schill et al., 1998). Stimulus pairs consisted of three types: asymmetrically associated/semantically dissimilar (e.g., fruit-fly), asymmetrically associated/semantically similar (e.g., bar-drink), and symmetrically associated/semantically similar (e.g., mad-anger). There were 18 pairs for each type. The two asymmetrically associated categories were further divided into two nine pair groups, one forward associated (e.g., fruit-fly) and one backward associated (e.g., fly-fruit). The target words of these pairs were used to construct two additional priming conditions: one with the neutral prime *BLANK* and one with an unrelated prime word selected without replacement from any one of all the other stimulus pairs. The occurrence of these three prime types (related prime, *BLANK* prime, and unrelated prime) was equiprobable. Finally, an equal number of trials contained words and nonwords, which were generated by taking a word matched to each word target in frequency (Francis & Kucera, 1982) and length and changing one of its letters. The primes for these nonword target trials were the same as the matched word target trials. Thus, each word prime appeared four times during the experiment (related prime, unrelated prime, and their two matched nonword pairs) and the *BLANK* prime appeared 108 times, half the time before a word target and half the time before a nonword target. Each target word appeared three times during the experiment (related prime, unrelated prime, *BLANK* prime). The nonword targets also appeared three times during the experiment (the matched nonword pairs for the related prime, unrelated prime, and *BLANK* prime pairs). The use of repeated primes and targets was identical to that used in the prior study (Thompson-Schill et al., 1998), with the exception that no constraint was made regarding the distribution of the stimulus pairs within the experiment blocks. Although it is unusual for a priming study to use repeated targets, a prior study has found that at a relatively long SOA of 550 ms repetition has additive effects with semantic priming so it should not be a problem (den Heyer, Goring, & Dannenbring, 1985). Although it has been reported that repeated primes can reduce the expectancy effect (Hutchison, Neely, & Johnson, 2001), in that study both repeats were immediately before the target whereas in the present study the repeats are in different trials.

An important methodological issue is the calculation of the conditional probabilities. The following explanation was kindly provided by James Neely (personal communication, 2004). The RelProp was calculated by dividing the total number of forward asymmetrical and symmetrical related priming trials by the sum of ALL word-target trials that do NOT include a neutral prime. The NWR was calculated by dividing the total number of nonword target trials that are NOT preceded by neutral primes by the total number of "unrelated" trials (i.e., the sum of nonword target trials NOT preceded by neutral primes plus the total number of word targets in the forward asymmetrical related prime condition and ALL unrelated prime conditions). The rationale for computing RelProp and NWR in this manner is as follows: what happens on neutral priming trials is irrelevant to how useful expectancy is when the prime is a WORD. Hence, neutral prime trials are not included in the RP computation. Nor are asymmetrical backward priming trials because the subject could not use the prime to generate an expectancy for the target that follows. That is, given the prime *fruit*, the expectancy would likely include *apple banana*, etc. but never *fly*. As for the NWR, the arguments are a more subtle and perhaps more controversial. The rationale for excluding neutral priming trials is the same. But in computing the total number of unrelated trials in the denominator, the forward asymmetrical related priming trials are considered to be "unrelated" because according to Neely et al. (1989) semantic matching is *retrospective* from the target to the prime. Thus, given the target *fly* participants would see a direct relation to *airplane*, *insect*, etc. but not to *fruit*. (If, however, one believes that in making the retrospective semantic match, the "simultaneous" activation of *fly* and *fruit* causes the participant to realize that there is a relation between the prime and target in the opposite direction, then the number of forward asymmetrical priming trials should be added to the numerator as well. If that were done in the present case the NWR would change to .70.)

2.3. Procedure

Each trial started with the presentation of the prime presented in upper-case for 200 ms, a "+" for a fixation for 800 ms (1 s SOA), presentation of the target in lower-case for 200 ms, 800 ms for response with a "+" fixation, and then a 1 s inter-trial interval (ITI) with a "•" fixation. There were a total of 324 trials, divided into three blocks separated by rest breaks. Participants were instructed to indicate "as quickly as possible without making errors" whether the target word was a word or a nonword by pressing a button with either the left or the right index finger (button assignment counterbalanced across participants). Participants were also instructed not to try guessing in advance whether the target would be a word since it would be random. Experiments began with twenty practice trials with stimulus pairs different from, but comparable to, the experimental stimuli. The participants were also instructed that there would be a recognition test at the end of the experiment on the prime/target pairs so "it is important to pay attention to the prime as well as the target."

2.4. Analysis

Electroencephalographic (EEG) data were collected using a high-density 128-channel electrical Geodesic system (Tucker, 1993) referenced to Cz. The data were recorded with a bandpass of .1–100 Hz and digitized at 250 Hz. The data were low-pass filtered at 30 Hz and transformed to average reference (Bertrand, Perrin, & Pernier, 1985; Dien, 1998) for analysis. Data were segmented on the prime word presentation with 50 ms pre-stimulus and 1946 ms post-stimulus. Eye blinks were removed using an automated independent components analysis routine developed by this lab (available for download at http://www.people.ku.edu/~jdien/downloads.html) using EEGLAB (Delorme and Makeig, September, 2002). In this procedure, ICA components correlating at least .9 with a the scalp topography of a blink template generated by averaging together eight blinks were removed and the data reconstituted from the remaining ICA components (cf. Jung et al., 2000; Vigario, 1997). Data were baseline-corrected for the 100 ms pre-target period for target analyses and the 50 ms pre-prime period for prime analyses.

Participant averages were computed using an automatic editing program. Trials containing uncorrected blinks (criteria of 70 μv difference between vertical EOG channels) were discarded. Trials were discarded if 10 or more channels exceeded an artifact voltage criterion. For trials with fewer than 10 bad channels, only the bad channels were discarded while the good channels were included in the average. Trials consistently bad across the majority of the trials were estimated from neighboring electrode recordings using spline interpolation (cf. Picton et al., 2000). Only correct response trials were retained in the averages.

For analyses of the N400 window, the mean amplitude was measured from about 300–500 ms. Prior literature was used to determine the focus sites of the putative components. The conventional N400 appears to have a focus just posterior to P4 at a site (Electrode 85) that will be termed pP4 (Nobre & McCarthy, 1994). The RecPot has been described as having a focus just anterior to P3 (Dien et al., 2003) but in this dataset it is not very evident at this electrode so instead it was measured at P3 itself. The window was 162–202 ms for the prime and 158–198 ms for the target. To take advantage of the high-density recordings, the mean of the focus sites and four surrounding electrodes were averaged together, resulting in a measure that should be more robust against individual differences in topography and isolated bad channels.

For the inferential tests, Keselman's SAS/IML code for conducting robust statistical tests (generously made available at http://www.umanitoba.ca/faculties/arts/psychology/) was ported to Matlab (available for download at http://www.people.ku.edu/~jdien/downloads.html). Following published guidelines (Keselman, Wilcox, & Lix, 2003) a 20% symmetric trim rule was used.

The seed for the number generation was set at 1000. The number of simulations used for the bootstrapping routine was set at 50,000 to ensure stable p values. Further description of the inferential issues, as they apply to ERP data, is available elsewhere (Dien, May, & Franklin, submitted; Dien & Santuzzi, 2004).

Although only the robust statistics will be interpreted, for comparison's sake, the results of conventional ANOVAs are also presented, using both multivariate (Pillai–Bartlett) and Geisser–Greenhouse (Geisser & Greenhouse, 1958) corrected univariate tests. For the latter, uncorrected degrees of freedom and corrected p values are reported. Although multivariate test statistics are less commonly used for ANOVAs, they are an equally valid alternative to the more commonly used univariate test statistic (for a review of their application to ERPs, see Dien & Santuzzi, 2004).

The symmetrical and asymmetrical priming conditions were analyzed with separate tests to allow for a fully crossed design for the asymmetrical conditions. Analysis of the conventional symmetric priming type was conducted as a two-factor design of prime (related, BLANK, unrelated) and hemisphere (left, right). For the asymmetrical priming analysis, a four-factor design of prime (related, BLANK, unrelated), direction (forward, backward), semantic similarity (similar, dissimilar), and hemisphere (left, right) was performed.

For the analyses of RTs, the median RTs of the correct trials in each cell were computed. For the accuracy data, trimmed means were not used since the low variability in the data (much of it pinned at 100%) resulted in singularity problems since the trimming often removed all the observations that differed from 100%. The ANOVAs were the same as for the ERP data except without the hemisphere factor.

3. Results

3.1. Behavioral measures

Arithmetic means of the individual participants' median RTs are presented in Table 1. As shown by Table 2, which reports all of the effects associated with p values <.10 in any analysis, there were no significant behavioral effects for the symmetric prime cell. As for the asymmetric priming analyses, no RT effect was significant either. As shown by the marginally significant prime $*$ similarity interaction for accuracy, accuracy rates tended to be lower for primed targets, but especially when the primes and targets were semantically dissimilar. Table 1 also shows a trend towards a nonword facilitation effect that did not reach significance.

3.2. Windowed ERP measures

Fig. 1 presents the grand average data for the different conditions. It appears that the N400 may be centered on P4, rather than the pP4 location seen in the prior study (Dien et al., 2003). To maintain the a priori nature of the analyses, pP4 was maintained as the analysis site.

Table 3 displays all of the ERP effects associated with p values <.10 in any analysis. As can be seen there, for the RecPot elicited by the prime stimulus (as opposed to the target), there was no significant effect for the symmetrical primes. For the asymmetrical priming analysis, there was an overall effect of the RecPot being more negative for primes taken from semantically similar stimulus pairs. However, as indicated by the direction $*$ similarity interaction, this effect of similarity did not hold in general for primes in the backward priming conditions in which the RecPots were actually somewhat

Table 1
Mean reaction times and accuracies

	Forward dissimilar	Backward dissimilar	Forward similar	Backward similar	Symmetric	Nonword
Related	389/.97	391/.95	361/.98	393/.99	354/.97	438/.94
Unrelated	395/.91	397/.93	374/.99	391/.90	376/.97	444/.92
BLANK	403/.92	405/.96	376/.94	424/.90	374/.95	451/.94
Priming	6 (18)	6 (15)	13 (15)	−2 (20)	22 (13)	10 (7)

Data represent the mean of the participant medians for each condition. The number in front of the slash is the reaction time and the number after the slash is the accuracy. The final row presents the priming effect (unrelated minus related) with the standard error of the mean in the parentheses. The final column is for the nonword targets and the priming effect is the nonword facilitation effect (neutral prime minus word primes).

Table 2
Results for behavioral analyses

Effect	Univariate	Multivariate	Robust
Symmetric prime RT	*n.s.*	$F(2, 14) = 3.13, p = .075$	*n.s.*
Symmetric prime acc	*n.s.*	*n.s.*	*n.s.*
Asymmetric prime $*$ similarity acc	*n.s.*	$F(2, 14) = 3.64, p = .053$	$T_{WJt}/c\ (2, 13) = 3.71, p = .080$
Prime $*$ similarity $*$ direction acc	$F(2, 30) = 4.00, p = .046$	*n.s.*	*n.s.*

Conventional univariate (Geisser–Greenhouse corrected), conventional multivariate, and robust statistics are presented. p values of over .10 are labeled nonsignificant (*n.s.*)

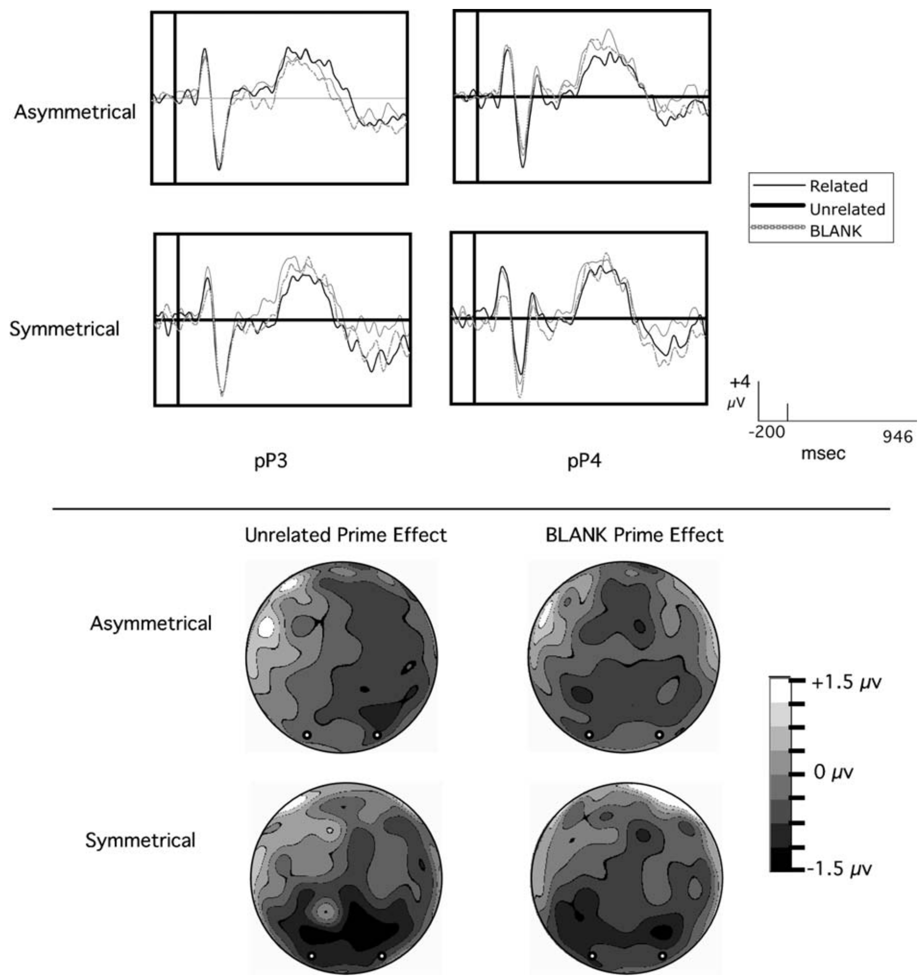

Fig. 1. N400 Effects. The waveforms show the N400 effects at the peak channels just posterior to P3 and P4. The topography maps show the scalp topography of the mean effects for the two neutral prime types within the 300–500 ms window. The top corresponds to the front of the head. The two white dots at the bottom of the maps correspond to the channels (66 and 85, just posterior to P3 and P4) shown in the waveform plots.

Table 3
Results for windowed analyses for asymmetric prime pairs

Effect	Univariate	Multivariate	Robust
Prime RP similarity	$F(1,15) = 8.91, p = .009$	$F(1,15) = 8.91, p = .009$	$T_{WJt}/c\,(1,9) = 9.21, p = .0074$
Prime RP direction ∗ similarity	*n.s.*	*n.s.*	$T_{WJt}/c\,(1,9) = 3.41, p = .083$
Prime RP direction ∗ similarity ∗ hemisphere	$F(1, 15) = 4.36, p = .054$	$F(1,15) = 4.36, p = .054$	$T_{WJt}/c\,(1,9) = 3.52, p = .063$
Target RP prime ∗ similarity	*n.s.*	$F(2,14) = 5.14, p = .021$	$T_{WJt}/c\,(2,8) = 4.44, p = .051$
Target RP prime ∗ direction ∗similarity ∗ hemisphere	$F(2,30) = 9.21, p = .020$	$F(2,14) = 6.76, p = .009$	*n.s.*
N400 prime ∗ hemisphere	*n.s.*	*n.s.*	$T_{WJt}/c\,(2,8) = 6.21, p = .029$
N400 prime ∗ similarity ∗ hemisphere	$F(2,30) = 3.34, p = .085$	$F(2,14) = 3.19, p = .072$	*n.s.*
N400 prime ∗ direction ∗similarity ∗ hemisphere	$F(2,30) = 9.21, p = .020$	$F(2,14) = 6.76, p = .009$	*n.s.*

Conventional univariate (Geisser–Greenhouse corrected), conventional multivariate, and robust statistics are presented. p values of over .1 are labeled nonsignificant (*n.s.*).

more positive for unrelated primes selected from semantically similar than from semantically dissimilar pairs. As indicated by the direction ∗ similarity ∗ hemisphere interaction, there was a marginally significant tendency for the left hemisphere RecPots to generally be more negative except for primes in the forward semantically related pairs.

For the target's RecPot measure, there were no significant effects for the symmetrical primes. For targets in the asymmetrical priming condition, there was a marginally significant tendency for the negativity to be larger for semantically dissimilar primed targets.

For the N400 measure, there was no effect for the symmetrical primes. For the asymmetrical primed targets, there was a significant interaction such that the topography was symmetrical for the primed targets, more negative for unprimed targets especially over the right hemisphere, and more negative for neutrally primed targets especially over the left hemisphere. None of the pairwise contrasts between the priming conditions, for either the left hemisphere sites or the right hemisphere sites, were significant. The trimmed mean for the right hemisphere site was relatively more negative in the unrelated condition compared to both the related condition and the neutral condition: (unrelated left 1.1, unrelated right .7, related left 1.0, related right 1.2, neutral left .4, neutral right 1.0). Also, the left hemisphere site was more negative in the neutral condition relative to the two word prime conditions. The appearance of the waveforms, as presented in Fig. 1, is consistent with the presence of the expected N400 effect.

4. Discussion

To summarize the results, no significant reaction time effects were observed, although trends were in the expected direction. The N400 measure showed a significant effect of prime type with a larger (relative to the related prime condition) negativity for the unrelated primes compared to both the BLANK prime and the related primes. As for the RecPot, there was a strong enhancement by semantic similarity for the prime's RecPot. Since the presence of semantic similarity could not been known in advance of the target presentation, this strongly suggests a confound of some sort. There was also a marginally significant enhancement of the target's RecPot for semantically dissimilar primed words. These ERP effects were all observed with the asymmetric priming pairs and not with the symmetric priming pairs, although the symmetric priming pairs had the largest reaction time difference. Finally, it appears that P4 may be a better site for measuring the N400 than pP4.

Before proceeding to the interpretation of the results, a couple caveats are necessary. First of all, although the RTs were in the expected direction, the priming effects were not statistically reliable. There are a number of reasons why this may have occurred: (1) The stimulus list was obtained from an experiment (Thompson-Schill et al., 1998) designed to minimize controlled processes since it was examining ASA. Thus, both the RelPot (which encourages expectancy) and the NWR (which encourages semantic matching) were not especially high. This was not recognized in advance due to a misunderstanding regarding how to compute these two conditional probabilities (see Section 2). (2) Although it has not been directly shown that repeating primes in separate trials, as opposed to the same trial (e.g., Hutchison et al., 2001), can reduce the priming effect, such an attenuation may have occurred. Not constraining the presentation of pair types to occur in separate blocks could have aggravated this issue. (3) The relatively short 1 s. ITI may have reduced the ability of the participants to engage in an attentional set. (4) There may have been too few participants and trials per condition to achieve sufficient statistical power. Insofar as the N400 has been linked to priming paradigms (including sentence priming) in hundreds of studies (Kutas, 1997; Kutas & Schmitt, 2003; Kutas & Van Petten, 1988), the present N400 effects are still of interest but the lack of significant RT effects may limit the generality of the conclusions.

A second concern is the degree of component overlap between the N400 and the succeeding P600. It was not possible to wholly exclude the P600 from the N400 window since the low numbers of trials per cell reduced the signal-to-noise ratio of the data too much to use a narrow windowed measure or PCA methods to separate the components. There are two reasons to feel confident that the effects do indeed represent modulation of the N400 rather than the P600. First of all, the scalp topography of the semantic effect clearly corresponds to that presented in a prior high-density mapping study (Nobre & McCarthy, 1994). We ascribe the discrepant N400 scalp topography in a different study (Curran, Tucker, Kutas, & Posner, 1993) are ascribed to a different component, as discussed elsewhere (Dien et al., submitted). Second, the right posterior topography of the priming type effect remains stable throughout the window, suggesting that the P600 is not contributing an additional effect.

Turning to the theoretical implications of the results, although one must be cautious in interpreting negative results, it is of great interest that the direction of priming did not affect the N400 effect. Since ASA and expectancy are thought to be minimized for backward priming pairs (such as *fly-fruit*), this observation is most consistent with the generalized semantic integration account for the N400. The dissociation between the reaction time effects and the N400 effects are also supportive of this conclusion since semantic integration, in the absence of evidence for the semantic matching strategy, would not be expected to affect reaction time measures in the lexical decision task. Thus, participants could be semantically integrating the stimulus pairs in parallel with, or after, the response decision.

A second observation is that no difference was seen between associative relatedness and semantic similarity pairs. Expectancy accounts for the N400 would not easily explain this observation, especially for backward primes. This offers some clues as to the nature of semantic integration, if that is what the N400 indeed represents. It would suggest that semantic integration is not primarily determined by semantic similarity unlike some reports of ASA (Lucas, 2000; Thompson-Schill et al., 1998). This in turn suggests that semantic integration operates outside the semantic network responsible for ASA effects. One possibility is that ASA is mediated by a semantic network whereas semantic integration is mediated by a compound cue process (Ratcliff & McKoon, 1988) wherein the stimulus pair is conjoined into a single chunk (rendering the nature of their relationship irrelevant) before they jointly access the semantic network. A caveat on this conclusion is that this study used a stimulus set from a prior study (Thompson-Schill et al., 1998) that has recently been criticized on a number of grounds (Hutchison, 2003, p. 795). The primary criticism is that, at least by one measure of association, semantic similarity and association strength are confounded. For the present study, this weakness reduces the significance of the finding that semantic similarity and association strength had similar effects on the ERP components.

A point of pragmatic interest is that the symmetric primes did not produce significant effects of any sort. Examination of the scalp topography data in Fig. 1 suggests that the right-lateralized N400 effect is indeed weaker for symmetrical primes. It may be that the symmetric prime pairs required less effort to semantically integrate than the asymmetric, regardless of whether they were associatively or semantically related. It is worth noting in this respect that the RT priming effect was larger for the symmetric pairs, although it did not reach significance. Whether this is a general principle or a confound in the experimental stimuli is unclear but does suggest that asymmetrical priming pairs may be more effective for eliciting the N400.

From the pragmatic standpoint of determining the best neutral prime for ERP experiments, we suggest that it depends on the goal of the experiment. If the goal is to examine priming effects within the reaction time tradition, *BLANK* produced the pattern of results that would be expected from a neutral prime and would be the appropriate baseline condition. We suggest that *BLANK* was treated as nonsemantic and so it did not elicit semantic integration, making succeeding targets' N400 similar to related targets which require very little semantic integration effort. *BLANK* should presumably require zero integration effort (it cannot be integrated if it is nonsemantic) so it acted like related primes for the N400 measure. Furthermore, the present findings suggest that the effect of the *BLANK* prime on the N400 is a function of the proportion of trials with the prime. When the proportion of *BLANK* primes are higher than the 17% used in the previous study (Brown et al., 2000), they evoked N400s to the following targets more similar to related primes than to unrelated primes. Thus, within the RT perspective, when *BLANK* occurs on a substantial portion of the total trials, *BLANK* seems to be a better choice as a baseline than unrelated primes because it should be possible to assess inhibition effects (reduction in amplitude) in the ERPs.

From the standpoint of the psychophysiology tradition, however, the unrelated primes are better primes. In the psychophysiology tradition, the primary concern is to use the N400 as a measure of semantic processing in a broad sense, by determining whether the mind is able to distinguish between semantically congruent and incongruent stimuli. For this purpose, the primary goal is to maximize the effect size of the N400 with respect to the incongruent stimuli. Thus, the best baseline condition for this purpose is the one using the unrelated primes since it produces the largest N400s when compared to the related primes. Ultimately, of course, the goal is to merge these two research lines such that the phenomena are understood from both perspectives. If, for example, the N400 does turn out to reflect semantic integration processes then the N400 will not serve as a reliable measure of semantic processing under conditions that do not support semantic integration.

Regarding the RecPot, the borderline significant effect of a larger amplitude for semantically dissimilar primed targets suggests that the RecPot may be primed more by semantic similarity than associative relatedness. Given that the RecPot is thought to possibly index lexical access (with a possible top-down influence of expectancy), this may indicate a dissociation between these semantic and associative priming at the lexical level; such a finding is consistent with findings that ASA is more affected by semantic similarity than associative relatedness (Lucas, 2000; Thompson-Schill et al., 1998) although this conclusion has been challenged (Hutchison, 2003). Note also the previous report of RecPot effects in a categorization task (Martín-Loeches et al., 2001). Obviously further study of these issues is required.

In summary, theoretically the results are most consistent with the N400 reflecting a semantic integration process that does not distinguish between associative relatedness and semantic similarity. Pragmatically, N400 ERP studies designed should use unrelated primes if the goal is to maximize the N400 effect and should use *BLANK* if the goal is to have a truly neutral prime, but only when the proportion of the neutral primes is at least 33%. It also appears that asymmetric primes may serve better than symmetric primes when trying to examine N400 effects.

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