

UNITIZATION AND SEMANTIC INFORMATION

BY

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THESIS

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## **Abstract**

Recognition memory can be supported by two distinct processes: recollection of an item and its related contextual information, and a general sense of familiarity for the item. Performance on recollection-based associative memory tests can be supported by familiarity when stimuli are “unitized”, or encoded as a single representation. Unitization generally produces greater positivity in mid-frontal (FN400) potentials during recognition in ERP studies, also suggesting recruitment of familiarity. However, several experimental manipulations can lead to FN400 modulation, as well as differences in estimates of familiarity; thus, it is unclear what mechanism underlies this increase in familiarity-based retrieval. One proposal is that unitization may modulate the semantic relatedness between the two items; thus, unitization of stimuli with little semantic content would lead to reduced effects. To assess this claim, two ERP experiments were performed with semantically sparse stimuli (abstract images and pseudowords), in which participants either unitized stimuli or encoded them separately, and were later tested for their memory for the items. Results suggest that unitization may still be possible with semantically sparse stimuli, but that the neural correlates of unitization (namely, the FN400) are affected by this manipulation.

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## **Chapter I: Introduction**

Recognition memory refers to our ability to discriminate between novel stimuli and those we have encountered previously. According to dual-process theories of recognition, this ability is supported by two cognitive processes: recollection, in which an item and its related contextual information is retrieved, and familiarity, in which an item is identified by a general sense or feeling of oldness (Yonelinas, 2002). In tests of single items, such as words or pictures, recognition can be supported by both recollection and familiarity. However, when more than one piece of information must be remembered, such as pairs of stimuli in an associative memory task or an item and its contextual “source” in a source memory task, then recognition will be reliant on recollection alone (McElree et al., 1999; Yonelinas, 1997). In an associative memory task, each individual item is essentially equally familiar; only by retrieving additional contextual information regarding the relationships or pairings between items can one discriminate between old and new pairs. Similarly, a source memory judgment requires retrieval of contextual details related to a particular item, thus resulting in recollection-based memory rather than reliance on familiarity.

Recent studies, however, have shown that familiarity can contribute to associative and source memory tasks under certain conditions; namely, if the to-be-remembered stimuli are encoded in a “unitized” fashion (Diana et al., 2008; Graf & Schacter, 1989; Quamme et al., 2007; Yonelinas et al., 1999). Unitization refers to representing previously distinct items as a single unit (Graf & Schacter, 1989), which occurs when some structure or coherence between separate items is perceived and encoded. For example, generating a meaningful sentence or definition for a pair of unrelated words is likely to establish a unitized representation of these two words. This unified representation of the two words can then be supported by familiarity, as well

as recollection, resulting in potentially greater memory. Conversely, simply reading the words without providing any additional definition would likely result in separate representations for each stimulus.

In one of the earliest studies providing evidence for the existence of unitization (Graf & Schacter, 1985), participants were given pairs of related words (e.g. ripe apple) and unrelated words (e.g. kindly stick) to study in two conditions. In one condition, participants constructed a sentence that related the two words together in a meaningful manner, thus resulting in a unitized representation. In the other condition, participants were required to compare the number of vowels in each of the words, leading to separate encoding of the items. Sentence encoding produced memory benefits on an implicit memory task (word stem completion) as well as an explicit memory task (cued recall), suggesting that unitization leads to benefits in memory. However, to assess whether this effect was simply due to greater elaboration, the authors investigated memory performance when different encoding strategies were used (Schacter & Graf, 1986). In general, any study method that promotes unitization will produce equal benefits to implicit memory, while more elaborate unitization procedures (e.g. producing a linking sentence vs. producing a single linking word) will produce greater explicit memory benefits. Thus, unitization may produce a combined representation that is easily accessed by the memory system, leading to implicit benefits, and that may be elaborated upon with greater detail, leading to explicit benefits.

More modern behavioral studies of these effects have generally employed receiver operating characteristics (ROCs) to separate the contributions of recollection and familiarity under the dual-process framework. With this method, separate parameters can be derived to estimate the contributions of recollection and familiarity to recognition performance by fitting a

signal detection model to confidence scale judgments. In this dual process model, recollection is considered a threshold process, in which contextual information is retrieved or is not, and thus supports high confidence judgments. Conversely, familiarity is conceptualized as a signal detection process with a Gaussian distribution, which contributes to a wider range of confidence responses (Yonelinas, 1994). Based on this model, a shift in the intercept of the ROC curve (the highest level of confidence) reflects a change in recollection, whereas a change in the degree of curvilinearity of the line reflects a difference in the contribution of familiarity. More specifically, recollection is measured as a probability (the probability of recollection), whereas familiarity is measured in terms of sensitivity or  $d'$ , with higher values reflecting a more easily detected signal or greater familiarity.

Typically, curvilinear ROCs with a non-zero intercept are found for item memory tests, representing contributions of both recollection and familiarity, whereas linear ROCs are found for associative memory tests, indicating the sole contribution of recollection (Yonelinas, 1994, 1997; but see Wixted, 2007, and Parks & Yonelinas, 2007). However, unitizing stimuli during encoding produces more curvilinear ROCs in associative memory tasks, reflecting a greater contribution of familiarity. This was first reported in memory for upright vs. inverted faces (Yonelinas et al., 1999), with more curvilinear ROCs for upright faces. Face recognition is considered to be a process by which facial features are encoded holistically and in a Gestalt-like manner, whereas encoding of inverted faces becomes a more “piecemeal” encoding process (Searcy & Batlett, 1996); thus, upright faces can be thought of as being unitized, whereas inverted faces are not. The finding of increased familiarity following unitization has been replicated for images and their colored backgrounds in a source memory test (Diana et al., 2008), consistent with the idea that familiarity can support associative representations if they are

unitized. This effect has been reproduced in older adults as well (Bastin et al., 2013), with unitization leading to alleviations in age-related decrements in associative memory, suggesting a potential translational application of unitization.

Additional evidence for unitization comes from neuropsychological, neuroimaging, and electrophysiological studies. Functional magnetic resonance imaging (fMRI) studies have indicated that the perirhinal cortex plays a critical role in unitization (Haskins et al., 2008; Staresina & Davachi, 2010), as unitization demands at encoding, as well as at retrieval (Ford et al., 2010) tend to produce greater activity in perirhinal cortex that correlates with increases in measures of familiarity. Additionally, individuals with specific damage to hippocampal regions through hypoxia exhibit impaired recollection but spared familiarity, and show greater contributions of familiarity for unitized stimuli, whereas individuals with more widespread medial temporal lobe damage show no unitization effects (Giovanello et al., 2006; Quamme et al., 2007). Results from these lesion studies corroborate with results from fMRI studies to suggest that unitization is not reliant on the hippocampus. This idea fits with previous findings showing that perirhinal cortex supports encoding of specific items, not associative information, and may be responsible for feelings of familiarity as well (Brown et al., 2010; Ranganath et al., 2004). Additionally, similar findings have been reported in studies with rats (Kent & Brown, 2012), in that intact perirhinal cortex functioning seems necessary for fusing stimuli together in conditioning experiments. One recent electrophysiological study with primates suggests that certain neurons in the perirhinal cortex respond very similarly to paired associate stimuli, but discriminated between pairs of items, suggesting that these neurons may represent pairs of items as single unitized items (Fujimichi et al., 2010). Thus, pairs of stimuli that are unitized may be represented as a single item, and consequently supported by perirhinal-mediated recognition,

while recognition of separately encoded pairs will be more reliant on hippocampal processes, such as recollection.

Electrophysiological studies have also investigated unitization effects (Bader et al., 2010; Diana et al., 2011; Rhodes & Donaldson, 2007, 2008). In general, unitization seems to modulate activity at frontally-located electrode sites; in one study (Diana et al., 2011), unitization led to greater behavioral measures of familiarity, as well as higher amplitudes at frontal electrodes in the 750-1000 ms time window. Other studies employing associative memory tasks have examined previously identified putative event related potential (ERP) correlates of recollection and familiarity; namely, an early (300-500 ms) mid-frontal effect related to familiarity, and a later (400-800 ms) left parietal component (LPC) related to recollection (Rugg & Curran, 2007). The early mid-frontal effect, also called the “FN400”, is modulated by unitization encoding demands (Bader et al., 2010; Rhodes & Donaldson, 2007, 2008); greater positivities, and thus reduced amplitudes, are observed within this time window when retrieving unitized pairs of stimuli than when retrieving non-unitized stimuli. The late parietal component, on the other hand, does not differ between conditions, suggesting no difference in recollection. Thus, unitization appears to allow for the contribution of familiarity, and accordingly the putative ERP correlate of familiarity is modulated by unitization demands, whereas neural measures of recollection remain unchanged by unitization.

However, despite the numerous studies linking unitization to familiarity-based recognition and the FN400, the current research does not adequately describe the specific underlying mechanism of unitization’s benefits to memory. This is due to several reasons. Firstly, there has been little consistency among studies of unitization in terms of tasks utilized to promote unitization. Some studies have utilized a “compound” condition, in which an unrelated



pair of words is combined to create a compound word with a unique definition (Quamme et al., 2007; Haskins et al., 2008). This is compared to a “sentence” condition, in which the unrelated words are used to complete an incomplete sentence, with the idea that this condition would not lead to unitized pairs. However, based on the original conceptualization of unitization (Graf & Schacter, 1989), these conditions may not differ in their resulting unitization at all, but only in the level of grouping of stimuli. In this original framework, unitization is a more rapid binding of stimuli that occurs in any situation where the stimuli are combined in some way, whereas grouping refers to the additional elaboration upon the unitized pair. Since the sentence serves as a structure for connecting the two stimuli, the stimuli may have been unitized in this condition as well. Other studies have simply compared compound words to unrelated pairs (Giovanello et al., 2006), with the idea that compound words are unitized while unrelated words are not. Without any further instructions, subjects may have employed strategies that might lead to unitization of the separate stimuli. Others still have compared related and unrelated words, and had participants either imagine the words interacting in some way, or create a separate mental image for each word (Rhodes & Donaldson, 2008). Finally, some studies have not used word stimuli at all, but have instead utilized a source memory paradigm in which an image must either be unitized with a background color by having the participant determine if a colored version of the object is plausible in real life (Diana et al., 2011; Staresina & Davachi, 2010). Ultimately, there may be important differences in resulting unitization effects between types of stimuli, as well as the type of encoding condition that is used. Unfortunately, no studies to date have employed implicit memory tests to understand how these different tasks affect implicit memory performance, or have compared various encoding strategies to assess differences in resulting effects.

Another important consideration in the literature is the connection between unitization, familiarity, and the purported neural correlates of familiarity. Several studies within this literature have tied unitization to familiarity, as well as the FN400; however, the validity of the link between familiarity and the FN400 is currently hotly debated. Specifically, several researchers contend that the FN400 is not in any way distinct from the N400, an ERP component that reflects early conceptual and semantic processing of information, including linguistic and pictorial stimuli (Kutas & Federmeier, 2011). Although FN400 components appear to exhibit a distinct topography from N400 potentials, it is difficult to interpret topographic differences, as a completely separate and distinct component from the N400 may overlap in the same time frame and thus alter the overall summed resulting ERP. Additionally, recent research has used carefully constructed experimental paradigms to show that “FN400” modulations from familiarity may in fact be representative of conceptual priming (Paller et al., 2007; Voss & Federmeier, 2011; Voss & Paller, 2007; Voss et al., 2010), a type of implicit memory in which prior conceptual processing of a stimulus facilitates future processing (e.g. *cake* could prime processing of *pie*, as they are in a similar category), leading to faster reaction times in identification tasks and generally superior performance on implicit memory tasks for primed items (Roediger, 1990). This implicit type of memory could affect performance or “contaminate” an episodic memory task such as a recognition task, leading to differences that aren’t necessarily due to changes in “familiarity”.

As an example, one such study (Voss & Paller, 2007) had participants study a series of abstract, novel shapes (squiggles), and give subjective ratings of meaningfulness for each stimulus. Results showed that FN400 potentials varied systematically with ratings of meaningfulness, despite familiarity being held constant. A later study (Voss et al., 2010)

additionally reported that FN400 amplitude was correlated with the magnitude of conceptual priming for squiggles, with higher conceptual priming for more meaningful stimuli. Thus, the purported ERP component of familiarity may in fact represent conceptual processing of information, and conceptual priming may lead to feelings of familiarity. In agreement with this idea, Wang & Yonelinas (2012) employed both an explicit and implicit memory test, and found correlations between conceptual priming and familiarity, but not recollection. Additionally, fMRI studies have shown that perirhinal cortex plays a critical role in conceptual priming (Heusser et al., 2013; O’Kane et al., 2005; Wang et al., 2010), the same neural structure involved in familiarity. This preponderance of evidence points to a large overlap between these two processes, suggesting that conceptual priming may in part underlie familiarity.

To further complicate matters, a recent study (Guillaume & Tiberghien, 2012) examined the effect of intention on neural correlates of memory. In this study, participants studied a series of faces, and later were given a recognition test including faces they had seen before (“old”), faces they had seen but now with a different facial expression (“different”), and new faces (“new”). Importantly, two different tests were given: an inclusion test, in which old and different faces should both be considered old, and an exclusion test, in which different faces should be considered as new. The results showed that FN400 potentials, as well as LPC potentials, were modulated differently depending on the demands of the test and intention on the part of the participant, giving rise to the idea that FN400 potentials may not simply represent one single process or another, but perhaps a combination of processes that are called upon based on task demands. This is critically important, as several studies of unitization have lacked any behavioral measures of familiarity, and have instead claimed that modulations of FN400 potentials are an adequate index of changes in familiarity. However, it is clear that this reverse

inference is questionable and potentially fallacious, as there are several methods and procedures that can lead to FN400 manipulations; additionally, this neural component may in fact reflect conceptual priming. It is possible that many of the FN400 amplitude differences seen in this literature reflect some sort of conceptual processing of stimuli that differs due to the varying task demands; this point is particularly important given the inconsistency in task demands across unitization studies. Ultimately, the familiarity account has proved inadequate in describing the mechanism of unitization, and it remains unclear as to the specific mechanism underlying unitization benefits.

A potential mechanism that unitization may act through is a modulation of semantic information. Semantic information or semantic memory is somewhat difficult to define, but is broadly construed as the processes and representations that relate to our knowledge of the meanings of items, objects, and stimuli in our environment, as well as the understanding of the relationships between those items (Kutas & Federmeier, 2000). Access to semantic information is critically important for language processing (Antonucci & Reilly, 2008), as well as for aspects of long term memory (McKoon et al., 1985). In the memory domain, prior semantic knowledge of stimuli may facilitate processing and future remembering of items (Bransford & Johnson, 1972), as well as provide a “semantic context” from which to-be remembered information can be recalled (Moscovitch & Craik, 1976). According to one spreading network activation model of memory (ACT), newly learned information may be integrated with prior semantic knowledge that is organized within a semantic network, where activation spreads across nodes (Anderson, 1981). Thus, information that is more closely linked or integrated may be more easily remembered.

It is possible that unitization demands lead to modulation of this semantic network. As an example, the words “knife” and “fork” are semantically related, and thus closely linked in the network, whereas the words “dog” and “fork” are not. However, by unitizing the words “dog” and “fork”, the representations or nodes of those items may become more closely linked. This would potentially lead to improvements in memory for those items, and would not require learning of new information, but simply re-adjusting of currently known information, thus obviating any dependence on hippocampal-based memory. Additionally, Tulving’s classic account of memory posits that recollection or “remembering” is dependent upon episodic memory, whereas familiarity or “knowing” is dependent on semantic memory representations (Yonelinas, 2002). This suggests that a change in familiarity following unitization is plausible within this semantic memory framework. A semantic modulation account may also potentially explain electrophysiological results, in that N400 potentials may in fact serve as an index of semantic memory retrieval (Kutas & Federmeier, 2000), and that manipulations of semantic knowledge and stimulus familiarity show similar effects on the amplitude of the N400 (Nessler et al., 2005; Nie et al., 2014). Finally, the neural substrates involved in processing semantic memory and familiarity are highly similar (Davies et al., 2004; Murray & Richmond, 2001), and individuals with hippocampal damage have preserved semantic memory and familiarity, suggesting a tentative link between these two processes (Vargha-Khadem et al., 1997). Thus, it is possible that unitization leads to a modulation of the semantic network, causing changes in familiarity measurements, N400 amplitudes, and perirhinal cortex activations.

Admittedly, the idea of a semantic network with nodes for items and connections between nodes is somewhat difficult to empirically test. Thus, it is difficult to ascertain whether unitization acts upon previously learned semantic structures or not. This paper describes two

studies that attempt to address this issue by giving participants items to study with little prior semantic knowledge. Currently, unitization studies have focused on unitization of words or pictures of everyday objects. These types of stimuli have rich semantic associations, and thus may be responsible for the memory benefits from the unitization procedure. In contrast, the abstract stimuli used in the current studies have little semantic content, and thus may minimize unitization effects. If these effects reflect semantic processing, then abstracting away semantic information should remove these effects, or at least reduce them. In contrast, if unitization selectively affects familiarity, then removing semantic information should seemingly have little effect, as familiarity for visual features will remain. To assess familiarity, subjects were given memory tests with confidence intervals, and these confidence responses were used to construct ROC curves from which dual process parameters could be estimated. Additionally, ERPs were recorded during the test phase to assess N400/FN400 and LPC components. If unitization acts upon semantic information, then changes in N400 amplitude may not be observed; however, if familiarity alone is affected, then canonical N400 effects should be observed, regardless of the lack of semantic information.

## **Chapter II: Experiment 1 – Unitization of Abstract Visual Objects**

In the first experiment reported here, participants were given a series of abstract visual images to study, and were later given an associative recognition memory test. Subjects either unitized stimuli (based on certain instructions) or encoded them separately. Importantly, the stimuli used in the experiment were designed to be abstract and meaningless, so participants would have no prior knowledge of the items that could influence their memory. Thus, if unitization is reliant on previously acquired semantic representations, then unitization effects should be reduced or absent.

### **Methods**

20 subjects (13 female) from the University of Illinois at Urbana-Champaign participated in the experiment. An additional 4 subjects were excluded from analysis due to low trial numbers after artifact rejection. All subjects were at least 18 years of age; the mean age across subjects was 22.32 (range 18-32). All subjects were right-handed, had no history of psychiatric illness, and were not taking any psychotropic medications.

All subjects participated in an associative memory experiment. The stimuli for the experiment were abstract, novel shapes (“pipe” stimuli, as the shapes were long and horizontal somewhat like a pipe) created for previous memory studies (Konkel et al., 2008). The pipes were 3-dimensional objects created with Bryce software, a 3D modeling and rendering program. Each stimulus was the same overall size; however, they varied in color, texture, and shape. Thus, each stimulus was distinct from every other stimulus in some way. These particular stimuli were especially useful for this experiment, as they were all similarly horizontal and the same size, allowing for ease in unitizing the stimuli (see Figure 1 for an example). 240 random

pairs of pipe stimuli were created for each individual subject and used in the experiment, so each participant saw different pairings during the experiment. Specific pairs were not used, as there was no expectation that the specific pairing of the stimuli would be important or have an effect on future memory. Additional random pairings were created for practice trials at the start of the experiment.

Participants were first given instructions on the experiment, which included several practice trials to make sure each participant understood the instructions, after which participants would begin the actual procedure. The experiment consisted of 24 study-test blocks, with 12 blocks of each condition: Unitize and Separate. In the Unitize condition, subjects were instructed to mentally combine the two shapes on the screen during the study phase (essentially to fuse the two shapes together at the ends), and then to give a subjective rating of how well the two shapes were together (i.e. to give a subjective rating of the pleasantness of the combined image), either well or not well. This procedure encouraged unitization of the two images. In the Separate condition, subjects were instructed to rate which of the two stimuli of the pair they preferred (i.e. which was most pleasant). This procedure encouraged separate encoding of the two images, as no structure or coherence between the two items was established. However, both items would have to be encoded to make this comparative judgment.

Within each block, subjects first studied a series of stimulus pairs and performed the necessary task for the block's condition, either Unitize or Separate. In each block, participants studied 8 unique pairs of pipes. Each pair was presented at the center of the screen for 5 seconds to allow enough time for adequate encoding. Pairs were presented with a visual gap in between them in an attempt to minimize any incidental unitization. Subjects responded to the task demands on a button box while the pair was presented on the screen. Following the stimulus



presentation was a brief ISI of 500 msec, in which a fixation cross was presented at the center of the screen. This repeated until each of the stimulus pairs had been presented. After the study session, subjects performed 30 seconds of simple arithmetic in an attempt to eliminate reliance on working memory and reduce primacy and recency effects.

Participants were then given a subsequent recognition test, containing intact pairs (previously studied pairs), rearranged pairs (previously studied stimuli in different pairings), and new pairs (never studied). Pairs were presented on the screen one at a time, and subjects were told to evaluate their memory for the pair. After 1500 msec, the word “respond” appeared under the pair to instruct participants to make their response, although subjects were told not to rush their answers due to the appearance of the word. Subjects responded with a 6-point confidence interval (sure-maybe-guess match, guess-maybe-sure non-match); the “match” phrasing was used to encourage subjects not to simply rely on familiarity or “oldness” for stimuli, but to consider whether the specific pairings matched previously studied pairings. Overall, in each of the two conditions subjects were tested on 48 intact, 48 rearranged, and 24 new pairs. Results from new pairs were combined across conditions, as familiarity was expected to be equal for new items regardless of condition.

EEG was recorded during the test phase to examine ERP components associated with memory retrieval. Recording was performed with a 64-channel ActiveTwo active electrode system from Bio-Semi, in which electrodes are positioned on a nylon cap following the international 10-20 organization system (Chatrian et al., 1988). Additional electrodes were placed on each mastoid behind the ear, as well as 4 facial electrodes, 2 around each eye, for recording eye movements and blinks. EEG was recorded using a reference-free procedure, and

continuously sampled at a rate of 512 Hz. Impedances were kept to a minimum to ensure clean recording.

Following recording, EEG data was processed and analyzed using EEGLAB and ERPLAB. Offline, the average of the average of the two mastoid channels were used for referencing, and continuous data was bandpass filtered at 0.1-30 Hz. Epochs for successful memory trials were created by taking 200 ms prior to the onset of each test pair (used for baseline correction) and 1500 ms following the onset of each test pair (the time interval between the onset of the test stimulus and the word “respond” appearing). Unsuccessful memory trials (misses and false alarms) were discarded. Next, eye movements and EOG artifacts were identified and removed using an automatic regression-based algorithm (Gratton et al., 1983). Epochs were then scanned additional for artifacts by implementing a moving window analysis in EEGLAB, in which a time window with a width of 300 ms made steps of 50 ms length that identified any amplitudes 100 uV or more from the baseline; these trials were removed from analysis. An additional visual scan for artifacts was also performed. Subjects who had less than 15 trials in any condition of interest were excluded from the data. Average trial counts across subjects for each condition were: Unitize Intact Correct (31), Unitize Rearranged Correct (30), Separate Intact Correct (33), Separate Rearranged Correct (29), and New Correct (41). Thus, a sufficient number of trials were collected to ensure valid results were obtained. These epoched trials were then averaged for each subject to create average ERPs for each condition, and these average ERPs were also averaged for grand average ERP waveforms.

## Results

Behavioral results from the memory test phase are summarized in Tables 1 and 2 below. Performance in each condition was above chance (50% accuracy). Broken down by confidence, participants were much more accurate when they made sure responses than when they made lower confidence responses (“Sure” responses more accurate than “Maybe” responses,  $t(79)=10.33$ ,  $p<0.01$ ; “Maybe” responses more accurate than “Guess” responses,  $t(79)=4.18$ ,  $p<0.01$ ). Hit rates for “Maybe” responses were significantly greater than chance performance ( $t(79)=8.31$ ,  $p<0.01$ ), whereas hit rates for lower confidence responses (“Guess”) did not differ from chance ( $p=0.89$ ). Thus, participants were likely actually guessing when making the lowest confidence responses. Hit rates did not differ between the two encoding conditions, Unitize and Separate ( $t(19)=1.72$ ,  $p=0.10$  for Intact items;  $t(19)=1.28$ ,  $p=0.22$  for Rearranged items), even when broken down by confidence. Ultimately, the participants performed above chance performance on the memory test, although there were no behavioral differences between the two encoding conditions.

Confidence interval responses were plotted with hits against false alarms, and analyses were conducted in which ROCs were fit using the dual-process signal detection (DPSD) model (Yonelinas, 2002). In this model, the ROC’s intercept of the ordinate gives a measure of recollection, whereas the curvilinearity ( $d'$ ) of the ROC is representative of familiarity. The grand average ROCs across subjects is shown in Figure 2 below. The ROCs for the Unitize and Separate conditions appear to be highly overlapping, although recollection (the left-most point of the ROC) seems higher in the Unitize condition than in the Separate condition. In order to assess this more closely, ROCs were constructed for each individual subject in order to calculate estimates for recollection and familiarity (shown in Figure 2 below). Average estimates for

recollection (in probability) were 0.254 and 0.204 for Unitize and Separate conditions, respectively; estimates for familiarity (in  $d'$ ) were 0.642 and 0.806. Differences between the conditions were not significant for either recollection ( $t(19)=0.944$ ,  $p=0.36$ ) or familiarity ( $t(19)=1.159$ ,  $p=0.26$ ). Thus, there were no differences in familiarity between the two conditions, despite the demands for unitization. Behaviorally, no differences between encoding conditions were observed.

Electrophysiological analyses were conducted on each individual subject's epoched time-series data. ERP analyses focused on differences between the two conditions, Unitize and Separate, specifically examining differences in canonical memory components, the FN400 and the LPC. To this end, groups of electrodes were identified and averaged together to create four regions of interest: left frontal (LF; channels F1, F3, FC1, and FC3), right frontal (RF; channels F2, F4, FC2, and FC4), left parietal (LP; channels CP1, CP3, P1, and P3), and right parietal (RP; channels CP2, CP4, P2, P4). This electrode montage is shown in Figure 3.

The ERPs are plotted in figures 4 (Unitize) and 5 (Separate). The mean amplitudes for these grouped channels were calculated over three time windows: an Early time window (300-500 ms), a Middle time window (500-800 ms), and a Late time window (900-1200 ms). These data were entered into a four-way repeated measures analysis of variance (ANOVA), with factors of location (anterior, posterior), hemisphere (left, right), encoding (Unitize, Separate), and condition (Intact, Rearranged, New). An ANOVA was run for each time window, and the Greenhouse-Geisser correction for nonsphericity was applied for the three levels of condition. In the Early time window, main effects were found for location ( $F(1,19)=52.46$ ,  $p<0.001$ ) and hemisphere ( $F(1,19)=6.21$ ,  $p=0.02$ ), and an interaction for location\*hemisphere ( $F(1,19)=13.79$ ,  $p=0.001$ ) was significant; no other significant effects were found. In the Middle time window,

significant main effects were found for location ( $F(1,19)=39.40, p<0.001$ ), and condition ( $F(2,38)=7.50, p=0.002$ ), as well as an interaction between condition and hemisphere ( $F(2,38)=5.99, p=0.01$ ); no effects were found with encoding. Lastly, in the Late time window, similar effects were found: main effects for location ( $F(1,19)=6.75, p=0.018$ ) and condition ( $F(2,38)=4.10, p=0.033$ ), a two-way interaction between condition and location ( $F(2,38)=16.93, p<0.001$ ), and a three-way interaction between condition, location, hemisphere ( $F(2,38)=4.48, p=0.022$ ). Overall, activity was generally higher for intact items in posterior sites, but unitization had no significant effect. As a final measure, I conducted t-tests between activity in the Unitize and Separate conditions, both Intact and Rearranged, in the three time windows. None of these t-tests reached significance ( $p>0.05$ ). Ultimately, there were no electrophysiological differences between the Unitize and Separate conditions in this experiment.

## Discussion

The aim of the present study was to test the hypothesis that unitization-like effects reflect modulation of semantic networks, and that by removing semantic information from stimuli, unitization effects would be reduced or perhaps eliminated. Several previous studies have linked unitization to familiarity, as well as the FN400; however, these two constructs have also been linked to conceptual priming, processing, and the N400. Thus, previously reported conclusions on unitization may in fact be misrepresentative, and in fact differences in semantic processing may lead to reported effects. As predicted, there were no differences between the Unitize and Separate encoding conditions in this experiment. One conclusion that can be reached is the hypothesized one: that unitization was not possible, or perhaps showed no effect, with a lack of

conceptual information about the stimuli. However, there are other conclusions that can be drawn as well.

First, it is possible that unitization for these stimuli occurred in both the Unitize and Separate encoding conditions. These abstract images are particularly well suited for unitizing, as they can be easily “stuck together” or combined; thus, participants may have mentally combined the images regardless of the encoding instructions, resulting in unitization. Participants may have also been influenced by the design of the study, in which blocks alternated between Unitize and Separate encoding. Participants may have been prompted to unitize in the Separate condition after going through a Unitize encoding block. This account could explain why curvilinear ROCs, rather than linear ROCs, are found in both conditions of the experiment; familiarity could contribute in both cases. However, it is not the case that associative memory tasks always result in linear ROCs (Healy et al., 2005; Wixted, 2007), and in fact the only way to estimate recollection and familiarity is from confidence intervals, which could have been influenced by the task or instructions. In this experiment, participants were told to do their best to “use the entire scale” in an attempt to encourage participants to evaluate their memory. This instruction could have influenced participants to spread their responses across the confidence scale somewhat fallaciously.

In a separate follow-up behavioral experiment, 14 subjects from the University of Illinois participated in an associative memory task nearly identical to the experiment above. The critical difference was that participants first performed several study-test blocks with the separate encoding instructions, and then followed this with several study-test blocks with the unitization encoding. The purpose of this was to ensure that the unitization instructions did not contaminate performance on the separate encoding task. As before, individual ROC curves were plotted to

obtain estimates of recollection and familiarity. Neither recollection nor familiarity was significantly different across encoding conditions. However, accuracy for rearranged items was significantly higher for unitized stimuli than for non-unitized stimuli ( $t(13)=5.227$ ,  $p<0.05$ ). Thus, there may have been some contamination in the original study, but this likely would not have led to changes in the ROC estimates.

Another explanation is that unitization is simply not possible with these stimuli. This is similar to the hypothesis that semantic processing is necessary for unitization; however, it may not be the lack of semantic information, but some other factor, that makes unitization impossible. Perhaps mentally combining visual stimuli, as the instructions of the experiment encouraged, does not result in unitization. Unfortunately, this is difficult to determine, as currently there is no specific behavioral or electrophysiological measure or index of unitization occurring. Increases in familiarity or FN400 amplitude may be an outcome of unitization, but this cannot be used as a proxy for unitization, as it is plausible that unitization could occur without producing these effects. One potential method would be to utilize an implicit memory procedure. Following Graf & Schacter's (1989) original distinction between unitization and grouping, it is possible that only an implicit memory test would be able to discriminate between items that have been unitized and items that have not. Unfortunately, it is somewhat difficult to develop an implicit memory test using abstract novel images, and a benefit to implicit memory may still not be a perfect index of unitization occurring, as there may be other factors or variables underlying this effect.

Interestingly, this study was in fact not the first to investigate associative recognition with novel visual stimuli. Speer & Curran (2007) had participants study pairs of abstract fractal patterns, and then administered a recognition test with intact, rearranged, and new pairs. This

study was not a unitization study per se, in that individuals were given no specific instructions during the encoding phase, other than to remember the pairs for a future memory test. The critical manipulation was that some pairs were presented five times during encoding, thus creating a “strong” representation, whereas others were paired together only twice, creating a “weak” representation. Additionally, in some pairs the positions of the fractals were constant, whereas in others the positions changed. Importantly, each individual fractal was presented five times overall, thus controlling for familiarity of the individual items. At test, results showed enhanced frontal positive activity in the N400 time window, as well as an increased LPC, for previously observed pairs compared to rearranged and new pairs. Behaviorally, participants were faster and somewhat more accurate for strong pairs than for weak pairs; however, there were no electrophysiological differences between these two conditions. The authors claimed that unitization was unlikely to occur for these stimuli, as the objects were very abstract, and no FN400 differences were found for the constant vs. variable position pairs, which should theoretically be influenced by unitization. Thus, this may provide further support that unitization is just not possible with visual stimuli; however, these results may have differed if specific unitization instructions had been given.

Ultimately, this study reported no statistically significant difference between the Unitize and Separate encoding conditions, either behaviorally or electrophysiologically, for abstract visual objects. This is potentially due to the lack of semantic information present in the pipe stimuli; if unitization requires semantic information to function, then unitization would not be possible with these stimuli. However, it is possible that abstract visual images are simply not possible to unitize, and thus a semantic modulation account may not explain these results. To investigate this semantic modulation hypothesis further, an additional set of experiments were



conducted with words and pseudowords. Most unitization studies are conducted with verbal stimuli, and thus it is expected that effects of unitization will be more apparent with this set of stimuli.

### **Chapter III: Experiment 2 – Unitization of Pseudowords**

In the following experiment, participants were presented with words and pseudowords to either unitize or encode separately. A pseudoword is a phonologically legal, but ultimately nonsensical word that is constructed from normal words by changing certain letters (e.g. “blurn”, “toop”, etc.). Pseudowords are an optimal choice for examining the semantic modulation hypothesis, as they share similar visual features to everyday words which are commonly used in unitization experiments, but importantly have impoverished semantic content. Considering that unitization has proven successful across several studies for word stimuli, it seems logical that a failure to find evidence of unitization for pseudowords would be due to the lack of semantic information in these stimuli. As before, electrophysiological signals were also recorded during the test phase to assess ERP components related to memory retrieval. If unitization is reduced or abolished for pseudowords due to the lack of semantic information, then the N400 amplitudes between the unitize and separate conditions should not differ for pseudowords, but should for normal words.

In actuality, two experiments were performed under this framework. The first experiment (experiment 2A) had participants unitize stimuli with a perceptual unitization task. The original conception behind this task was that in a perceptual unitization task, the semantic information present in words would still lead to benefits, whereas the lack of semantic information in pseudowords would not. However, it is possible the results from this task differed from results in the literature due to the task; thus, in order more appropriately compare to experiments in the literature, a second experiment was conducted with a standard conceptual unitization task (experiment 2B). The results from experiment 2A were included in this document, as they proved to be somewhat interesting.

## Methods

In both experiments, subjects (13 in 2A; 12 in 2B) from the University of Illinois participated in the study. All subjects were right-handed, had no history of psychiatric illness, and were not taking any psychotropic medications. Additionally, subjects were native English speakers, as verbal stimuli were used. Due to the low number of participants, the power of the reported effects are likely somewhat low; for the purposes of this document, statistical analyses and interpretations will still be reported. More subjects are expected to be run in the future.

The stimuli used for this experiment were 596 English words, along with 596 pseudowords, paired together to create 298 pairs of each. The words were chosen such that minimum word frequency based on Francis & Kucera norms (1982) was 40 (average word frequency = 160) and words were 3-6 letters long (average word length = 4.7). The wordlist contained a mixture of nouns, verbs, and adjectives. Pseudowords were created in Wuggy, a multilingual pseudoword generating program (Keuleers & Brysbaert, 2010). Wuggy operates by breaking words up into subsyllabic elements and recombining them to form pseudowords. However, to constrain the number of pseudowords generated, as well as attempt to retain some similarity to the template word, Wuggy maintains segment length so that the word and pseudoword are the same length, as well as maintains transition frequencies between subsyllabic elements so that highly unexpected syllabic transitions don't occur. Wuggy also calculates the orthographic Levenshtein distance between each generated pseudoword and its 20 most similar words (known as the OLD20), giving a fairly good measure of neighborhood size. Lastly, the program gives the number of orthographic neighbors to the pseudowords that can be made by changing a single letter (neighbors at edit distance 1, or NED1). These statistics allow the user to more carefully select pseudowords and attempt to match template words as much as possible.

For pseudowords in these experiments, the average OLD20 difference between the template word and selected pseudoword was 0.11 (marginally smaller neighborhood) and the average NED1 difference was -0.4 (marginally higher number of words).

In both experiment 2A and 2B, participants were given alternating blocks of pairs of words to study and pairs of pseudowords to study. In experiment 2A, pseudoword blocks contained pairs of 2 pseudowords. Due to somewhat low behavioral performance, pseudoword blocks in experiment 2B contained pairs of 1 word and 1 pseudoword. In half of these pairs, the word was first, and in the other half the pseudoword was first. While it is possible that this change may produce noticeable differences, it is expected that even having one pseudoword in a pair will still produce substantial difficulty in unitization due to the lack of semantic information. In total, participants worked through 8 word blocks and 8 pseudowords, studying 18 pairs of stimuli in each block. As before, following each block was an associative memory test with intact, rearranged, and new pairs. Participants used a scale to rate their confidence in their memory for each test pair. In each test, participants saw 12 intact pairs, 6 rearranged pairs, and 6 new pairs, leading to a total of 96 intact, 48 rearranged, and 48 new pairs across the 8 word blocks, and the same amount across the 8 pseudoword blocks.

On each trial of each block of the study session, participants either unitized stimuli or separately encoded them. The order of this presentation was randomized. The primary difference between experiments 2A and 2B were the strategies that participants were instructed to employ. In experiment 2A, the unitization procedure entailed combining the two words together and rating how pleasurable the combined word sounded, while the separate encoding procedure entailed rating which of the words sounded better than the other. This perceptually-based task was used in an attempt to de-emphasize conceptual processing of the stimuli;

however, in order to more adequately compare results to other unitization studies, a second experiment with a conceptual procedure was performed. In experiment 2B, the unitization instruction was to mentally combine the two words into a compound word and invent a definition for this compound word, and separate encoding instructions were to choose which word was more meaningful. This was expected to be fairly difficult with the word-pseudoword pairs, but participants were instructed to do their best to come up with something.

Stimulus presentation and timing specifications were essentially identical to experiment 1. Words were presented simultaneously with a visual gap between them. Subjects were seated approximately 100 cm from the computer monitor to ensure a small visual angle and reduce horizontal eye movements between the words. As in experiment 1, EEG was recorded during the memory test in order to assess electrophysiological components of recognition memory. Recording parameters and analysis procedures were the same in these experiments as they were in the first experiment. Unfortunately, accuracy was low for the Pseudoword-Rearranged items, and thus ERP trial counts were often not above 15, thus reducing the signal to noise for these averaged datapoints. However, analyses will include this data for the purpose of examining potential differences due to encoding. Inferences drawn from these analyses should take this lack of sufficient trials into account.

### Experiment 2A Results

Behavioral accuracy scores across conditions and stimulus types were analyzed. Accuracies are reported in tables 3 and 4. In this experiment, all accuracies were above chance except for Rearranged Pseudowords, which were not significantly different from chance accuracy. However, this data will still be analyzed for consistency. First, accuracies were

analyzed in a repeated measures ANOVA with within-subject factors of Stimulus (Word, Pseudoword), Condition (Intact, Rearranged), and Encoding (Unitize, Separate). The “New” condition was left out of this analysis, as unfortunately the lower number of trials led to non-full rank data; however, the accuracy for “New” items was well above chance. A t-test showed that accuracy for New Pseudowords was significantly lower than accuracy for New Words ( $t(12)=3.001$ ,  $p<0.05$ ), suggesting participants were more likely to false alarm to New Pseudowords. The ANOVA revealed significant main effects for all three factors: Stimulus ( $F(1,12)=23.54$ ,  $p<0.01$ ), Condition ( $F(1,12)=13.28$ ,  $p<0.01$ ), and Encoding ( $F(1,12)=6.87$ ,  $p<0.05$ ), as well as a significant interaction of Stimulus and Condition ( $F(1,12)=5.185$ ,  $p<0.05$ ). No other interactions were significant. Accuracy for Words was greater than accuracy for Pseudowords, and accuracy for Intact items was higher than accuracy for Rearranged items. Accuracy was much lower for Rearranged Pseudowords, leading to the significant interaction. Accuracy for unitized items was higher than for separately encoded items ( $t(51)=2.74$ ,  $p<0.01$ ), though this difference was small (0.69 vs 0.65). However, this was only when collapsing across words and pseudowords; t-tests for these specific comparisons were not significant. Importantly, no interactions were found with Encoding; thus, unitizing stimuli did not differ based on items or condition.

As before, confidence responses were plotted on an ROC curve and fit with a dual process signal detection model. The grand average ROC is shown in figure 6, with the accompanying estimates for recollection and familiarity. The ROC curve for the separately encoded pseudowords appears nearly linear, suggesting little familiarity in this case. In the Word condition, neither estimates for recollection nor familiarity were significantly different between the Unitize and Separate encoding conditions (recollection,  $p=0.26$ ; familiarity,  $p=0.43$ ).

In the Pseudoword condition, estimates for recollection did not differ ( $p=0.15$ ), whereas estimates for familiarity were significantly higher in the Unitize condition than in the Separate condition ( $t(12)=2.96$ ,  $p=0.012$ ). This change in familiarity was not accompanied by an increase in accuracy. Thus, unitization encoding instructions had an effect in the Pseudoword condition, but had no effect for Words.

ERP waveforms are presented below in figures 7 (Words) and 8 (Pseudowords). As previously stated, rearranged items are plotted and analyzed despite the low trial numbers. Repeated measures ANOVA were ran with factors of Stimulus (Word, Pseudoword), Condition (Intact, Rearranged), Encoding (Unitize, Separate), Location (frontal, posterior), and Hemisphere (left, right) across three time windows: Early (300-500 ms), Middle (500-800 ms), and Late (900-1200 ms). In the Early time window, a significant main effect was found for location ( $F(1,12)=16.03$ ,  $p=0.002$ ), and significant four-way interaction between stimulus, condition, encoding, and location ( $F(1,12)=7.53$ ,  $p=0.018$ ). Planned comparison tests revealed that separately encoded Pseudowords had higher amplitudes than unitized Pseudowords in all clusters, a finding opposite than expected. In the Middle time window, there was a significant main effect for location ( $F(1,12)=28.07$ ,  $p<0.001$ ), and significant main effects for stimulus\*condition ( $F(1,12)=19.02$ ,  $p<0.001$ ), condition\*location ( $F(1,12)=6.70$ ,  $p=0.02$ ), stimulus\*hemisphere ( $F(1,12)=8.08$ ,  $p=0.01$ ), and stimulus\*condition\*hemisphere ( $F(1,12)=5.33$ ,  $p=0.04$ ). A cross-over interaction was observed, in that activity for rearranged pseudowords was higher than intact pseudowords, whereas activity was higher for intact words than for rearranged words, another opposite effect than expected. Activity was higher in the posterior channels, specifically for intact words on the left side; however, unitization had no effect. Lastly, in the Late time window, a main effect was found for location ( $F(1,12)=5.79$ ,  $p=0.03$ ), and significant

interactions between stimulus and condition ( $F(1,12)=4.82$ ,  $p=0.049$ ), condition and location ( $F(1,12)=7.62$ ,  $p=0.017$ ), and stimulus, encoding, and location ( $F(1,12)=15.87$ ,  $p=0.002$ ). The previous cross-over interaction continued in this time window. Overall, separately encoded pseudowords had higher activity than unitized pseudowords, especially in the time window of the N400, whereas words showed no effect of unitization.

### Experiment 2B Results

As before, overall accuracies were analyzed in a repeated measures ANOVA with within-subject factors of Stimulus (Word, Pseudoword), Condition (Intact, Rearranged), and Encoding (Unitize, Separate). Significant main effects were found for Stimulus ( $F(1,11)=55.25$ ,  $p<0.01$ ), Condition ( $F(1,11)=8.82$ ,  $p=0.013$ ), and Encoding ( $F(1,11)=12.58$ ,  $p=0.005$ ), and a significant interaction between Stimulus and Condition was found ( $F(1,11)=5.95$ ,  $p=0.033$ ). Words had higher accuracy than Pseudowords, Intact pairs had higher accuracy than Rearranged pairs, and Unitized items had higher accuracy than Separately encoded pairs. As in experiment 2A, the large drop in accuracy for Rearranged Pseudowords led to a significant interaction (figure x). These behavioral results essentially parallel those from experiment 2A: unitized items were remembered with greater accuracy than separately encoded items, but this was not dependent on stimulus type. Follow-up planned pairwise comparisons revealed that for both Words and Pseudowords, unitizing stimuli led to higher accuracy than separately encoding stimuli, an important difference from experiment 2A.

ROC estimates and the grand average ROC are shown in figure 9. The ROCs clearly illustrate the higher performance with Words compared to Pseudowords. Statistical comparisons revealed that for Words, estimates of recollection were different with trending significance



( $t(11)=2.05$ ,  $p=0.066$ ), while estimates of familiarity did not differ ( $p=0.22$ ). For Pseudowords, estimates of recollection did not differ ( $p=0.84$ ), whereas estimates of familiarity did ( $t(11)=3.06$ ,  $p=0.01$ ). This increase in familiarity was accompanied by an increase in accuracy for unitized information. Thus, unitization led to an increase in familiarity for pseudowords, but not for word stimuli.

The ERP waveforms are shown in figures 10 (Words) and 11 (Pseudowords). As before, repeated-measures ANOVAs were run with the same factors across three time windows: Early (300-500 ms), Middle (500-800 ms), and Late (900-1200 ms). In the Early time window, no significant main effects or interactions were discovered, suggesting no effects in the N400 time window. In the Middle time window, a significant main effect was found for condition ( $F(1,11)=15.60$ ,  $p=0.002$ ), and significant interactions were found for location\*hemisphere ( $F(1,11)=10.04$ ,  $p=0.009$ ) and stimulus\*encoding\*hemisphere ( $F(1,11)=14.04$ ,  $p=0.003$ ). In this time window, intact items had higher amplitudes than rearranged items, and higher amplitudes were found for unitized words in sites on the right side. Lastly, analysis in the Late time window revealed a myriad of effects, including a significant main effect for hemisphere ( $F(1,11)=6.92$ ,  $p=0.02$ ), and interactions between encoding and location ( $F(1,11)=7.18$ ,  $p=0.02$ ), condition and hemisphere ( $F(1,11)=8.78$ ,  $p=0.013$ ), location and hemisphere ( $F(1,11)=14.61$ ,  $p=0.003$ ), condition, encoding and location ( $F(1,11)=6.75$ ,  $p=0.02$ ), and condition, location and hemisphere ( $F(1,11)=5.64$ ,  $p=0.04$ ). Thus, there were differences in activity due to encoding strategy and condition based on the location, but the stimulus type was not particularly important. A follow-up analysis based on visual inspection revealed significant differences between Unitized Words and Separate words in parietal clusters (left,  $t(11)=2.63$ ,  $p=0.023$ ; right,  $t(11)=2.46$ ,  $p=0.032$ ), but not in frontal clusters. Ultimately, effects were found for activity in later time windows and in

parietal areas, but not in the early time window and frontal clusters, suggesting changes in the LPC, not in the N400.

## Discussion

Across two experiments, unitization for stimuli with impoverished semantic content, pseudowords, was examined. In the first experiment, participants were given a perceptual unitization task, in which stimuli were combined based on their sound. In the second experiment, participants were given a conceptual unitization task, in which they were asked to come up with a definition for the combination of stimuli. For both of these stimuli, the power is lower than likely necessary to make strong claims about the statistical results, due to the low number of subjects; however, for the purposes of this paper, inferences will be drawn from the current results.

Behavioral results from both experiments revealed benefits to memory following unitization, consistent with other findings in the unitization literature (Bastin et al., 2013; Giovanello et al., 2006). Additionally, in both experiments unitization led to increases in familiarity estimates for Pseudowords; however, this was curiously not observed for Word stimuli, as a change in familiarity is often the case. It is unclear what would cause this lack of effect for Words; it is possibly due to the novel method used in these experiments. No experiment to date has employed a perceptual unitization task, and other conceptual tasks generally provide a definition for each pair of words, rather than have participants develop definitions. It is unclear whether there was contamination from the unitization condition to the separate condition or not; however, given the large changes in familiarity for Pseudowords, this

explanation is not likely the case. In any case, it is clear that unitization produces benefits for memory of pseudowords, despite the lack of semantic information for these stimuli.

These experiments provide important evidence that, despite the clear behavioral evidence of unitization of pseudowords, the electrophysiological changes do not follow the usual effects observed in the literature. In experiment 2A, activity in the N400 time window displays the opposite result of what is usually observed – activity is much more positive for separately encoded items than for unitized items. In experiment 2B, no differences between the two conditions are found in the ERP waveform, despite the large change in familiarity. This is the first unitization experiment to report such results, and this gives important insight into the link between the N400 and the process of unitization. The activity of the N400 may be more closely related to semantic access and the semantic content of the processed stimuli; thus, this activity may not be as closely linked to unitization, and more importantly to familiarity, as previously posited.

Why would an opposite effect be observed for pseudowords in experiment 2A, but not in experiment 2B, despite the fact that both experiments contain these stimuli? It is possible that the difference could be due to the change in design; as previously stated, in experiment 2A, participants were shown pairs of two pseudowords, whereas in experiment 2B they were shown a pseudoword paired with a word in order to make the task less difficult. If the N400 is in some part driven by orthographic or phonological factors (Deacon et al., 2004), then it is possible that a representation that is a phonological combination of two pseudowords would drastically change N400 activity, whereas a conceptual change might not produce such large effects. From an orthographic perspective, a pseudoword has some similarity to other actual words (e.g. “blurn” is similar to “blurt”, “burn”, etc.); however, a combination of two pseudowords

(“blurntoop”) has little similarity to any word, and thus will likely produce a change in the N400 activity, although the predicted change would be a larger (more negative) N400. Another possible explanation is that the effects seen are due to the task demands of the experiment, as manipulating task demands have been shown to lead to repetition priming for pseudowords and even illegal strings (Laszlo et al., 2012). Importantly, neither of these accounts have little to do with familiarity, and these results provide evidence that under certain circumstances, the N400 is not a reliable measure of familiarity.

One familiarity-based account that could potentially lead to the results seen here is that the effects may be driven by a relative familiarity signal, as opposed to an absolute familiarity signal. This distinction, described in detail by Mandler (1980), states that absolute familiarity is the overall pre-experimental familiarity that has been built up for a stimulus over a person’s lifetime, whereas relative familiarity (or incremental familiarity) refers to the change in familiarity that occurs after a new presentation of the stimulus during an experiment. This phenomenon has been used to explain the finding that lower frequency words are easier to remember; a lower frequency item will have a greater relative familiarity than a higher frequency item, as the new presentation will lead to a greater increase in familiarity for an unfamiliar stimulus than for a familiar stimulus (Coane et al., 2011). A similar case could be made for pseudowords, which likely have drastically lower absolute familiarity than words, and thus will have higher relative familiarity following a presentation during an experiment. A recent ERP experiment (Bridger et al., 2014) found that old /new effects for low frequency items that was greater than high frequency items overlapped in time and distribution with the mid-frontal FN400 effect, suggesting that this activity may represent relative familiarity. However, the current data does not follow this pattern; while the behavioral results could potentially be

explained by a relative familiarity account, the electrophysiological results do not change in accordance with a relative familiarity explanation. Additionally, it is unclear why relative familiarity changes would be dramatically higher for unitized information than for separately encoded information.

It is possible that traditional unitization and familiarity effects are only observed for stimuli with a pre-existing, established semantic representation or meaning, such as words or everyday objects. The failure to find canonical unitization effects in these studies may be due to the novel status of the stimuli in the experiments. If this is the case, one must question what value these results have; considering that most objects and words we encounter in our lives have pre-existing semantic representations, why does memory for abstract novel stimuli matter? I would posit that these results support the notion that at some point during cognitive processing of stimuli, low-level perceptual features are integrated to form a conceptual representation, suggesting that the meanings of information that we encode is particularly important. When novel information is encoded, that processing step cannot be completed, as no conceptual representation has been formed; however, it is possible that such a representation could be formed over time. If novel stimuli were repeatedly observed, I would expect that even these items would begin to become familiar and show the behavioral and neural effects commonly seen. Importantly, unitization instructions led to memory benefits even for pseudowords in the second experiments; thus, unitization may represent a method of more efficiently processing stimuli to produce a conceptual representation.

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## Figures

Table 1. Experiment 1: Overall behavioral accuracy on the memory test.

Overall Accuracy		
	Separate	Unitize
Intact	0.76	0.73
Rearranged	0.68	0.71
New	0.95	0.95

Table 2. Experiment 1: Accuracy by confidence.

Accuracy by Confidence		
Response	Separate	Unitize
Guess New	0.67	0.71
Guess Old	0.51	0.45
Maybe New	0.78	0.73
Maybe Old	0.54	0.53
Sure New	0.89	0.89
Sure Old	0.81	0.83

Figure 1. Experiment 1: Examples of the abstract “pipe” stimuli used in the experiment.

Participants are instructed to mentally combine the images to create one “pipe”.

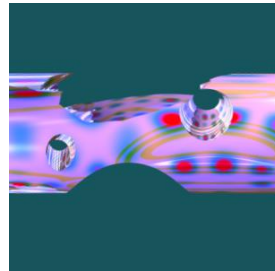
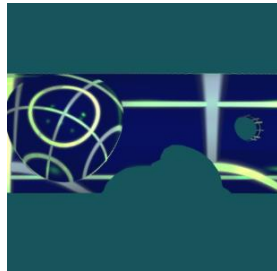


Figure 2. Experiment 1: Grand average ROC across all participants and ROC estimates. Lines are plotted with the dual process signal detection model. Differences between estimates were not significant.

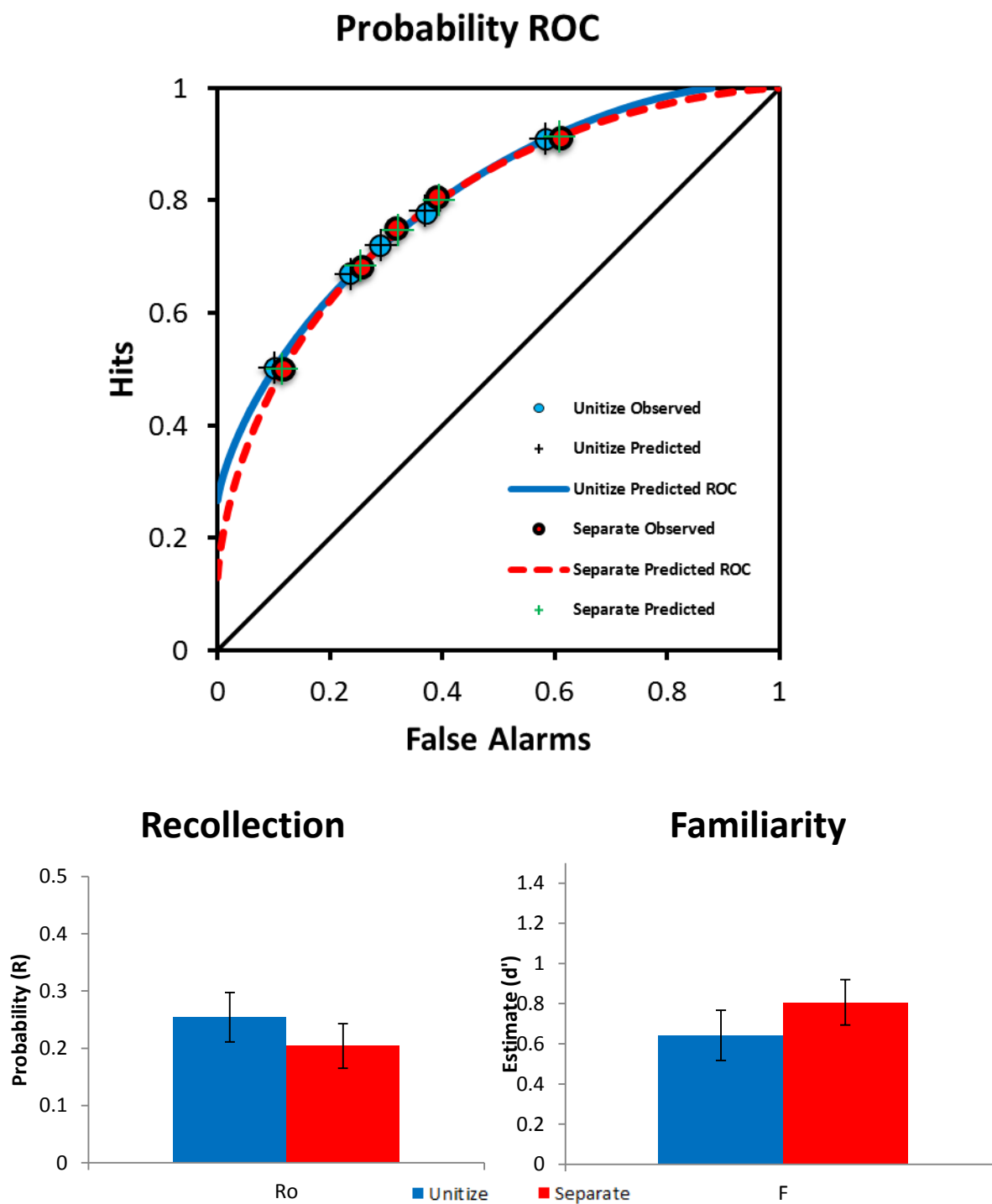




Figure 3. Scalp map showing montage and electrode clusters used for ERP analyses. Electrode clusters are represented by bold electrode labels.

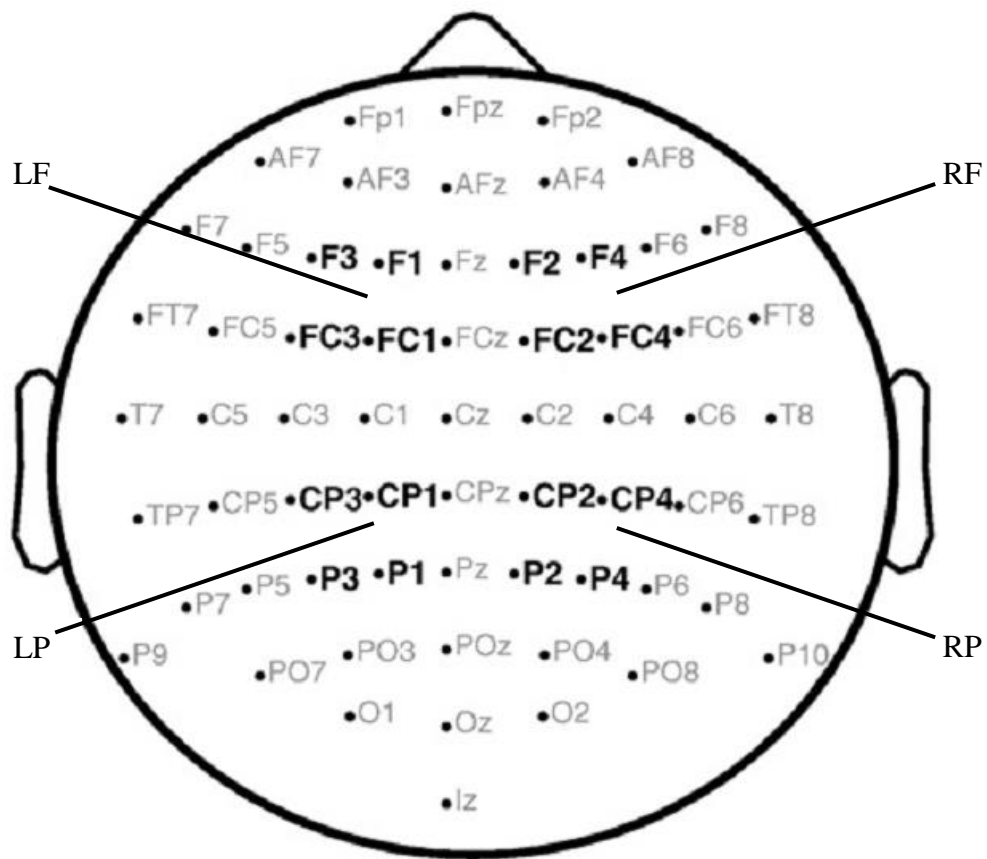


Figure 4. Experiment 1: Time-courses of ERP data for the Unitize condition. The channel labels represent the 4 clusters discussed previously.

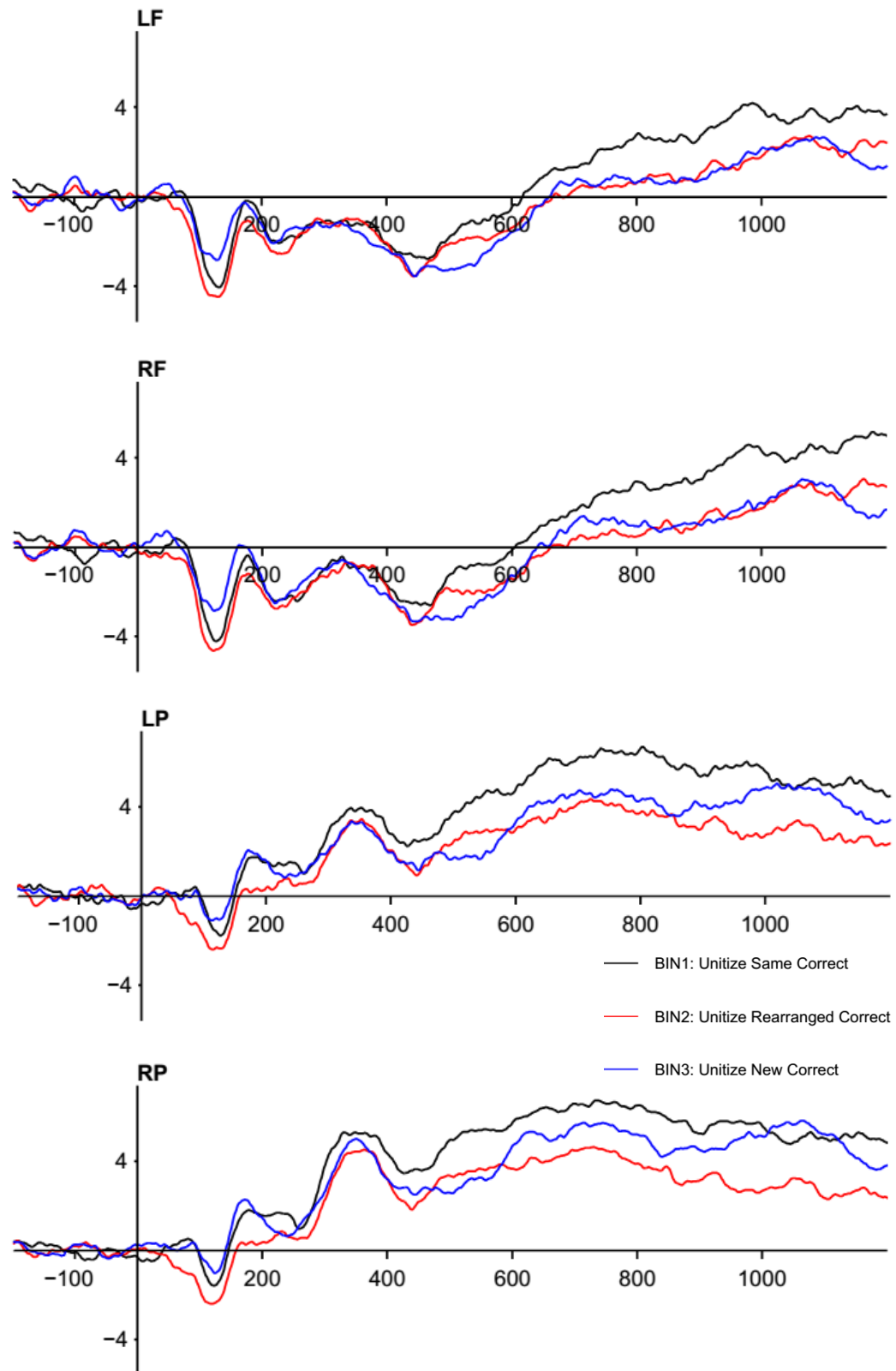


Figure 5. Experiment 1: Time-courses of ERP data for the Separate condition. No significant differences between Unitize and Separate ERP amplitudes.

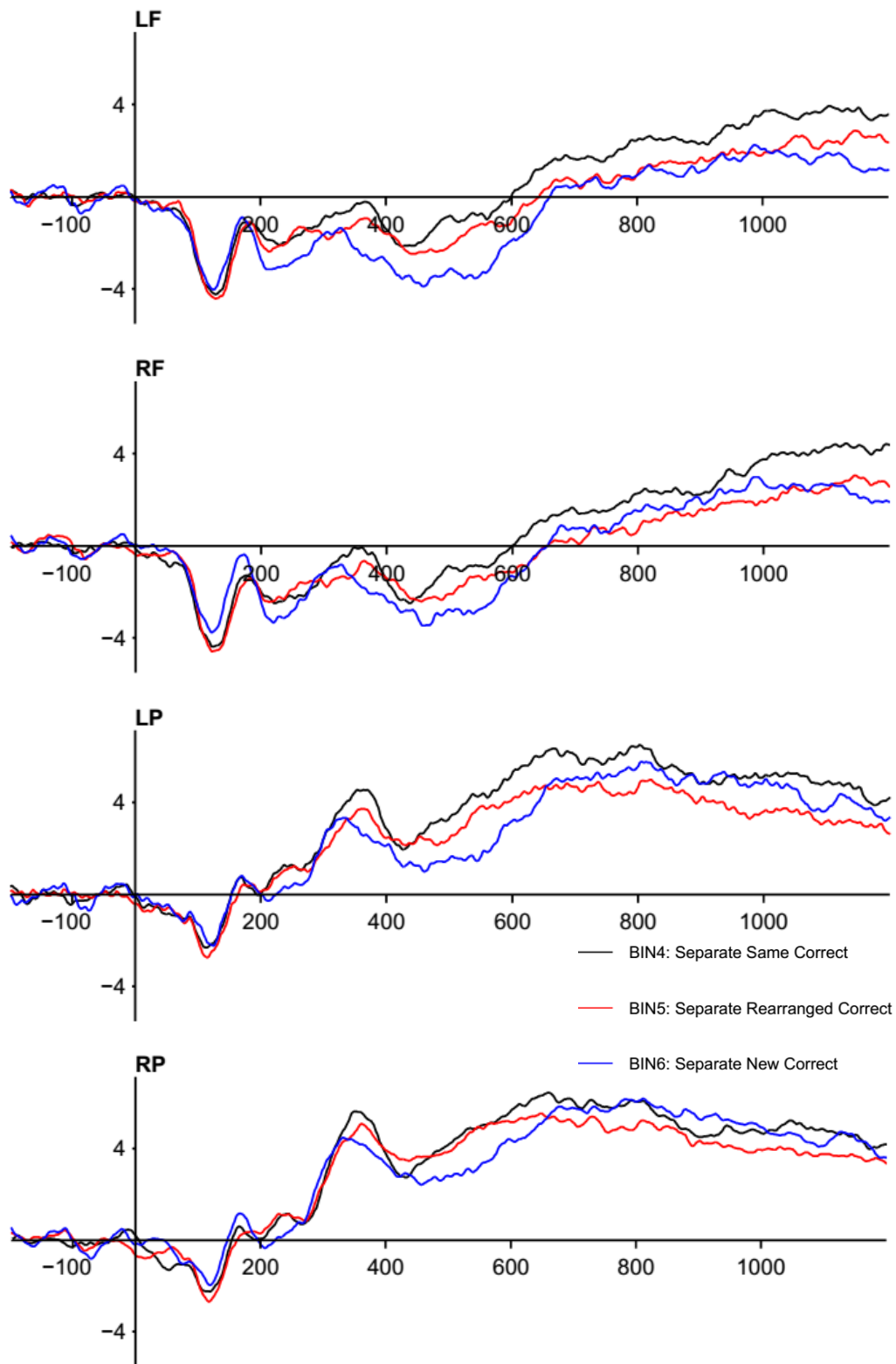


Table 3. Experiment 2A: Overall behavioral accuracy on the memory test.

Overall Accuracy				
	Word		Pseudoword	
	Unitize	Separate	Unitize	Separate
Intact	0.85	0.79	0.76	0.74
Rearranged	0.66	0.63	0.48	0.44
New	0.91	0.91	0.84	0.84

Table 4. Experiment 2A: Accuracy by confidence.

Accuracy by Confidence				
	Word		Pseudoword	
	Unitize	Separate	Unitize	Separate
Guess New	0.57	0.58	0.41	0.34
Guess Old	0.71	0.62	0.57	0.65
Maybe New	0.54	0.53	0.50	0.42
Maybe Old	0.56	0.67	0.64	0.68
Sure New	0.73	0.63	0.52	0.51
Sure Old	0.88	0.86	0.79	0.75

Figure 6. Experiment 2A: Grand average ROCs and ROC estimates. ROC estimates are plotted on the same figure for convenience; however, recollection estimates are in terms of probability of recollection, while familiarity estimates are in terms of sensitivity or  $d'$ . Significant differences are marked with an asterisk.

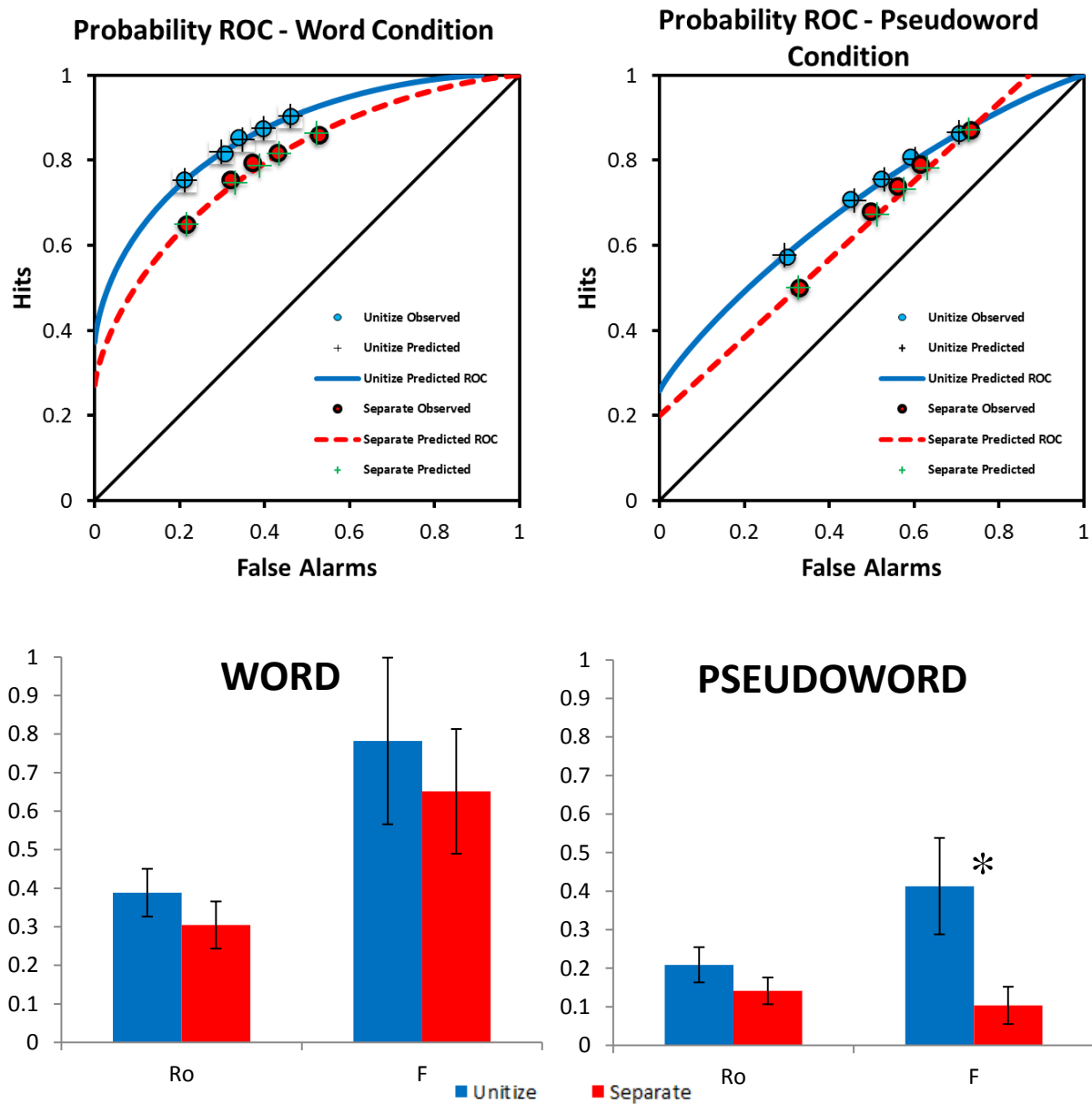


Figure 7. Experiment 2A: ERP waveforms for each channel cluster for Word stimuli.

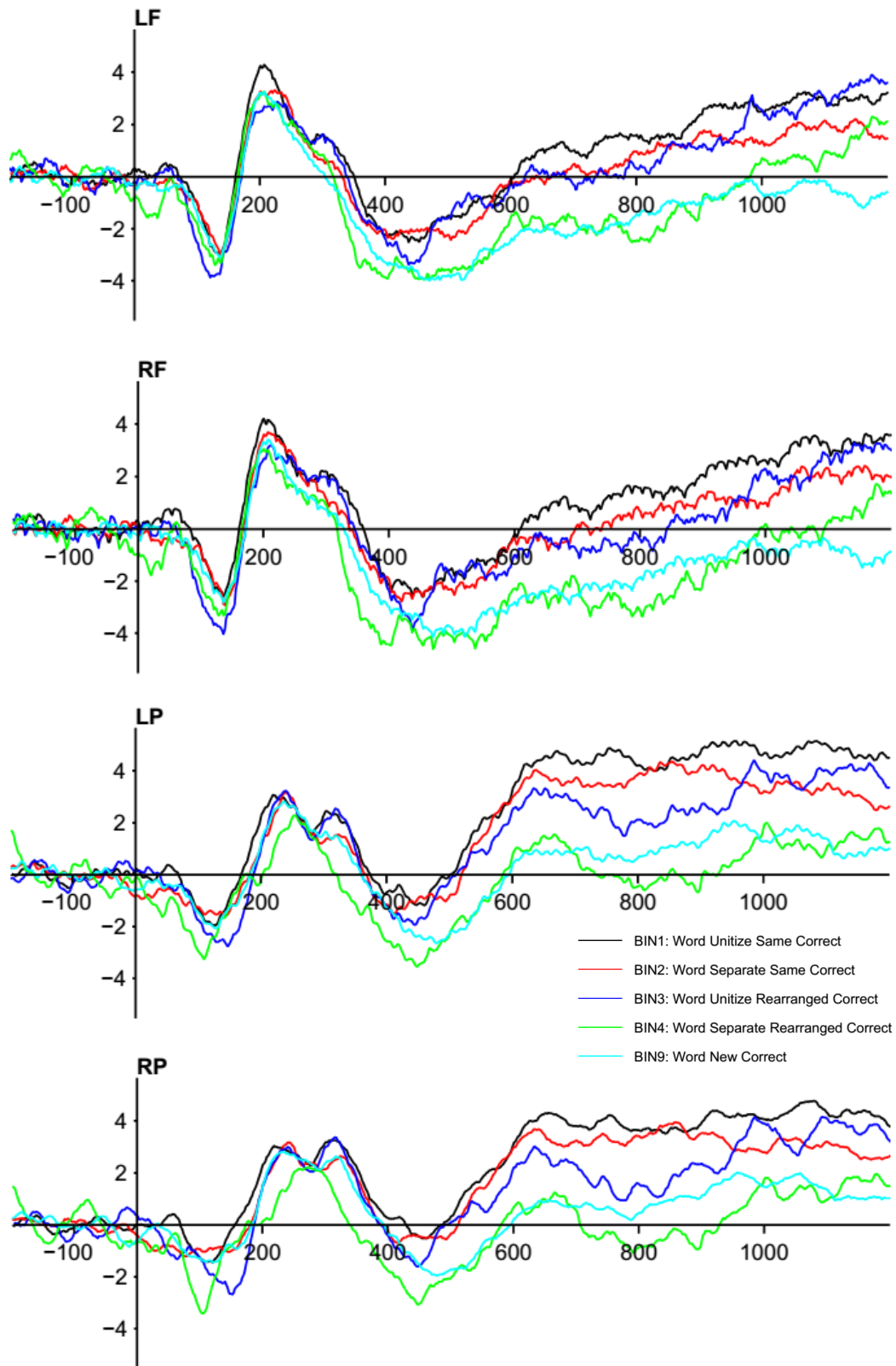


Figure 8. Experiment 2A: ERP waveforms for each channel cluster for Pseudoword stimuli.

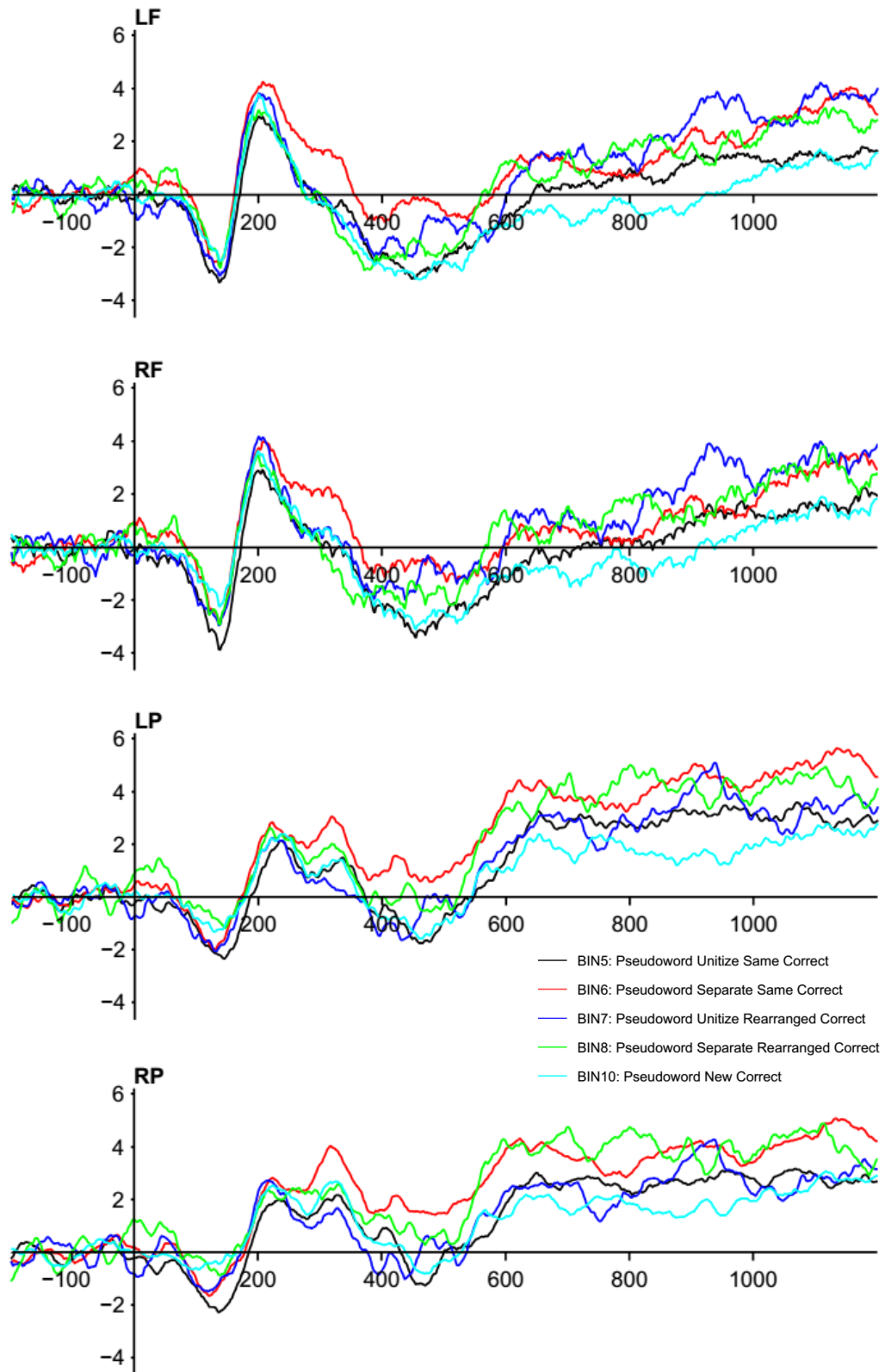


Table 5. Experiment 2B: Overall behavioral accuracy on the memory test.

Overall Accuracy				
	Word		Pseudoword	
	Unitize	Separate	Unitize	Separate
Intact	0.91	0.84	0.81	0.74
Rearranged	0.87	0.71	0.65	0.59
New	0.98	0.98	0.97	0.97

Table 6. Experiment 2B: Accuracy by confidence.

Accuracy by Confidence				
	Word		Pseudoword	
	Unitize	Separate	Unitize	Separate
Guess New	0.38	0.33	0.50	0.57
Guess Old	0.65	0.71	0.00	0.57
Maybe New	0.45	0.50	0.62	0.49
Maybe Old	0.61	0.66	0.54	0.69
Sure New	0.71	0.57	0.88	0.76
Sure Old	0.89	0.84	0.97	0.90



Figure 9. Experiment 2B: Grand average ROCs and ROC estimates.

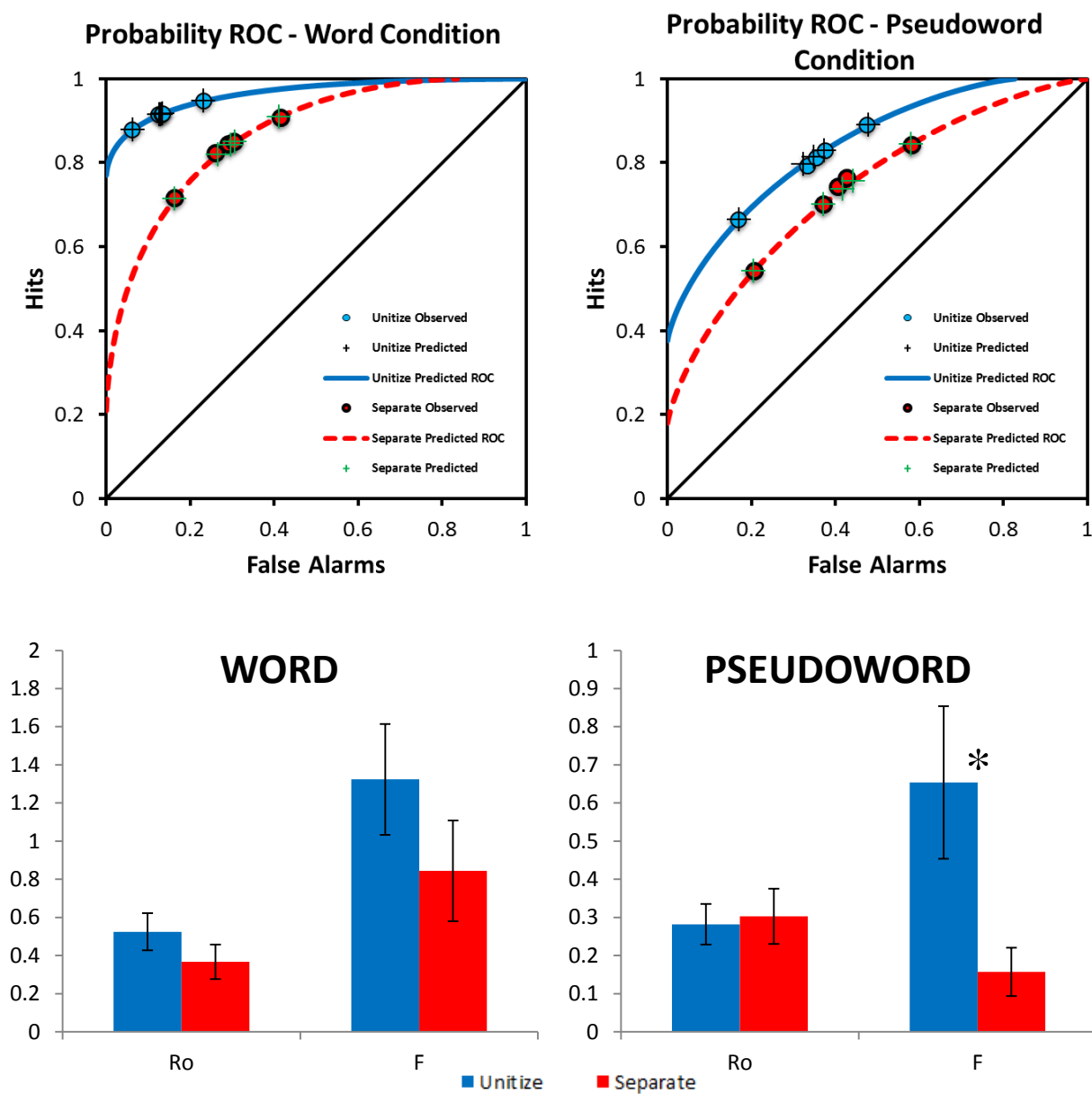


Figure 10. Experiment 2B: ERP waveforms for each channel cluster for Word stimuli.

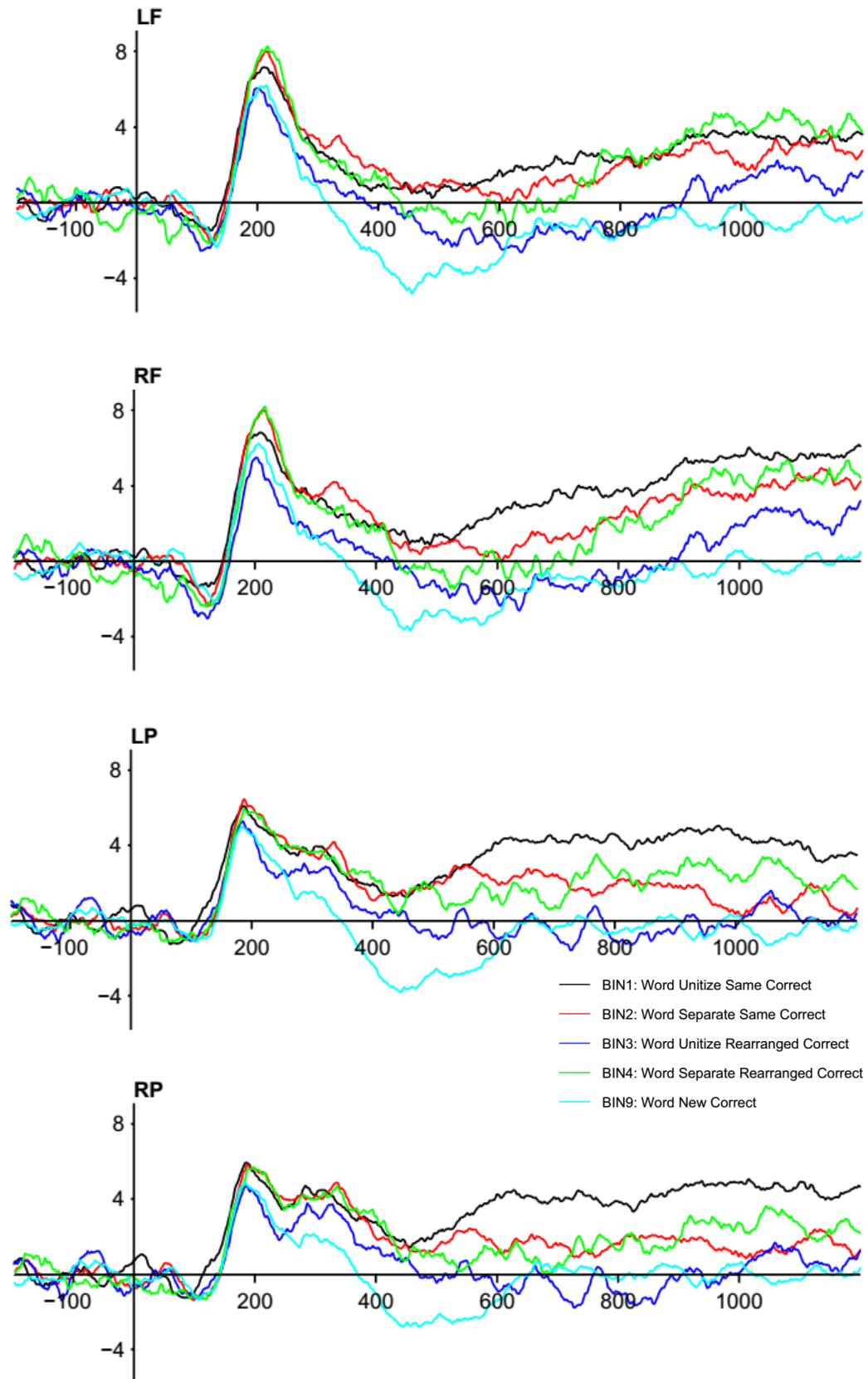


Figure 11. Experiment 2B: ERP waveforms for each channel cluster for Pseudoword stimuli.

