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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 word is presented, also known as the prime. This word is followed by 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 N400 waveforms for the different categories of words and associations. This encouraged the formation of expectancies due to the pairing format. That is to say, 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 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 ms 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 (Juan Silva-Pereya et al. 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) set up 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 fault 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 would indicate that ASA was taking place, as the masked prime condition did not allow controlled processes to take place.

Kiefer (2002) 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 experiment, judgments requiring information pulled from masked primes 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 or not. This task eliminates semantic priming in LDT’s, but not in repeated word priming (Friedrich et al. 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 research focused on relatedness of words and how it 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 relation 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. 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. (Nelson, McEvoy &, Schreiber, 2004)

Associative and semantic relationships between words are something we can measure using existing methods and 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 associative strength and semantic distance between individual words. This database displayed the separable differences between semantic and associated relatedness, as well as forming a common database of semantic distances (levels of semantic relatedness). These distances were measured using the terms Forward Strength (FSG) and the Jiang and Conrath measure of semantic distance (JCN). FSG refers to the probability that a prime word will elicit the target word, representing their level of association. JCN measures the word pairs' informational distance from one another, or their semantic similarities. Therefore, a high FSG score shows strong associative relation, whereas 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 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, leaving eighteen participants (13 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 was 2:1.

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, as well as being the software in which the lexical decision task was programmed and run. 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 lexical decision task 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 or not it had repeated letter or not (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), or “2” for no (fake word). The experiment made use of 6 sets of 60 randomly assigned word pairs for a total of 360 trials, 180 of which were lexical decision tasks. These trials were presented in Arial 19 point font, and the inter-trial interval was set to five seconds to allow for complete recording of the N400 waveform.

Results

*N400 Waveform Analysis.*

*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 positive 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 negative 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.

*Letter Search Task.* THIS PART NEEDS TO BE WRITTEN.

*Task Performance.*

Task data were analyzed for correctness in the lexical decision and letter search tasks individually. See Table XX 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 XX 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 XX, 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 msec faster unrelated word pairs, *t*(15) = 6.38, *p*<.01. Non-words were significantly slower than unrelated word pairs by about 200 msec, *t*(14) = -5.18, *p*<.01. Given previous research, it is 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).

*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 msec faster than unrelated word pairs, *t*(16) = 2.99, *p*<.01. Semantic word pairs were primed approximately 85 msec 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 msec slower than unrelated word pairs, *t*(14) = -5.24, *p*<.01.

Discussion

Brief review of what we found

How does that related to previous studies on priming in the brain?

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Table XX. *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 XX. *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 |