N400 Differences Between Associative and Semantically Primed Word Pairs

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**Abstract**

The N400 waveform carries new insight into the nature of linguistic processing and may shed light into the automaticity of priming word relationships. In this experiment, we investigated semantic and associative word pairs in classic lexical decision and letter search tasks to examine their differences in cognitive processing.

*Keywords*: association, semantics, priming, N400, EEG, lexical decision, letter search

N400 Differences Between Associative and Semantically Primed Word Pairs

Semantic priming is faster processing of a word following presentation of a word related in meaning (Lucas, 2000). An example of this would be if a person were reading about a YACHT race, the word BOAT is easier to process due to the related meanings having already been activated in semantic memory. Semantic priming is believed to be caused by two processes, an automatic process and a controlled process.

The automatic model proposes that related words are linked in the brain due to similarities (Collins & Loftus, 1975) and are activated without conscious control due to automatic spreading activation (ASA) within related cognitive networks. These networks were expanded on by Stolz and Besner (1996) as moving upwards from a word level through to the semantic level. Semantic priming, therefore, is when activation from the semantic storage level speeds the recognition of a second concept at the word level. The overlap of the second word’s semantic relatedness makes word recognition easier because it, in essence, has already been processed.

The controlled-process model proposes that people actively use cognitive strategies to connect related words together. One model of this is expectancy generation, in which people consciously attempt to predict the words and ideas that will appear next, especially in sentences (Hutchinson, 2003). Another model for controlled processing is post lexical matching, in which people delay processing of a secondary word until it can be compared to the previous word for evaluation. Processing for the second word is facilitated by a related prime word, whereas it is delayed in the case of an unrelated word (Neely, 1991).

To differentiate between controlled, automatic, and combined processes, researchers have developed methods to limit the capabilities of the controlled processes. Traditional priming studies involve pairs of a first “prime” word to facilitate the processing of a second word, or “target”. These experiments are usually lexical decision tasks, requiring participants to identify presented symbols as words or nonwords. These words are presented in a manner in which an initial prime word is presented, before the non-word judgment. This word is followed by a judgment of a string of letters that could potentially be a semantically associated word, an associatively related word, or a nonword. This design is structured to elicit word activation in the cognitive networks for the different categories of words and associations. This paradigm encourages the formation of expectancies due to the pairing format. When these words were presently recognizably as pairs, participants naturally assumed they should be related, and could potentially use cognitive strategies to process the words.

To control for the expectancy effect, the single lexical decision task was introduced. Single lexical decision tasks involve participants judging single sets of symbols as words or nonwords, eliminating the expectancy forming process (Hutchinson, 2003). Researchers still faced the problem of post lexical matching, which was addressed by masking the prime words, so they were unnamable. When primes are shown, they are overlaid with nonsense symbols, much like TV fuzz, to hide or mask the perception of that prime. This procedure allows semantic priming, but thwarts use of control mechanisms, since the word is perceptually unnamable.

Event related potentials (ERP) are able to help distinguish if semantic priming is exclusively an automatic or controlled process. ERPs measure brain activation as processes occur, with relatively good temporal resolution. The N400 is a negative waveform occurring 400 msec after the participant is presented with a stimulus (Brown & Hagoort, 1993). The N400 has been described as a “contextual integration process”, in which meanings of words are integrated together (Silva-Pereya, Rivera-Gaxiola, Aubert, Bosch, Galan, & Salazar, 2003). When presented with related words, there is an attenuation of the N400; meaning a more positive spike. This difference in waveforms indicates a lack of contextual integration due to word meanings already being activated by the prime word.

Brown and Hagoort (1993) tested a lexical decision task paired with masked priming. No differences were found in the N400 wave between related and unrelated words in the masked prime condition. Brown and Hagoort concluded that this indicated the N400 was a controlled process, because attenuation only occurred when words were known; this supposedly ruled out automatic processes, because the masked prime condition only allowed automatic processes to take place. Masked priming did not allow the participants to consciously name the prime words they had seen, so they were not able to purposefully employ conscious cognitive strategies in processing these words.

Deacon, Heweitt, Yang, and Nagata (2000) found problems with the setup of Brown and Hagoort’s (1993) study. They postulated that Brown and Hagoort’s study had too long of a stimulus onset time, thus eliminating the early, quick automatic processes. Their study replicated that of Brown and Hagoort, but with shorter stimulus onset asynchronies (SOAs). SOAs are the time interval between the prime word presentation and the target word appearance. Short SOAs are thought to only allow for automatic processing because the controlled, attention based processing has not had time to occur. Their study showed the masked primes long enough to enhance priming, while remaining imperceptible. Due to their modifications to the study, Deacon et al found equal attenuation for the masked and unmasked primes. This result would indicate that ASA was taking place, as the masked prime condition did not allow controlled processes to take place.

Kiefer (2003) set about to determine if partial information was obtainable from a masked prime for use in making controlled process decisions about target words. In his experiments, judgments requiring information pulled from masked primes for lexical decision tasks and feature analysis were accurate only around the same level as chance guessing, eliminating the chance for controlled processes in the masked event. This result indicates that N400 modulation is probably an automatic processing in the form of ASA.

Letter search is another method used to eliminate semantic priming effects in lexical decision tasks (LDTs). A letter search task is a process in which participants must identify whether or not a letter was present in the prime word. This task eliminates semantic priming, but not in repeated word priming (Friedrich, Henik &, Tzelgov, 1991). Stolz and Besner (1999) stipulate that this finding indicates the prime word is processed at a lexical, but not semantic level, consequently making semantic activation (SA) not automatic. In opposition to this, Mari-Beffa et al. (2005) found ERP evidence for semantic processing of the prime word during letter search tasks with the attenuation of the N400.

The next step in EEG research focused on the relatedness of words and how that relatedness affects N400 attenuation. Rolke, Heil, Streb, and Hennighausen (2001) used an attention blink rapid serial visual presentation (RSVP) paradigm, which presented words in rapid succession, causing certain words to be missed, or “blinked“. The words used in this study were identified as having a strong or weak relation, or being unrelated. Strongly related words were identified as being related by the participants, and had the strongest N400 attenuation; weakly related words were sporadically identified as being related by the participants, but showed a slight attenuation of the N400 waveform; and unrelated words were not identified as related, and showed no attenuation. This research illustrates a linear relationship between prime-target strength and N400 modulation.

A linear relationship between prime-target strength and N400 modulation was also found by Kreher, Holcomb, and Kuperberg (2006). Their experiment showed strong N400 attenuation for directly related words, moderate attenuation for indirectly related words, and no attenuation for non-related words. Their study found specifically that with indirectly related words, or words mediated by a third-party word, such as LION and STRIPES (TIGER) were not identified as related by participants, but showed a moderate N400 attenuation. This finding further supports ASA of semantic information.

As previous studies have aimed at discerning the level of relatedness between the prime and target words, the next step in this line of research would be to investigate the effect, if any, of the type of relatedness shared between the prime and target words. Words can be related semantically or associatively. Associative word pairs are words that are linked in one’s memory by contextual relationships, such as BASKET and PICNIC (Nelson, McEvoy &, Schreiber, 2004). Associative words are linked due to the language a person uses and the culture they are a part of. Using words together contextually forges associative relationships in the brain, such as the words ALIEN and PREDATOR, which would be associatively linked for most Americans due to the movies and popular culture. Semantic word pairs are those linked by their shared features, such as WASP and BEE.

Associative and semantic relationships between words are experimentally definable by the use of normed databases. Maki, McKinley, and Thompson (2004) took the online dictionary, WordNet, and using methods by Jiang and Conrath (1997) and software by Patwardhan and Pederson (2003) created databases of words displaying the semantic distance between individual words. This database displays the relatedness between two words by measuring how sematically close words appear in hierarchy, or the JCN. JCN measures the word pairs' informational distance from one another, or their semantic similarities. Therefore a low JCN score demonstrates a close semantic relationship.

Another useful database, created by Nelson, McEvoy, and Schreiber (2004), is centered on the associative relationships between words. These relationships were measured using extensive norming via a large population of people from many different backgrounds providing feedback on words associated with other words in their memory. Participants were given cue words and asked to write the first meaningfully related or associated word that came to mind. These responses were asked of and averaged over many participants. This method creates the forward strength (FSG) or the probability that a prime word will elicit the target word, representing their level of association. This method allows for the greatest diversity in participants’ previous life experiences, which prevents the database from being culturally or regionally biased towards one group or another.

The current study seeks to discover if there are significant differences between N400 activation in the brain when presented with semantic-only, associative-only, and unrelated word pairs. Further knowledge of the role different types of word associations play in the N400 waveform will facilitate future research in priming and ERP data. If differences are found in specific types of word relations, the study of cognitive language comprehension will shift towards understanding further these specific differences.

These factors will be studied by presenting participants with a lexical decision task involving a mixed progression of semantically, associatively, and unrelated words. The N400 modulation will be observed in each of these, and any differences noted. It is expected that the N400 modulation will vary from the different types of word relation, as they are organized differently in the brain’s cognitive schemas.

Method

*Participants.*

Twenty undergraduate students were recruited from the University of Mississippi (13 women and 7 men) volunteered to participate. All participants were English speakers. Volunteers received no incentive for participation. The experiment was carried out with the permission of the University of Mississippi Institutional Review Board, and all participants signed the corresponding consent forms. One participant's data was corrupted and could not be used, and another participant was excluded for poor task performance, leaving eighteen participants (12 women and 6 men).

*Apparatus.*

The system used was a 32 Channel EEG Cap connected to a NuAmps monopolar digital amplifier, which was connected to a computer running SCAN 4.5 software to record the data. This SCAN software is capable of handling the digital data captured by the NuAmps amplifier. STIM2 was used to coordinate the timing issues associated with Windows XP and collecting EEG data on a separate computer. STIM2 also serves as the software base for programming and operating experiments of this nature. The sensors in the EEG cap are sponges injected with 130 ml of electrically conductive solution (non-toxic and non-irritating). Also, to protect the participants and equipment, a surge protector was used at all times during data acquisition. The sensors record electrical activity just below the scalp, displaying brain activation. This data was amplified by the NuAmps hardware, and processed and recorded by the SCAN software

*Materials.*

This experiment consisted of 360 word pairs separated into pairs in which the target words were unrelated to the prime (60), semantically associated to the prime (60), associatively related to the prime (60), or were nonwords (60). Of the 360 pairs, 180 involved a lexical decision task, and 180 involved a letter search task. The ratio of yes/no correct answers for words and non-words in the lexical decision task was 2:1 and 1:1 yes/no decisions in the letter search task.

The stimuli were selected from the Nelson et al. (2004) associative word norms, and Maki et al. (2004) semantic word norms. The associative word pairs were chosen using the criteria that they were highly associatively related, having an FSG score greater than .5; with little or no semantic similarities, determined by having a JCN score of greater than 20. An example of this would be the words DAIRY and COW. The semantic word pairs were chosen using the criteria that they had a high semantic relatedness shown in a JCN of 3 or less; and were not associatively related, having an FSG of less than .01. INN and LODGE are an example of this type of relationship. The unrelated words were chosen so that they had no similarities between the paired words on any scale, such as BLENDER and COMPASS. For non-word pairs, the target word had a letter changed so that it was no longer a real word, but the structure was left intact to require that the participant process the word cognitively. These words were entered into a program written in the Gentask (Generalized Task Editor) function of the Stim2 software.

*Procedure.*

Testing occurred in one session consisting of six blocks of acquired data, broken up by brief rest periods. These recordings were later processed to extract the N400 waveform data.

A NuAmps monopolar digital amplifier headpiece was used to detect EEG patterns occurring just below the scalp. This device was hooked to a computer running both the STIM2 and SCAN software packages capable of interpreting and encoding EEG data. Each participant signed a consent form prior to the experiment. Before each participant was measured, the system was configured to the correct settings and the hardware prepared. This setup consisted of inserting sensor sponges into the appropriate slots of the EEG cap, and securing the cap to the participant’s head with a Velcro chinstrap. Next two ground sensors (baseline scalp electroconductivity without underlying brain activity) were placed on the right and left mastoid bones, or the slightly protruding bones just behind each ear. With the cap and sensors in place, a non-toxic, non-irritating electrically conductive solution was applied to the sensors with an automatic pipette. Once the participant was fully prepared, the impedance value of the signal received from their scalp was measured to ensure accurate readings. In the event of too much impedance (not enough electrical conductivity), manual measures were taken to remedy the problem: applying pressure to expand the sensor sponges, pressure to the scalp to complete the circuit, more solution added to increase conductivity, etc. Once proper operating conditions were reached, the participants were asked to blink their eyes rapidly a few times to establish a base for determining eye blink artifacts in the data. Once these baselines were acquired the experiment began.

The lexical decision involved the participants observing a word onscreen and deciding whether or not it was a word or non-word (such as TORTOISE and WERM) using pre-determined button presses. The letter search task involved the participants observing a word onscreen and deciding whether it had repeated letter (like the repeated letters in DOCTOR as opposed to no repeated letters in NURSE) using pre-determined button presses. The word would be presented onscreen, and would stay there until the participant pressed either “1” for yes (real word/repeated letters), or “9” for no (fake word/no repeated letters).

Participants were first given instructions on how to perform the lexical decision task, followed by 15 practice trials. Next, they were given instructions on how to judge the letter search task, followed by 15 practice trials. Participants were then given a practice session with both letter search and lexical decision trials mixed together. Trials were color coded for the type of decision participants had to complete (i.e. letter search was green, while lexical decision was red). The experiment made use of 6 sets of 60 randomly assigned word pairs for a total of 360 trials. These trials were presented in Arial 19 point font, and the inter-trial interval was set to five seconds to allow complete recording of the N400 waveform.

Results

*EEG Data*

*N400 Waveform Analysis.* The data were cleared of artifact data using EEGLAB, an open source MATLAB tool for processing electrophysiological data. The program automatically scanned for and removed muscular artifacts caused by eye blinks. Next, the datasets were visually inspected and any remaining corrupted sections were removed manually. Ninety percent of the data was retained across all trials and stimulus types after muscular artifact data were removed. Finally, data were combined by task and stimulus type exclusively for the second word in each pair.

*Lexical Decision Task.* Five sites were chosen to examine priming for non-words, associative and semantic word pairs based on a survey of the literature. FZ, FCZ, CZ, CPZ, and CZ were used from the midline. OZ was excluded due to equipment problems. After each set was processed as described in the data processing section, differences from normal processing were calculated by subtracting unrelated word pair averages from each stimuli type. These stimuli were then tested with a single sample t-test comparing each processing difference from zero. The following hypotheses were expected:

* Non-word pairs will have significantly negative values because there will be a need to search the lexicon before a non-word decision can be made.
* Semantic word pairs will have significantly positive values because priming will decrease the need to search the mental lexicon.
* Associative word pairs may have significantly different values from unrelated word pairs, but a direction is not predicted. More positive values would indicate priming in the same mental lexicon as semantics, while more negative values would indicate a separation from the theorized semantic network and need to search the mental lexicon.

The predicted effects appear to occur in the crown area in CZ and CPZ. Non-words are significantly more negative than unrelated word pairs, and semantic word pairs had significantly more positive N400 values. Associative word pairs were more positive than unrelated word pairs, which indicated some priming at the neural level, but were only significant at *p*<.10 levels. Refer to Table 1 and Figure 1.

*Letter Search Task.* The same five sites were analyzed as the lexical decision task. Again, data were subtracted from unrelated word pairs averages and then compared against zero with single sample t-tests.

The following hypotheses were expected:

* Non-word pairs will have significantly negative values because the participants will be confounded by the novelty of the non-words and lack of reference within their cognitive repertoire.
* Semantic and associative word pairs may have significantly positive values because priming will decrease the need to search the mental lexicon; however some research literature indicates that letter search tasks eliminate semantic priming. Positive values would indicate a priming effect, which is evidence for semantic activation (SA) spreading automatically within the mental lexicon. More negative values would indicate processing at the lexical, but not semantic, level; which would suggest a lack of automatic SA.

The predicted effects for non-word pairs appear to occur in the crown area in CP and CPZ. Non-words are significantly more negative than unrelated word pairs. The effects for semantic and associative word pairs are more complicated. The values obtained for these have a very low significance values. This finding may be due to the position put forth by Friedrich et al. (1991) that letter search tasks eliminate semantic priming. Another possibility is a lack of sufficient participants to qualify for adequate power, as can be inferred from the minor evidence of semantic priming. Power analyses were run on the effect sizes for semantic and associative sites that showed some evidence of priming (FZ, FCZ, PZ). These analyses suggested that anywhere from 75 to 130 people would be needed to show significant priming effects for measurement sites, which was not practical for the current study. Refer to Table 2 and Figure 2.

*Task Performance.*

Task data were analyzed for correctness in the lexical decision and letter search tasks individually. See Table 3 for average proportions by condition and stimulus type. Participants were eliminated from conditions in which they performed 3 standard deviations below the mean. Error rates were tested with a 2X4 (task by stimulus) repeated measures ANOVA. Overall, performance in the letter search task (*M*=.97, *SD*=.02) was equal to the lexical decision task (*M*=.97, *SD*=.02), *F*(1,13)=1.54, *p*=.24. The interaction between task type and stimuli was also not significant *F*(3,39)=1.74, *p*=.18. The different types of stimuli showed a difference in performance, *F*(3,39)=9.85, *p*<.001, between non-words (*M*=.94, *SD*=.03, *t*(13)=-3.02, *p*=.01) and unrelated word pairs (*M*=.97, *SD*=.01); non-words and associative word pairs (*M*=.98, *SD*=.01, *t*(14)=-5.55, *p*<.001); and non-words and semantic word pairs (*M*=.98, *SD*=.02, *t*(14)=-3.45, *p*=.01). The other stimuli comparisons were all non-significant.

*Reaction Time Performance.*

Reaction time data were excluded for incorrect trials and participants with very low percent correct rates (as described above). Average reaction times were calculated for each task type and stimulus. Next, associative, semantic, and non-word conditions were subtracted from their matching unrelated word conditions. Figure 3 depicts the priming differences for each condition. Each stimulus difference was analyzed with a single sample t-test against zero to examine for priming.

*Letter search task.* All conditions in the letter search task were significantly primed over unrelated words pairs, while non-words were significantly slower than unrelated word pairs. As shown in Figure 3, associative words pairs were almost 200 msecs faster than unrelated word pairs, *t*(16) = 3.54, *p* < .01, and semantic word pairs were also around 200 msecs faster unrelated word pairs, *t*(15) = 6.38, *p*<.01. Non-words were significantly slower than unrelated word pairs by about 200 msecs, *t*(14) = -5.18, *p*<.01. Given previous research, it was slightly surprising that semantic word pairs would be primed during a letter search task, however, the current word list has also shown this effect in Buchanan (2010). This effect does not match results found from the N400 waveform, which is explored in the discussion.

*Lexical decision task.* Priming was found for associative word pairs in the lexical decision task, a marginal effect semantic word pairs, and slowing for non-word pairs when compared to unrelated word pairs. Associations were about 120 msecs faster than unrelated word pairs, *t*(16) = 2.99, *p*<.01. Semantic word pairs were primed approximately 85 msecs over unrelated pairs, which approached significance, *t*(16) = 1.93, *p*=.07. Semantic priming was expected in the lexical decision task, and this effect was most likely due to our small sample size. Non-words were again 200 msecs slower than unrelated word pairs, *t*(14) = -5.24, *p*<.01.

Discussion

These experiments were designed to explore the differences between N400 activation in the brain following presentation of semantic-only, associative-only, and unrelated word pairs to distinguish any divergences in the cognitive processing of semantically related and associatively related words. N400 data indicated that semantically related word pairs are possibly primed during a lexical decision task. The letter search diminished and possibly eliminated priming on both associative and semantically related word pairs at the automatic level. Reaction time data presented a different picture of priming, however. Associative word pairs were significantly primed in both a letter search and lexical decision task, while semantic data was primed in a letter search task, but there was diminished priming in the lexical decision task. These results may indicate that automatic processing of primes was reduced or eliminated in the N400 data, while controlled processing of primes speeded reaction time responses. Controlled processing of non-words was seen in N400 and reaction time data with larger negative waveforms and longer reaction times.

The current datasets agree with the postulate advanced by Collins and Loftus (1975) that related words are activated more quickly in the brain when observed in close temporal-spatial proximity to one another. The letter search task appears to have minimized ASA in the N400 data, allowing controlled processes for both semantic and associative word sets which can be observed in the reaction time data and may have been facilitated by the long SOAs used in these experiments. The N400 data for the lexical decision task does indicate ASA for semantic relationships, but the sample size in this experiment was too small to achieve significance in the reaction time data. These findings point towards processing of associative information being mostly a controlled process, while semantic information seems to be processed automatically.

A paradigm shift in the understanding of language cognition may well be in order following these findings. To date research has focused on the levels of relatedness between prime and target words, but a new objective in understanding word comprehension has been presented: the differences in the mode of processing within the brain of separate categories of words. New paths of research may now be pursued in the acquisition of knowledge regarding human comprehension.

Limitations do exist within these experiments. As previously mentioned a larger sample size would increase the power coefficient of the findings. Future studies should focus on the extent of priming in semantic word pairs during a letter search task, which is a controversial topic within the literature. An application for these types of specific knowledge may one day benefit the language classroom or persons with language processing disorders such as dyslexia via increased understanding of the electrical operations of the brain in processing various classes of words.

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Table 1.

*Mean, Standard Errors, and t-value differences from zero for the Lexical Decision Task.*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | *M* | *SE* | *t* | *p* |
| FZ |  |  |  |  |
| Non-words | -93.394 | 77.883 | -1.199 | 0.247 |
| Associative | 97.926 | 63.186 | 1.550 | 0.140 |
| Semantic | 165.288 | 111.869 | 1.478 | 0.158 |
| FCZ |  |  |  |  |
| Non-words | -81.346 | 72.095 | -1.128 | 0.275 |
| Associative | 81.757 | 48.400 | 1.689 | 0.109 |
| Semantic | 157.369 | 93.712 | 1.679 | 0.111 |
| CZ |  |  |  |  |
| Non-words | -171.506 | 68.665 | -2.498 | 0.023 |
| Associative | 117.840 | 67.121 | 1.756 | 0.097 |
| Semantic | 124.051 | 52.756 | 2.351 | 0.031 |
| CPZ |  |  |  |  |
| Non-words | -166.015 | 54.220 | -3.062 | 0.007 |
| Associative | 80.063 | 56.047 | 1.428 | 0.171 |
| Semantic | 113.651 | 51.669 | 2.200 | 0.042 |
| PZ |  |  |  |  |
| Non-words | -74.184 | 60.749 | -1.221 | 0.239 |
| Associative | 39.453 | 76.152 | 0.518 | 0.611 |
| Semantic | 143.395 | 101.600 | 1.411 | 0.176 |

*Note*. DF = 17 for all t-tests.

Table 2.

*Mean, Standard Errors, and t-value differences from zero for the Letter Search Task.*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | *M* | *SE* | *t* | *p* |
| FZ |  |  |  |  |
| Non-words | -0.891 | 25.840 | -0.034 | 0.973 |
| Associative | -7.768 | 40.831 | -0.190 | 0.851 |
| Semantic | 52.965 | 50.094 | 1.057 | 0.305 |
| FCZ |  |  |  |  |
| Non-words | -28.225 | 24.210 | -1.166 | 0.260 |
| Associative | -2.566 | 37.069 | -0.069 | 0.946 |
| Semantic | 54.958 | 49.622 | 1.108 | 0.283 |
| CZ |  |  |  |  |
| Non-words | -85.508 | 44.338 | -1.929 | 0.071 |
| Associative | -8.477 | 39.570 | -0.214 | 0.833 |
| Semantic | -8.477 | 39.570 | -0.214 | 0.833 |
| CPZ |  |  |  |  |
| Non-words | -107.266 | 42.753 | -2.509 | 0.023 |
| Associative | 7.250 | 48.728 | 0.149 | 0.883 |
| Semantic | -36.598 | 43.525 | -0.841 | 0.412 |
| PZ |  |  |  |  |
| Non-words | -17.802 | 23.229 | -0.766 | 0.454 |
| Associative | 69.862 | 64.407 | 1.085 | 0.293 |
| Semantic | 58.977 | 42.259 | 1.396 | 0.181 |

*Note*. DF = 17 for all t-tests.

Table 3.

*Descriptive Statistics for Task Performance*

|  |  |  |
| --- | --- | --- |
|  | *M* | SD |
| **Letter Search** |  |  |
| Non-Words | 0.95 | 0.02 |
| Unrelated Words | 0.97 | 0.02 |
| Associated Words | 0.97 | 0.03 |
| Semantic Words | 0.98 | 0.02 |
| **Lexical Decision task** |  |  |
| Non-Words | 0.94 | 0.05 |
| Unrelated Words | 0.98 | 0.02 |
| Associated Words | 0.99 | 0.01 |
| Semantic Words | 0.98 | 0.03 |

*Figure 1.* N400 waveform averages for the lexical decision task separated by electrode site.

*Figure 2.* N400 waveform averages for the letter search task separated by electrode site.

*Figure 3.* Priming reaction time averages for both experiments.

|  |  |
| --- | --- |
| CPZ | CZ |
| FCZ | FZ |
| PZ |  |

*Figure 1.*

|  |  |
| --- | --- |
| CPZ | CZ |
| FCZ | FZ |
| PZ |  |

*Figure 2.*

*Figure 3*