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Recognition Memory Revisited: An Aging and Electrophysiological Investigation

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RECOGNITION MEMORY REVISITED:

AN AGING AND ELECTROPHYSIOLOGICAL INVESTIGATION

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DEDICATION

To my Mother Susan Jardin for being my editor and participant, my father Fred Jardin for convincing me to finish my dissertation, and my sister Kiana for being awesome. To my Ohio support team Evan and Jamie Shelton, Hannah and Peter Mallik, Zach and Amanda Gerdes, Jennifer Turner, Joe Iselin, Anthony Villalba, and my partner in crime Catalina Flores. To my Ohio parents Goksu and Brian Kretch, and Ashley Shelton and Susan Elaine. To the Elliott, Jardin, Escorcio, Broberg, Soemantoro, Cranfil, Ables and Dekker families. To my support animals Buster Mallik (Paws ‘N Claws Academy) and Gilbert, Jada, and Humphrey Shelton. This was all made possible through the advising of Dr. Philip Allen and my committee members, Dr. Eric Allard, Dr. Mei-Ching Lien, Dr. Harvey Sterns and Dr. Karen Keptner. May this further be dedicated further in loving memory of my Grandmother Helen Elliott, and dear friend Kyle Malkasian.

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ABSTRACT

This study provides a better understanding of contributing factors to age differences in human episodic memory. A recurrent finding in recognition memory is that older adults tend to have lower overall accuracy and tend to make fewer false-alarm errors in judging new items, relative miss errors (Coyne, Allen & Wickens, 1986; Danziger, 1980; Poon and Fozard 1980).

Two possible causes for decline in these abilities include an age-related decrement in speed of processing (Salthouse 1991) and changes in information processing ability due to entropy (Allen, Kaufman, Smitch, & Propper 1998a; Mallik et al., in preparation). Additionally, age differences may be partially explained by a tendency for older adults to exhibit a conservative response bias. Surprisingly this study found no age-related differences in recognition memory accuracy, and older adults did not show a more conservative response bias. Due to these null results for age, the study examined the role of response bias (propensity to indicate a probe as being recognized, or new) on recognition memory accuracy and the role of the release from proactive interference (PI) across age. This study introduces a new ERP (Event-Related Potential) component to measure the recognition of "miss" responses called "FN400 Below Threshold". This component, when

looked at collapsed across Experiment 1 & Experiment 2 was positively correlated to behavioral accuracy suggesting that a more conservative response criterion hurts overall behavioral accuracy. Experiment 2 found that words learned from four categories were easier to remember than words from a single category due to a reduction in interference across items. This effect was found for both age groups.

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INTRODUCTION

With increasing age, many individuals often worry about their ability to both remember previous events and construct new functional memories. Long-term memory is often broken down into three functionally distinct subcomponents: episodic memory (ability to recall autobiographical events), semantic memory (general world knowledge), and procedural memory (ability to remember certain procedures in life,) (Tulving, 1972, 1985). Within each subcomponent are high levels of between-person differences and age-related change, which has been labeled "multi-directionality", in Baltes (1987). The most common findings are that semantic and procedural memory are largely spared during the aging process and episodic memory typically shows declines (Mitchell, 1989).

Previous studies have postulated that age differences in information processing may be due in large part to increased processing variability/neural noise (Allen, 1990, 1991; Allen & Coyne, 1988; Allen, Namazi, Paterson, Groth, & Crozier, 1992; Allen, Patterson, Propper, 1994; Allen, Weber, & May, 1993; Cremer & Zeef, 1987; Krueger, 1978; Kruger & Allen, 1987; Stadtlander, 1995; Welford, 1958). An increase in processing variability is thought to cause interference between to-be-remembered items and decrease memory performance (Brown, Neath & Chater, 2007; Thurstone, 1927). The present study aims to examine in more detail, mechanisms contributing to age-related differences in episodic memory. Specifically, it is hypothesized that age differences in episodic memory performance are due, at least in part, to age-related differences in neural noise/entropy (i.e., the deleterious effects of increased randomness in a physical/biological system that can reduce memory familiarity by interfering with the representation of order, time, or location) (Allen, Kaufman, Smith, & Propper, 1998a, 1998b, Mallik et al., in preparation) that result in differences in response bias that disproportionally affect older adults (to be tested in Experiment 1), as well increases in proactive interference (Experiment 2). As discussed in more detail later, the neural noise theory allows for a theoretically plausible framework for what is neurologically causing age-related differences in episodic memory, unlike other accounts which describe associated dysfunctions in: speed of processing (Salthouse, 1991,1996), inhibition (Hasher & Zacks, 1988), working memory (Baddeley, 1992) and sensory function (Lindenberger & Baltes, 1994.

1.1.Human Long-term Memory

Long-term memory (LTM) is widely studied due to its importance in everyday life. It is often necessary to recall certain facts, remember certain events, or follow procedures stored in memory. Mitchell (1989) reported evidence for three separate memory systems in an aging study using factor analysis. Three factors loaded onto the model with factors 1, 2 and 3 accounting for 21.8%, 18.7% and 14.6% of the variance respectively. The first factor represented episodic memory, the ability to recall certain autobiographical events with contextual cues (e.g., time, space, or emotional state), such as a detailed recollection of the first time that an individual drove a car. The second factor represented was procedural memory, the ability to remember certain procedures in life, such as highly practiced motor memory (e.g., walking, swimming, or riding a bike). The third factor represented was interpreted as semantic memory, which is context-independent memory that involves our general knowledge of the world. Semantic memory refers to instances where people can recall certain facts, such as how many states are in the USA, but cannot recall exactly when or where the information was learned.

Age differences in episodic memory are robust in the literature. A meta-analytical study of episodic memory showed that older adults are about 1 standard deviation below younger adults in tasks such as list recall (Verhaeghen, Marcoen, & Goossens, 1993). Generally speaking, semantic memory is maintained with age. In the Seattle longitudinal study which included approximately 6,000 participants, word knowledge increased or was maintained with age (Schaie, 1996). In another meta-analytic study, including 210 articles, older adults showed an advantage in vocabulary tests compared to younger adults with a group difference as large as .8 standard deviations in vocabulary tests (Verhaeghen, 2003). While most aspects of semantic memory are maintained with age, one ability which has shown some decline is the ability to remember names (Cohen & Faulkner, 1986)—although this may require contextual/episodic processing. Unlike patterns in semantic memory, a longitudinal study by Rönnlund et al., (2005) suggests that age differences in episodic memory begin around age 60. These episodic differences extend to item recognition (Coyne, Allen, & Wickens, 1986), spatial recognition (Allen, 1991; Allen et al., 1998a, Allen et al., 1998b) and recall (Verhaeghen & Marcoen, 1993).

Human cognitive aging is characterized by increases, decreases and maintenance across a variety of domains, which are subject to great levels of individual difference (Dixon, 2000; Drag & Bieliauskas, 2010). Three domains that are particularly sensitive to age-related differences are processing speed, working memory and inhibition (Baddeley, 1986; Hasher & Zacks, 1988; Salthouse, 1991,1996). In fact, these domains account for so much variance in age-related differences across cognitive studies that they were each proposed to be the common cause of age-related change. While these theories have been helpful, they provide little in understanding the causal mechanisms at the more basic level (e.g., why do older adults have slower processing speed; Allen, 1991; Allen et al., 1998a, Allen et al., 1998b).

1.2 *Theories of Episodic Memory*

A common finding in the field is that old information hinders subsequent learning, especially if the material is similar (Keppel & Underwood, 1962). This phenomenon is known as proactive interference (PI). Some of the best evidence for PI comes from the release from PI phenomenon (Wickens, Born, & Allen, 1963), where PI no longer interferes with subsequent learning when new items are drawn from different classes. This means that additional to-be-remembered words do not hinder performance if they are of a different category. For example, using a short-term memory task, Keppel and Underwood (1962) found that when items were of the same class (consonants, numbers or common words) that performance dropped from the first to the third or fourth trial, demonstrating that earlier items interfered with subsequent retention performance (PI). In Wickens et al., (1963), participants were presented 8 trials per block. The blocks consisted of consonants and numbers, and these were presented sequentially. The order consisted of three of one group, followed by 3 of the other, followed by two of the original group, thus the possibilities were (NNNCCCNN or CCCNNNCC: where N=number and C= Consonant). Performance went down from trials 1 to 3, then up at trial 4, then down until trial 7 and then down again at trial 8. These results produced strong evidence for the release from PI after a shift in item type (from number to consonant or from consonant to number). At continuous presentation of the same class of items, performance initially spiked (e.g. release for PI), then quickly declined until another class was presented (e.g. PI), which increased performance (e.g. release from PI; See Figure 1).

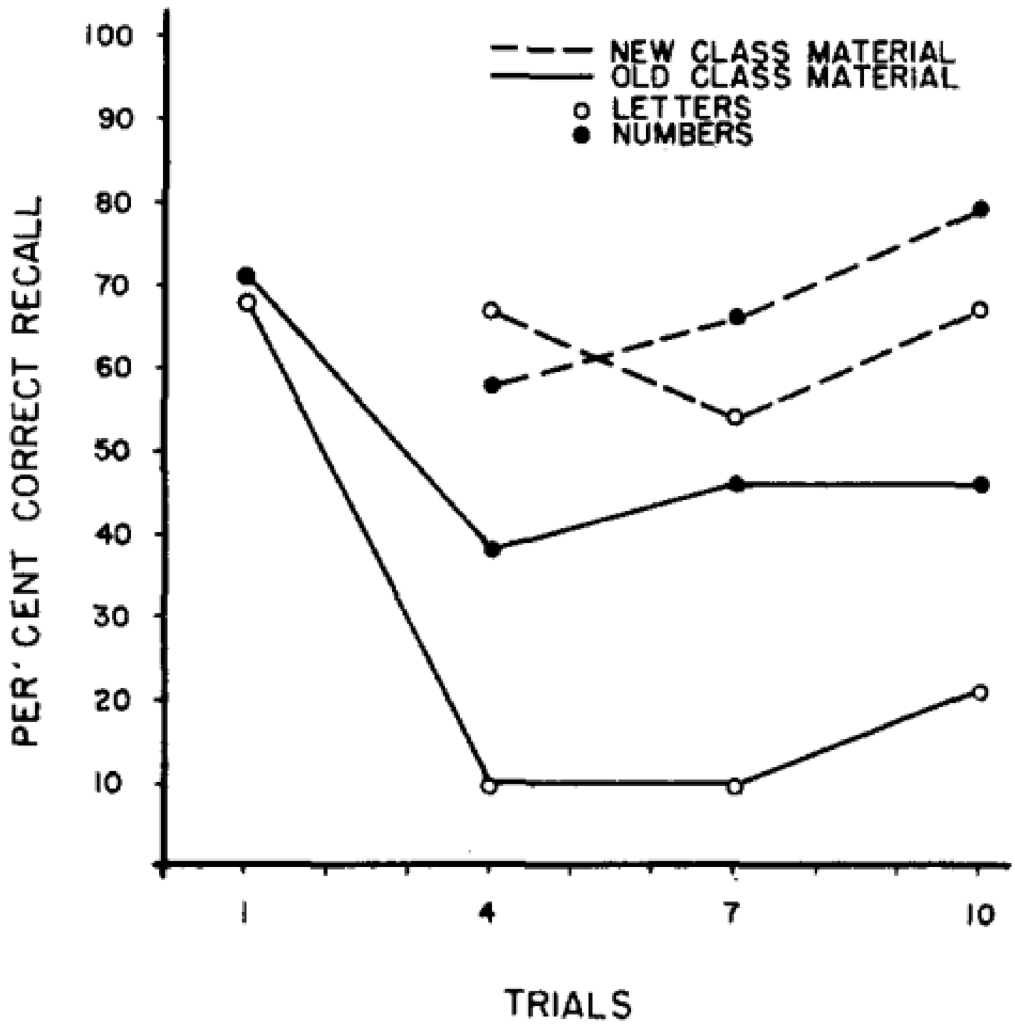

Figure 1. Proactive Interference (Wicken, Born and Allen, 1963)

The SIMPLE (scale-independent memory, perception, and learning) model can help explain why PI occurs. According to the SIMPLE model developed by (Brown, Neath & Chater, 2007), greater levels of neural noise facilitate increased interference (in space, time, and emotional contexts) in episodic memory tasks for older adults, leading to decreased performance. The SIMPLE model provides a theory of memory which is based on four main claims. First, a significant amount of a memory's strength can be accounted for by the to-be-remembered (TBR) item's location in relation to other TBR items in psychological space (this is an extension of the model presented by Allen et al., 1998a). Second, across different timescales, similar mechanisms direct memory retrieval. Third, errors on memory tasks are due to interference with other items, and lastly, interference can account for all forgetting that occurs (e.g., not trace decay). The SIMPLE model assumes that episodic memories occupy a multidimensional psychological space that is reliant partially on temporal distances between items and other factors such as similarity between items. The timeline in psychological space is logarithmically compressed, meaning that distant locations (items presented earlier) will be relatively closer to one another (i.e more confusable), than items more recently presented. The probability of an item being retrieved is inversely proportional to its summed confusability with other items being stored in memory. Items which are most distinct is psychological space, meaning further away from other distracting items are more likely to be remembered. This theory is for all to-be-remembered items, whether it be a recall or recognition task.

This temporal interference model provides insight to why previously learned TBR items have the tendency to hinder subsequent learning of TBR items (PI). The old items take up psychological space which interferes with future learning. Figure 2 shows a logarithmically compressed model of 20 items and Figure 3 shows a logarithmically compressed model of 10 items. The first 10 item in Figure 2 which were omitted from Figure 3, hinder subsequent learning by creating additional interference between items.

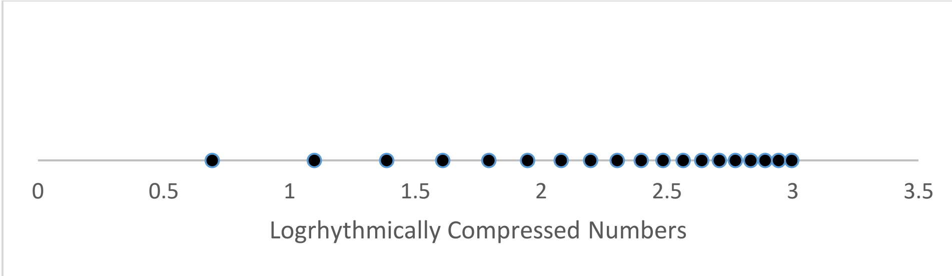

Figure 2. Twenty compressed items

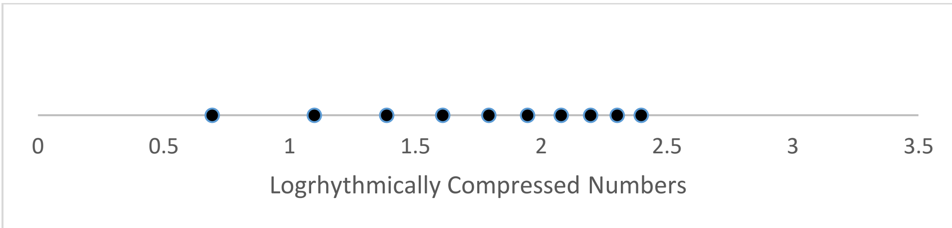

Figure 3. Ten compressed items

Because of the added confusability with other items, performance with 20 items is worse than performance with 10 items. Graphical depictions of the SIMPLE model illustrate how PI functions by suggesting the concept of multidimensional psychological space. Just as interference is affected by temporal space between presentation, semantic proximity also affects interference. Figure 4 and Figure 5 illustrate how changing semantic categories leads to a release from PI (i.e. more distinctive space in psychological space due to an increase of variability in semantic space). The items in Figure 4 are all positive words, where the items in Figure 5 are half positive words and half negative words. Because the positive and negative words are held in different areas of semantic cognitive space, they show lower levels of interference than the list of all positive words (this can be seen by greater average distances between points).

Memory representations become more easily overlapped and confused with increased levels of entropy (randomness/disorder in a biological system), as shown by a manipulation of physical distance and its effect on interference (Mallik et al., in preparation). In the SIMPLE model, as levels of entropy are increased, memory representations become increasing closer in psychological space, leading to additional errors in recognition. Previous studies have shown this phenomenon in STM (Allen et al., 1998a) and spatial attention (Mallik et al., in preparation). Experiment 2 aims to extend these findings to recognition memory through a manipulation of semantic cognitive space.

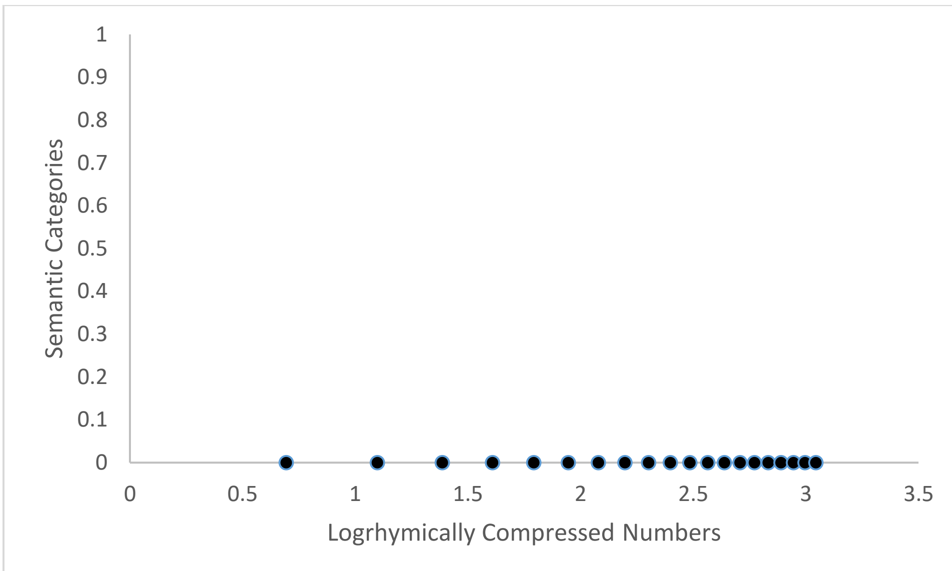

Figure 4. Twenty positive words

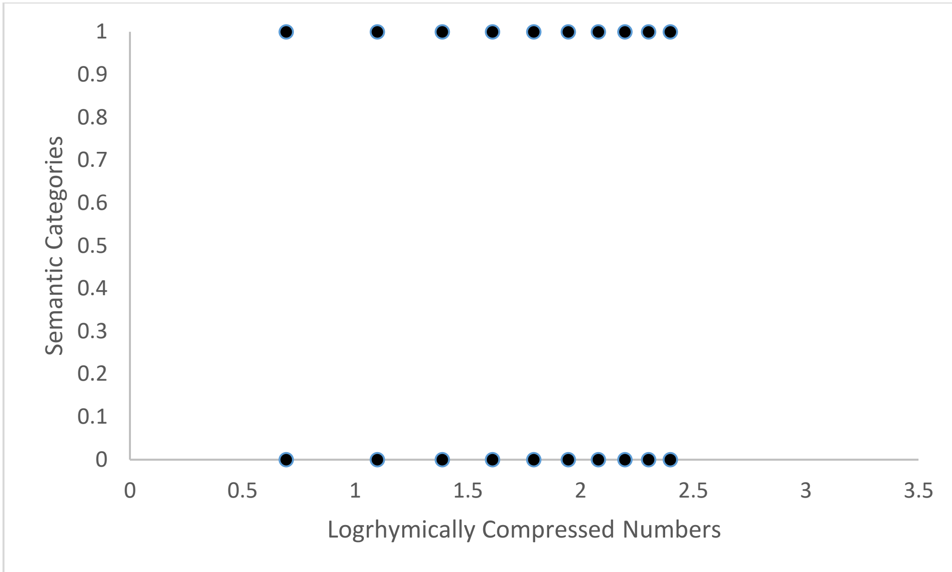

Figure 5. Ten positive words and ten negative words

Individual differences in susceptibility to interference may be at least partially explained by the law of categorical judgment. According to this theory, all sensory (discriminal) processes result in a sensory value which is formed on a quantitative continuum based on the strength of the signal (Thurstone, 1927). This value is hypothesized to fluctuate across instances in a normally distributed fashion. Discriminal dispersion represents the amount of variance in sensory values of a stimulus and is quantified its standard deviation.. Applied to a recognition memory paradigm, the strength of any to-be-remembered word will land somewhere on a continuum between well encoded (likely to recognize) and poorly encoded (unlikely to recognize). If hundreds of words are presented, and a value was given to each word on the continuum, its distribution would resemble a normal distribution. A larger discriminal dispersion would be indicative of increased variability in points across the continuum. It is thought that oscillations (or disorder) in a signal, leading to a larger discriminal dispersion is due to entropy (increased randomness in a physical system). Discriminal dispersion has been approximated using behavioral (Allen, 1990, 1991; Allen et al., 1998a; Noack, Lövden and Lindenberger, 2013; Mallik (in preparation), and electrophysiological measures (Mallik – in preparation). Noack, Lövden and Lindenberger (2013) operationalized discriminal dispersion as the standard deviation of their psychometric model built to predict behavioral performance for a change detection task. Older adults had a greater standard deviation than younger adults providing evidence for increased discriminal dispersion in older adults.

Therefore, we argue that interference in human memory may be explained by confusability with other items. Memory errors are most likely to occur when confusability is high, such as when words are not distinct semantically or temporally (SIMPLE). This can be further exacerbated by increased variability of sensory and cognitive processes (discriminal dispersion), leading to less distinct memory representations. The effect of increased randomness in a physical system (entropy) leading to lower quality memory, as been labeled "neural noise" (Allen, 1990, 1991; Allen & Coyne; 1988; Cremer & Zeef, 1987; Welford, 1958).

Yates conceptualized the role of entropy across the lifespan (Yates, 1988). According to Yates, entropy directly opposes homeodynamic stability which is necessarily for growth, maintenance and order in the human biological system. Homeodynamic stability begins low as a newborn and reaches peak maturity at approximately age 30 (Yates, Benton & Rosen, 1995). At this age physiological processes are functioning at their peak. After the age of 30, there begins a gradual decline in homeodynamic stability until approximately age 70, where the rate of senescence sharpens (figure 6). Death occurs when the threshold of minimum stability for system autonomy is crossed, leading to destruction of reasonable order with the living system (Schroots, 1998; Schroots & Yates, 1999).

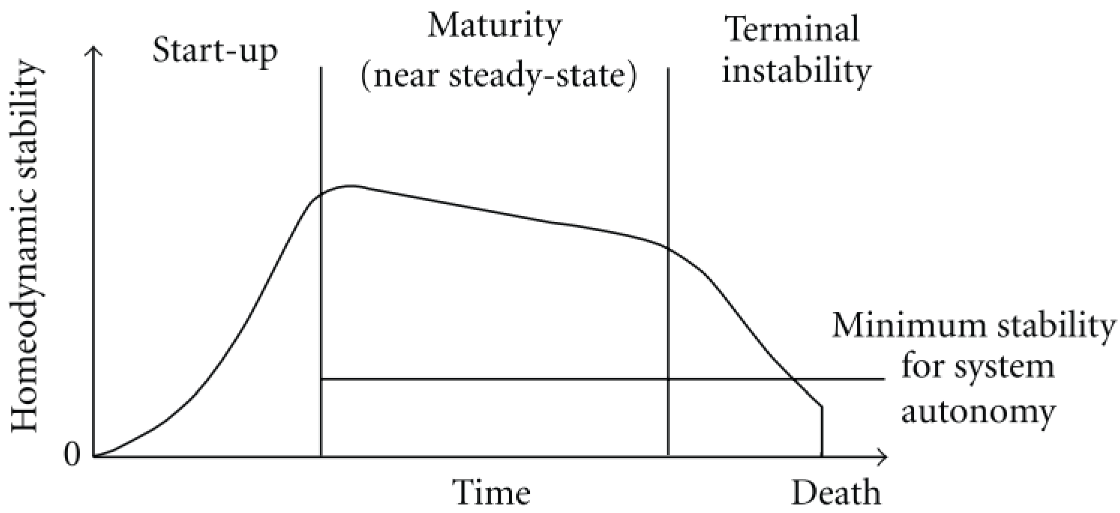

Figure 6. Homeodynamic Stability (Yates, Benton & Rosen, 1995)

Specific to human memory, Allen et al., (1998a) used a statistical physics method to compute entropy across age groups using a molar neural network model. The modeling provided strong evidence that older adults exhibit higher levels of entropy than younger adults in a very-short-term-memory task (VSTM). Entropy in Allen (1998a, 1998b) was calculated by equation 1 which was used to calculate the entropy of a subject in an experimental condition with a set of N possible outcomes.

$$S = -\sum_{j=1}^{N} p_j \ln p_j \qquad (1)$$

Where p_j is the relative frequency of outcome #j.

Equation (1) is the standard formulation (C. E. Shannon, 1948) of uncertainty as it satisfies certain common-sense requirements: (1) the lowest entropy (S = 0) corresponds to one of the p's being 1 and the rest being zero (i.e., perfect information); (2) the largest value for the entropy, S = lnN, is achieved when all p's are equal to each other (i.e., the absence of any information); and (3) S is additive over partitions of the outcomes.

Allen et al. (1998a, 1998b) showed that behavioral data (RT and errors) fit the pattern of results predicted by an entropy model. The molar entropy model (a computational "temperature" model based on the Boltzmann-Gibbs equation—in which it is assumed that entropy increases in a molar neural network in older adults relative to younger adults) successfully predicted the real data points across experiment 1 and experiment 2 within a 95% confidence interval in 83 of 84 instances (Allen et al., 1998a). Figure 7 shows the fit of the model across all conditions of experiment 1. Figure 7 shows the empirical and predicted probabilities of each outcome for a same response. In this location discrimination task where each trial consisted of a target, followed by a mask and with a probe in which participants were asked to respond. The target, mask and probe could all appear in one of seven horizontal locations in the center of the screen. If the probe location was the same as the target locations participants were instructed to indicate a "same" response, and if the target and probe were in different locations, they were instructed to indicate a "different" response. The probe was either located in the same location and the target (same trial) or located between one and three spaces to either the right or left (different trials). In the figure 3, -3 indicates that the probe was three spaces to the left from the target, 0 is the same location and 3 indicates that the probe was three spaces to the right. Probe duration was manipulated within subjects creating three conditions (100ms exposer, 200ms exposer and 400ms exposer).

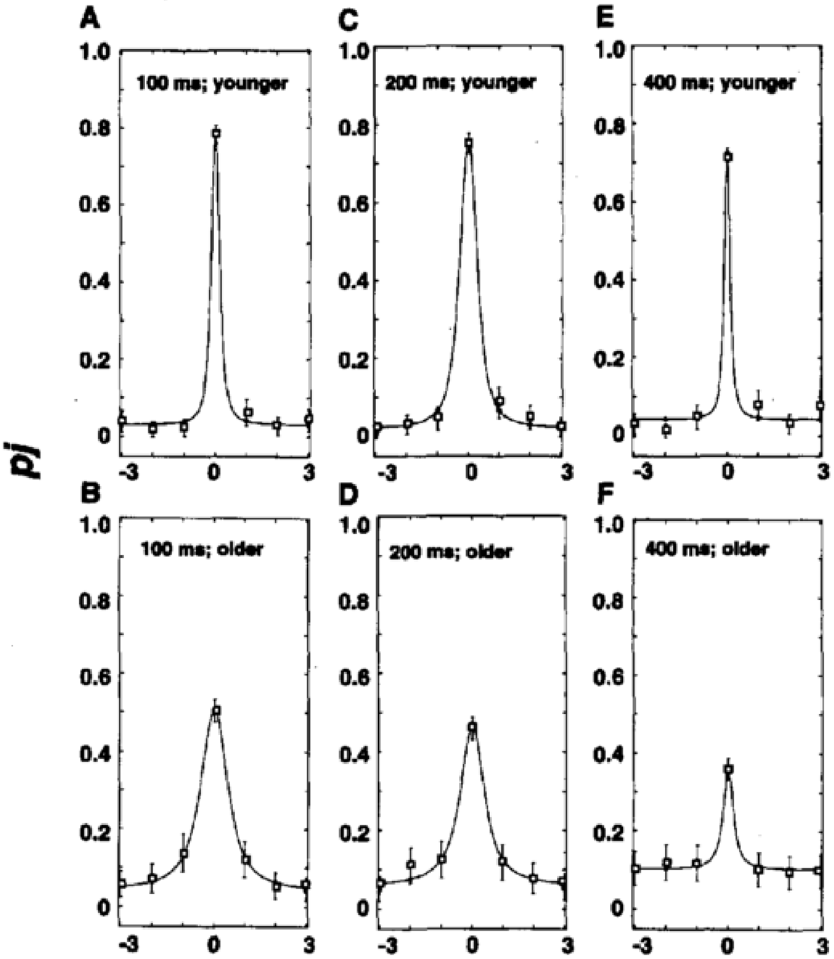

*Figure 7: P*rediction from the entropy algorithm (Allen et al., 1998).

Mallik (in preparation) used a spatial probe task (based on Allen et al., 1998a) in which a target would appear in the same location as the probe on 50% of trials, or would be shifted to a different location, 1, 2 or 3 spaces to either the left or right of the original target location (transposition distance). Participants were asked to indicate if the probe moved. Using an electrophysiological measure of perceptual categorization, where more difficult probes elicited a larger effect (P3 ERP component: measured in Parietal scalp regions). This study aimed to examine the theories of entropy and speed of processing in spatial memory. The study was designed to where each theory would predict different results. The entropy account would predict a Transposition by Age interaction where older adults would exhibit larger differences across transposition distances than younger adults. That is, older adults would show relatively more familiarity for "no" probe items shifted one space from the original target position than would younger adults, but both groups would show low familiarity for "no" items shifted two or three positions from the original target position. Meaning that spatial representations were close in physical space (target shifted 1-space away from the probe) were the most likely to be confused by older adults). Older adults disproportionately benefitted from the manipulation to a larger distance (target shifted 3-spaces away from the probe) than younger adults creating an Age by Transposition effect interaction. These data provide evidence for increased interference for older adults because their performance was more greatly impacted by interference caused by spatial proximity.

According to the entropy account, familiarity should fit a normal distribution, and the standard deviation of this distribution should increase with increasing entropy. That is, as entropy increases, the distribution describing transition distance effects should become "flatter" (more platykurtic). This means that as entropy increases, transposition distance effects for "no" trials should show a steeper slope. The speed of processing account would predict no such interaction and was not supported by these data.

Figure 8 and Figure 9 are taken with permission from Mallik et al., (in preparation) to graphicly display this transposition distance effect and steeper slope. This can be observed as a transposition distance by age interaction, where older adults exhibited increased differences/variability across distances, lending evidence to the entropy account.

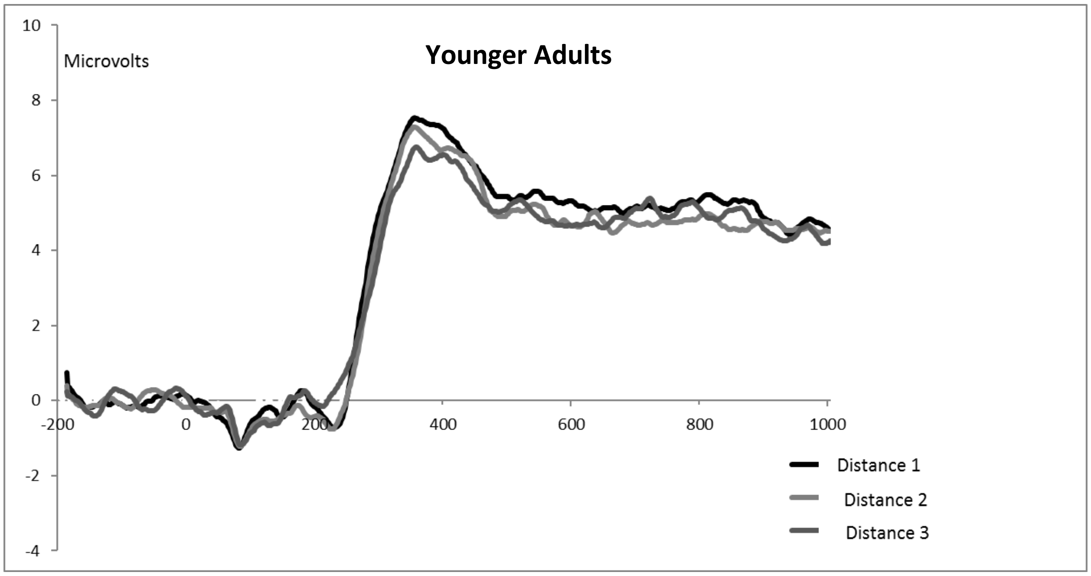

Figure 8. P3 component across transposition distances for younger adults.

Figure 9. P3 component across transposition distances for older adults.

1.3 *Event-Related Potentials Indexing Recognition Memory*

The field of human memory has received a vast amount of attention over the last 40 years. During this time, most of the memory research has been conducted using only behavioral methods (yes/no decisions on whether information is recognized). Although these behavioral methods have proven insightful to human performance and its limitations, more direct measures such as EEG have received markedly less attention. When combined with behavioral measures, the EEG adds valuable and unique information to help better understand the time-course of various cognitive events, such as familiarity and recollection (Lien, Allen & Crawford, 2012; Lien, Allen & Martin, 2014; Vogel, Luck & Shapiro, 1998).

Using extreme temporal precision, they can tap into underlying cognitive processes to reveal individual operations and their hierarchical organization. Unlike behavioral measures, ERPs are not reliant on a behavioral response. This makes them useful in collecting measurements in people who are unable to respond, unwilling to respond, or attempting to conceal information. Schoenle et al. (2004) used the semantic memory ERP N400 to show that some individuals who could not provide an overt response, still semantically processed information. In this study, 12% of those in a vegetative state showed a clear semantic memory ERP as did 76.7% of individuals in a near vegetative state.

Further evidence of significant ERPs without a behavioral response was shown in Farewell and Donchin (1986, 1991). They used the P3 component, which is sensitive to the effects of probability, to detect deception by identifying the objects related to crimes or antisocial acts which the participants had knowledge of. The P3 wave was larger for items that they saw less frequently. Using a stimulus presentation where one target is less common than other targets will induce a larger P3 wave for the less frequent target, this is known as the oddball paradigm (Sutton, Braren, Zubin, & John, 1965). Allen et al. (1992)

used a similar oddball paradigm that instead required participants to learn a list of words. Similar results were obtained in this experiment, where learned words, which were provided at 1/6 of the frequency of unlearned words elicited a large P3, meaning that learned words able to be differentiated from unlearned words due to ERP amplitude. This was also found in Hooff, Brunia, and Allen (1996), providing further evidence that event-related potentials serve as a dependable direct measure of recognition memory. Critically for this study, the P3 is not affected by later processes of response criterion, unlike behavioral methods where responses are inevitably confounded. The P3 provides a pure measure of categorization which is not contaminated by decision making threshold for response (response criterion). This is particularly important for future studies because this method removes the potentially confounding element of response criterion and directly measures recognition. For instance, if younger and older adults showed identical ERPs for recognition memory (i.e., they showed equivalent familiarity for "yes" trials), but older adults performed worse behaviorally, with a tendency to have a more conservative response criterion through a signal detection theory approach, it would provide evidence supporting the notion that cognitive function of recognition memory is preserved with age (at least in terms of "hit" performance). Under these hypothetical circumstances, the age-related differences would likely be attributable to increases in entropy for older adults resulting in greater neural noise (i.e., older adults would have the same familiarity for "yes" items, but higher familiarity for "no" items as yes items). In order to compensate for the increased familiarity for "no" items presented close to the original target position, older adults appear to adopt a more conservative response bias. If older adults show the same P3 amplitude for "yes" trials, but relatively higher "no" amplitude, but show lower accuracy for recognition memory trials (more "misses" and lower "hit" rates) than younger adults, then this will provide a more complete picture of age differences.

Electrophysiological investigations of recognition memory have identified a robust ERP component for familiarity and recollection (Strozak et al., 2016). The familiarity-based component is known as FN400, (Curran, 2000) which is a positive mid-frontal component typically measured between 300-500ms post stimulus onset. The recollection-based component, known as the Late Positive Complex (LPC) is typically measured between 500-800ms post-stimulus onset and is largest in the central and parietal regions (Strozak et al., 2016). Both familiarity-based, and recollection-based ERP components are measured by subtracting the associated ERPs of correctly rejected new items (correct rejections) from old items (hits). This is done to quantify the difference between items which were recognized and items which where correctly rejected.

The preponderance of evidence suggests that normal aging is associated with decreased recollection, while familiarity remains relatively intact (Yonelinas, 2002). A more recent meta-analysis found moderate to large age-related differences in recollection, and small but detectable age-related differences in familiarity (Koen & Yonelinas, 2014). In studies using methodologies that typically lead to relatively lower recollection scores, age differences in recollection are found (Jacoby, 1999; Jennings & Jacoby, 1997). When using paradigms that lead to greater overall accuracy, (higher than .6; Johnson, Gross & Angell, 1997; Perfect & Dasgupta, 1997) age-related differences are less likely to be found in recollection. It is believed that this finding may represent a ceiling effect (Yonelinas, 2002). Older adults tend to show an interaction between recollection and task difficulty, where items which are easier to recall are unaffected by age, and items which are more difficult to recall show an age-related decline. It is thought that the primary mechanisms leading the reduced recollection include reduced encoding by associative and strategic components (Moscovitch, 1992; Werkle-Bergner, Müller et al., 2006) and frontal lobe dysfunction (Yonelinas, 2002).

The present studies will use an Old/New item recognition paradigm. In this Old/New item recognition paradigm, participants were asked to remember items during a learning phase, which is followed by a testing phase, which includes half learned items and half new items. Participants were then asked to indicate whether the item is old or new. Previous electrophysiological investigations of aging using the Old/New item recognition paradigms have typically used either pictures (Ally et al., 2008b; Craik & Schloerscheidt, 2011- experiment 1b; Yonelinas, 2002) or words (Ally et al., 2008a; Craik & Schloerscheidt, 2011- experiment 1a; Nessler et al., 2007; Wolk et al., 2009).

Previous investigations have shown the importance of stimulus type (picture or word) on result. Older adults tend to recognize pictorial stimuli better than words (Ally et al., 2008; Craik & Schloerscheidt, 2011). One explanation for this being that, pictures provide a richer array of perceptual detail than words (Yonelinas, 2002). Applied to this SIMPLE model, pictorial stimuli may hold highly distinctive locations is psychological space due to its perceptually rich detail and distinguishable features. Perhaps even with individuals moderately higher levels of entropy, the memory representations of pictorial stimuli are distinctive enough to not be confused. In recognition tasks using words the deleterious effects of entropy are more likely to be found due to memory representations holding closer areas of psychological space (e.g. higher confusability). The entropy theory would suggest that entropy is experienced by all individuals and that entropy tends to become greater with increased age. The deleterious effects of entropy are only to occur when the task difficulty is high enough for the level of disfunction to show through a behavioral response. Previous findings would suggest that recognizing pictures is a task that is easy enough that the threshold for task difficulty and entropy, to where deleterious effects are found is not met. This is an important thing to note, as increased levels of entropy cannot cause memory performance change in some scenarios. The present study will use words, because the ability to remember words is of practical interest in everyday life, and this task is of adequate difficulty.

1.4 *Age-Related Changes in Response Criterion*

One common finding in the cognitive aging literature is that younger and older adults tend to have different thresholds for decision making. The term “response criterion” will be defined in this paper as the propensity to favor a particular response in a decision-making task. In this case, a participant might disproportionality label words “old” or “new” in a recognition memory task. One of the most robust findings across cognitive tasks, is a speed-accuracy tradeoff is found between younger and older adults (Pachella 1974). For all tasks, participants must balance between responding as quickly as possible and responding as accurately as possible. Common practice is to ask participants to provide equal amounts of attention to both. Often, participants are told to “respond as quickly and accurately as possible”. By asking participants to respond in this manner, the experimenter is intentionally encouraging a response criterion which favors both accuracy and speed equally. Even with these instructions, it is common for older adults to respond more accurately and slower (Allen et al., 1993).

If response criterion is stable across age, it would lead to clarity in results, however if response criterion sets are different, it would lead to more ambiguous findings. Similar to older adults being “more conservative” in time needed to make a response, a common result across cognitive tasks is that older adults tend to be “more conservative” in response criteria (Coyne, Allen & Wickens, 1986; Danziger, 1980; Poon & Fozard, 1980; Ratcliff, Thapar & McKoon, 2004). In a recognition task a more conservative response criterion would require additional certainty before labeling a stimulus as recognized. Diffusion models have shown that older adults require additional information before deciding than younger adults do (Ratcliff, Thapar, Gomez, & McKoon, 2004; Ratcliff, Thapar, & McKoon, 2001). Because of this decision-making strategy, less items would be correctly recognized (hits), and fewer items would be falsely recognized (false alarms; Figure 10).

	Old Item	New Item
Yes	Hit	False Alarm
No	Miss	Correct Rejection

Figure 10. Signal Detection Theory

Like speeded perceptual tasks, recognition memory is another area of inquiry where response criterion may be affecting results. As in speeded perceptual tasks, older adults tend to have a more conservative response criterion than younger adults (Poon & Coyne et al., 1986; Danziger, 1980; Fozard, 1980). In recognition memory, most paradigms present one or multiple targets at a time to be remembered for future testing. Participants are later asked to identify whether words were presented during the previous study phase. The words could be from the study phase (old word) or a decoy word which was not on the study phase (new word). Older adults do as well or better than younger adults on correctly rejecting words which were not presented in the study phase. However, large age differences are found for old words, meaning older adults do not recognize previously presented items as well as younger adults. These age differences are further exacerbated by increasing task difficulty (i.e., adding additional items per probe and when investigating secondary memory instead of primary memory; Coyne et al., 1986). Poon and Fozard (1980) note that age differences in identifying old words are only found when at least four distractors are presented or at least 12 seconds have passed since the original presentation.

Because familiarity tends to be maintained with age (Yonelinas, 2002), it is possible that recognition memory, which is reliant on both familiarity and recollection (which shows more age-related change), is more intact than previous studies have concluded for many older adults. Older adults may have a more conservative response criterion than younger adults due to increases in internal noise, meaning that older adults will need a greater level of recognition to elicit a positive response. If older adults recognize old words, but not enough to reach their higher response threshold, it will lead to additional incorrect responses for old word trials (misses). This interpretation is consistent with the finding that older adults tend to have far more misses (not recognizing an old word) than false alarms (incorrectly identifying a new word as an old word).

The hypothesis of a more conservative threshold for older adults to require a “hit” can be tested using ERPs. If older adults do have a higher threshold for “hits” it would mean that old word trials with relatively moderate amounts of recognition will be “Misses”. These trials would differ considerably in levels of recognition relative to correct rejections, where older adults would have extremely low levels of recognition because they perform well at correctly rejecting false probes. Using the ERP components P3, LPC and FN400 we will be able to measure recognition levels (by using ERP-based amplitudes) of "misses" relative to "correct rejections". If older adults show a higher-amplitude P3, LPC or FN400 component (relative to younger adults) indexing recognition "misses," this would suggest that they are retaining the episodic memory information better than previously thought. This would support the account that age-related changes in response criterion are partially responsible for age related changes in recognition memory.

To our knowledge, this method of measuring ERPs in a signal detection framework is novel to the field and will allow researchers for the first time to examine response criteria from temporally precise electrophysiological brain voltage. This method will allow us to gauge levels of recognition for each trial, something that a behavioral measure would be incapable of doing. This is critically important to the present study, as we can measure the decision-making threshold of how much recognition is needed to elicit a "recognized response". Additionally, we suggest that the age-related pattern of a more conservative response criterion with increased age is due at least in part to greater levels of entropy in older adults. Specifically, increased neural noise leads to less clear memory representations which lead to older adults to question themselves more.

1.5 Signal Detection Theory (SDT)

In working airport security, is it preferable to falsely detect a non-dangerous package, or fail to detect a truly dangerous package? On your business email server, would you rather have the spam filter mistakenly label true mail as spam, or allow actual spam into your inbox? These error tradeoffs are relevant across professions involving categorization judgements. Similarly, in recognition memory tasks, participants must decide if mistakenly identifying a new item as an old item (false alarm) or failing to recognize an old item (miss) is preferable. From this judgment, a response criterion is formed, which facilitates the propensity to favor an "old item" or "new item response". Figure 11 shows the distribution of new words and old words on recognition. Naturally the old words will have higher levels of recognition than the new words because they were seen during the learning phase. However, there is an amount of overlap in the distributions meaning that some new words will be as recognized or more recognized than some of the old words. As a result, some degree of error is likely to occur. The black vertical line represents the location of the response criterion. Because in this model the response criterion is at "2", all words recognized at a "2" or higher will be labeled "old words" and all words underneath this threshold will be labeled "new words".

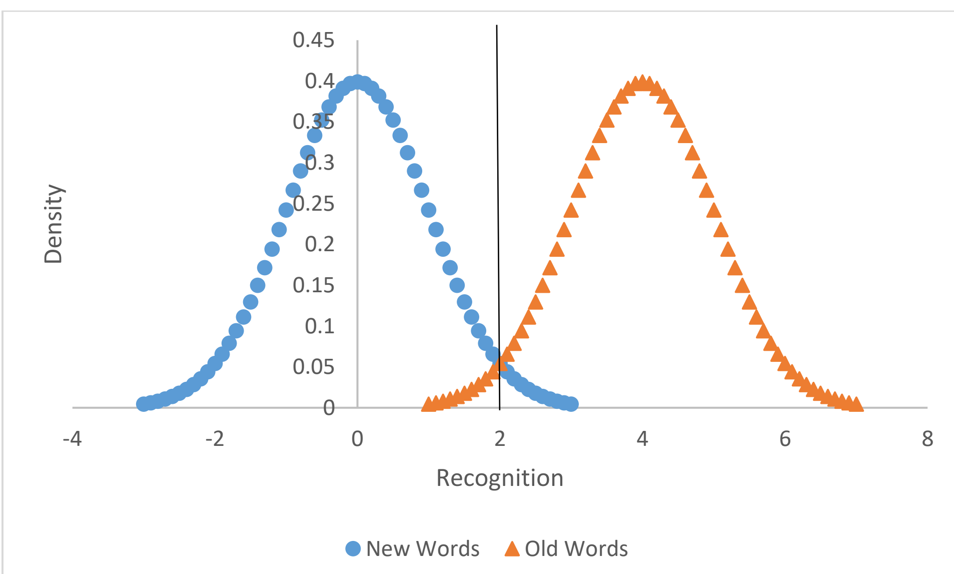

Figure 11. Recognition distribution.

As seen in figure 11, the black line is the response criteria. Items greater than 2 on recognition will be labeled old words and items less than 2 will be labeled new words. The area to the right on the response criterion under the "Old Words" distribution is a hit. The area to the left under the "Old Words" distribution is a miss. The area to the right on the response criterion under the "New Words" distribution is a false alarm. The area to the left under the "Old Words" distribution is a correct rejection.

If the criterion were to be shifted to the right, it would limit the amount of false alarms, but reduce the number of hits. If the criterion is shifted to the left it would increase the number of hits and increase the amount of false alarms. It is expected that younger and older adults will vary on two aspects of the signal detection process. First, younger adults will have a better discriminability index (d': hit rate – false alarm rate) than older adults. This is predicted because younger adults typically perform significantly better on recognition tasks relative to older adults. Second, older adults will have a more conservative response criterion than younger adults (β). Figures 11 (younger adults) and 12 (older adults) illustrate how these age differences affect the components of SDT. These two differences manifest as younger adults having less overlap between "old" and "new" word distributions as the two distributions are further apart, and older adults having a response criterion pushed further to the right (indicating a more conservative response criterion that limits false alarms at the expense of fewer hits). In signal detection models it is essential to control for additional variables when making an inferential judgement (E.g. d', β). Because response criterion (β) is central to our hypotheses, we must control for d' to allow for inferential judgements on age-related differences. Due to traditionally found age-related increases in variability and subsets of older adults who perform as well or better than younger adults, we can use this high performing subset on older adults with equal d’ scores to compare to younger adults when analyzing age-related differences in β.

Applied to the present study, assuming age-related increases in neural noise, two specific predictions are made. First, one strategy for dealing with increases in internal noise is to make one’s response criterion more conservative (Mallik et al., in preparation). Not only should this increase response bias using traditional signal detection theory methods (e.g., beta), but it should also result in relatively higher-ERP amplitudes on miss trials for older adults than for younger adults (compared to hit trials). Second, if increases in neural noise result in increases in interference, then older adults should show a smaller release from proactive interference (e.g., Wickens, 1972) than younger adults for both behavioral and ERP measures.

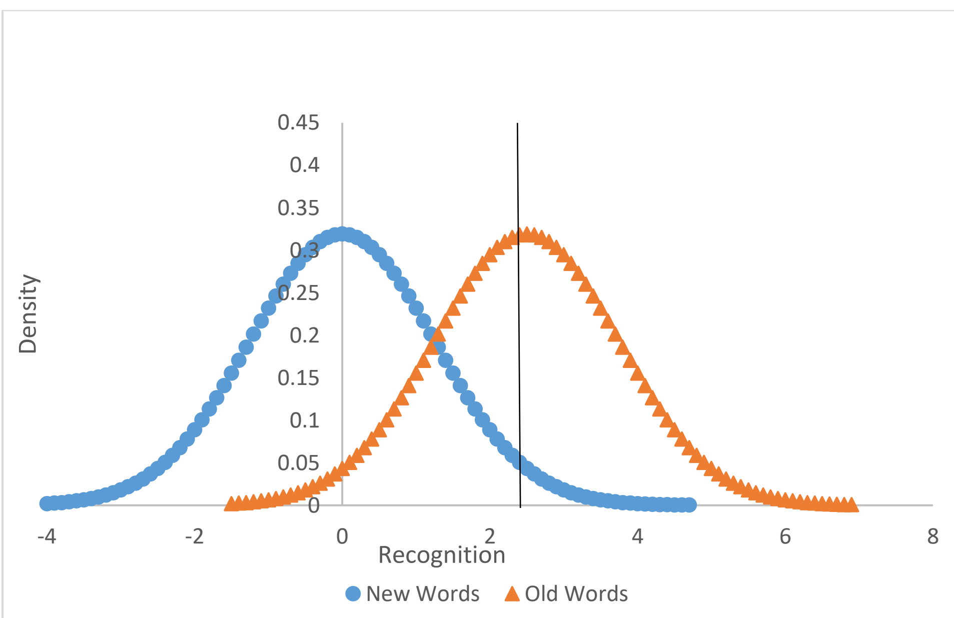

Figure 12. Older adult signal detection model.

1.6 The Present Experiments

The present study will consist of two experiments. The first experiment will examine whether response criterion differences between younger and old adults exist using a combination of behavioral and electrophysiological measures for a recognition task. In the first experiment, participants will be asked to remember as many words as possible from list of 100 words. The targets will be words from the English language and will be presented for three seconds each. Immediately after this learning phase, participants will be asked to make a new/old recognition judgement, where they will press the response key indicating “old” if the word was shown on the study list and press the key for “new” if the word was not on the original study list. In Experiment 1, the first list will be of 100 positive words, which participants will be asked to make “Old/New” judgments on a later task which includes 100 distractor positive words. Experiment 2 will use five molar blocks of trials: one with the same single category of positively valenced words to be used in Experiment 1, and other blocks of trials using four different semantic categories (Animals, Fruits, Money, & Sports) making associative binding easier, and providing greater release from proactive interference, making the task less difficult (Brown et al., 2007; Naveh-Benjamin, 2000, Wickens, 1972). The reasoning for including this manipulation is that if older adults have increased neural noise compared to younger adults, then the oscillations predicted by entropy model Allen et al. (1998a, Mallik et al., in preparation) and the SIMPLE model of Brown et al. should increase the effect of proactive interference in older adults relative to younger adults—thereby resulting in an increase in the release from proactive interference for older adults. This can be observed by an age group by condition (one-category vs. four-categories) interaction, where older adults will benefit from the manipulation of switching between one and four semantic categories. A more detailed discussion will be provided in the following research questions and hypotheses section.

1.7 *Research Questions and Hypotheses*

Research Hypothesis and Question for Experiment 1

Research Question 1: Can age differences in recognition be partially explained by differences in response criterion?

Research Hypothesis 1: Older and younger adults will use different response criteria when making recognition judgements as measured by signal detection and ERP methods. This will be informed by traditional SDT measures and ERPs (to be described in more detail in the data analysis section). Previous research has shown that older adults tend to use a more "conservative" response criterion in recognition memory experiments (Coyne, Allen & Wickens, 1986; Danziger, 1980; Poon & Fozard, 1980). It has been suggested that age-related difficulties in encoding, transferring information from primary to secondary memory and retrieval – facilitated by interference caused by entropy may be responsible for this pattern of results (Allen et al., 1998a; Brown et al., 2007; Mallik et al., in preparation). An entropy model would suggest that, due to increased levels of interference, memory representations are less clear in older adults, leading to less confident responses and a more conservative response criterion. The present study examines whether age-related changes in response criterion affect accuracy scores in recognition memory tasks. A similar finding has been shown in perceptual tasks, where a more conservative decision strategy in older adults is an important factor to assess when analyzing age differences (Salthouse, 1979).

Research Hypothesis 2: The cognitive mechanisms supporting recognition memory are more intact than previously thought. If age-related differences in response criterion are a contributing factor to recognition memory, it would give support to the notion that cognitive processes are not the only mechanism at play and that recognition memory is better preserved than previously thought for older adults. Support for this claim would come using the ERP method and SDT approach, with the FN400 and P3 component which measure familiarity and categorization respectively. Because older adults have shown to use a more conservative response criterion, some older adult "misses" should occur when they have equal amounts of recognition to younger adults who get a "hit". By comparing miss amplitude to correct rejection amplitude on these waves we will be able to index "recognition below threshold" which is a more sensitive measure than a behavioral response. We expect older adults to have moderate amounts of recognition on "misses" (some, but not enough to pass the threshold to become a hit) and very low recognition for correct rejections. For younger adults, we expect low amounts of recognition for "misses" (because the recognition was not strong enough to meet their more liberal threshold) and very low recognition for correct rejections. These results would be consistent with the entropy account in which older adults encounter greater amount of interference, leading to overall less confidence responses, and additional information being required to make a "recognized response".

Research Hypothesis and Question Experiment 2

Research Question 1: Are age-related differences in recognition memory partially due to increases in interference?

Research Question 2: Do older adults show this response pattern due to increased levels of interference? Would using an easier task that leads to a release from PI adjust their response characteristics?

Research Hypothesis 1: We predict older adults will show increased levels of interference in the single category condition relative to younger adults, leading to poorer performance (as shown by a simple main effect of age in the one-category condition). Previous research has shown older adults to be more vulnerable to the buildup of PI than younger adults (Hasher, Chung, May & Foong, 2002). Earlier studies have hypothesized that entropy is that causal mechanism leading to greater levels of confusability in spatial memory (Allen et al 1998a; Mallik et al in preparation). The present study's aim is to lend support to the entropy account using semantic space, instead of physical spatial and acoustic representations used in the previous studies. The entropy view can explain PI as a phenomenon and predict why it would be greater in older adults, unlike a complexity/speed of processing model.

Research Hypothesis 2: In experiment 2 we predict that older adults will receive a greater release from PI as indicted by disproportionally better performance in the four-category condition (low PI) than the single-category condition (high PI) relative to younger adults. This pattern was found in Allen (1998a) and Mallik (in preparation) using spatial distances (instead of semantic distance) where older adults showed greater transposition distance effects, meaning that they benefited when the memory representations were more distant in physical space (just as experiment 2 is separating the distances in semantic space). The entropy view could account for these findings, in that older adults have more easily confused memory representations due to increased randomness in their memory systems. This effect would be exacerbated in conditions leading to the most confusability, and less pronounced when representations are more distant. Meaning that more difficult tasks are more likely to show deleterious effects of entropy than easier tasks. We predict that due to interference, the single-category tasks will be the most difficult (closer representations in semantic space), and that this will be especially challenging for older adults due to the buildup of PI (which is exacerbated by greater levels of entropy). As a result, older adults will experience a greater release from PI in the four-category condition than younger adults when they are no longer confronted with a task with as many close semantic representations.

Evidence for this would be provided by an interaction occurring between age group (younger vs. older) and categorization type (4-category vs. 1-category) where older adults benefit to a greater extent from the release from PI afforded by the four-category condition, relative to younger adults. Younger and older adults are expected to show simple main effects of condition, where they each perform better and have higher levels of ERP recognition for the four-category condition than the single-category condition. Additionally, older adults will adopt a response criterion similar to younger adults in the 4-category condition.

The present study examined episodic memory. The primary goals of the study were (1) to investigate the role of response bias on memory performance with increased age and

(2) examine the role of increased interference (likely due to entropy) with increased age. A recognition memory paradigm was used because it lends itself far better to understanding response selection. A recognition memory paradigm affords the ability to investigate response bias through the use of electrophysiological measures such as summed EEGs (event-related potentials, ERPs). This study provides a novel measure which we argue is a pure measure of recognition, which is not influenced by recognition decision making criteria which is shown to change with age (Botwinick, Brinley & Robbin, 1958; Coyne, Allen & Wickens, 1986; Danziger, 1980; Poon & Fozard, 1980; Ratcliff, Thapar & McKoon, 2004.) Using the ERP method, we measured recognition before the later response criterion stage where the participant decides if they have enough information to label an item as recognized. We later provide more detailed rationale for why we predict older adults require greater levels of confidence before labeling an item as "recognized" and how this has the potential to decrease accuracy performance. We suspect that older adults will respond incorrectly (e.g. miss) on items that were recognized, but not recognized enough to meet the decision threshold required to label the item as recognized. This will lead to high levels of recognition for higher levels of recognition for items that were "misses" for older adults. The utility of this novel ERP method is that it leads to increased precision in measuring recognition because behavioral paradigms cannot easily disentangle the influence of response criterion due to the fact that only a single measure is taken (correct vs. incorrect), unlike the continuous data provided by the ERP method. These methods add a great benefit to present study, as previous studies which have used an episodic memory approach, or a purely behavioral approach have not been able to utilize this innovative method of analyzing decision making. To our knowledge, this is first study

to investigate the role of decision-making criteria on episodic memory with age, using the precision of ERPs.

CHAPTER II

METHOD

2.1 *Measures and Design*

Sample: The participants in Experiment 1 and Experiment 2 were recruited from the same population. Each experiment had 20 younger-adults and 20 older-adult participants. The younger adults were 18-35 years of age and participated for course extra credit at The University of Akron. The older adults were above the age of 60, were community dwelling and received $20 payment for their participation in the study. All participants were screened for 20/40 vision or had corrected-to-normal vision and were screened for MCI. This sample size was chosen because it falls in the typical range of participants in an ERP recognition investigation (Nessler et al., 2007). A power analysis was conducted for the proposed mixed design ANOVA using a medium effect size (d= 0.5, Rice & Harris, 2005) indicated that power of .95 could be achieved by a sample of 36 participants.

Measures:

1. Montreal Cognitive Assessment (MoCA)

In an effort to study a "non-pathological" sample, the MoCA was used to assist in the detection of mild cognitive impairment (MCI). In a validation study involving 93 participants with mild Alzheimer's disease and 90 clinical controls, the MoCA detected

90% of MCI subjects, compared to 18% using the common Mini Mental State Exam (MMSE), with a cutoff of 26. The measure takes about ten minutes and includes tasks that tap into decision making, memory, attention and visuoconstructional skills (e.g. drawing a clock with the accurate time). (Nasreddine et al., 2005).

2. Digit Symbol Substitution Task

The Digit Symbol Substitution is a subtest of the Wechsler Adult Intelligence Scale-Revised (WAIS-R; Wechsler, 1981). Participants are asked to draw, as quickly and accurately as possible, corresponding symbols under each number in an allocated box. This measure evaluates speed of processing and took about two minutes including instructions. We included this measure to show that speed of processing did not influence results between Experiments 1 and 2 and that the sample did not deviate greatly in terms of speed of processing from other samples used in the cognitive aging literature.

3. Mill Hill Vocabulary Scale

The Mill Hill Vocabulary Scale was administered to assess the vocabulary of participants (Raven, 1982). The scale took roughly five minutes to complete. It is was important to include this measure to show that semantic knowledge did not influence results between Experiments 1 and 2 and that the sample did not deviate greatly in terms of semantic knowledge from other samples used in the cognitive aging literature.

4. Years of Education

Years of Education (YOE) was calculated by number of years spent in school (excluding pre-school and kindergarten). This was measured because YOE is linked to greater cognitive skill and less age-related decline with age (Springer, McIntosh, Winocur & Grady, 2005).

5. Recognition Memory

The recognition memory task included a study phase and a recognition phase. In the initial study phase, participants viewed a series of 100 positive words. The words were chosen to be positive out of practicality. In the English language there are many words with positive meaning, which made creating two separate lists of 100 words which were matched on world length, and word usage possible. Participants began the study passively viewing positive words on a computer screen. The words remained on the screen for 3 seconds before automatically switching to the next word. 3 seconds was used because it gave participants enough time to fully process the word, but was not excessive to the point that it would interfere with retaining previous words. Participants were asked to remember these words to the best of their ability because they would be tested later. Once the study phase has ended, they were asked to complete the test phase of the recognition memory task. In this task, 200 words were presented (half old/studied words, and half new/unstudied words). Each word appeared on the screen until a response was made concerning whether it is an old or new word. Accuracy was the primary behavioral measure; and response time was included to test for speed/accuracy tradeoffs. Experiment 1 ended after this study and test session. Experiment 2 included the same word study and word test phase done in experiment 1 and included another study and testing phase. The second study/test phase included a counter-balanced presentation of 25 words from the following categories: Animals, Kitchen Items, Money, Sports, which they will be asked to remember for a recognition session immediately after the study session. Using the English Lexicon Project database, word length (positive words = 5.84, other words = 5.88) and log word frequency (positive words = 8.62, other words = 8.54) were controlled for. Two-sample T-tests confirmed that group differences between positive and other words did not approach statistical significance for word length or log word frequency. Each of the categories were presented in their entirety before moving on to the next category. Thus, a participant may be presented 25 animal words, then Kitchen item words, then words related to money, followed by words related to sports. This order was counterbalanced. As in Experiment 1, words in the study phase were presented on the screen for 3 seconds before switching automatically to the next word. The test section included a random presentation of the 100 studied words (old words) and the 100 new words. Participants made a self-paced button press indicating if they believed the new was old or new. The rationale for having both the single-category and quadruple-category tests in the same session in Experiment 2, was to create a within-subjects design. In attempt to measure the release from PI (e.g the extent of increased performance in the four-category condition, relative to the single-category condition), we chose to limit individual differences by having the same groups of younger and older adults take each test in a counterbalanced fashion. Response times less then 300ms and greater than 5 seconds were excluded from the behavioral analysis as outliers. Responses which were conducted faster than 300ms were deemed “too quick” because the decision-making stage is thought to occur after “object familiarity” which itself doesn’t occur until roughly 300ms (Curran, 2000). Excessively long response latencies over 5 seconds were excluded as well.

ERP Data Collection and Signal Processing: The FN400 component was calculated by using the following sites: F3, Fz, F4, C3, Cz and C4 from 300-500ms post-stimulus onset Curran, 2000). The P3 component was time-locked to 400-600ms (Mallik et al., in preparation) post-stimulus onset and was recorded at the following sites: F3, Fz, F4, C4, Cz, C4, P3, Pz, P4. The Late Positive Complex (LPC, Strozak et al., 2016) was measured from 500-800ms post-stimulus onset and was recorded at the following sites: F3, Fz, F4, C4, Cz, C4, P3, Pz, P4.

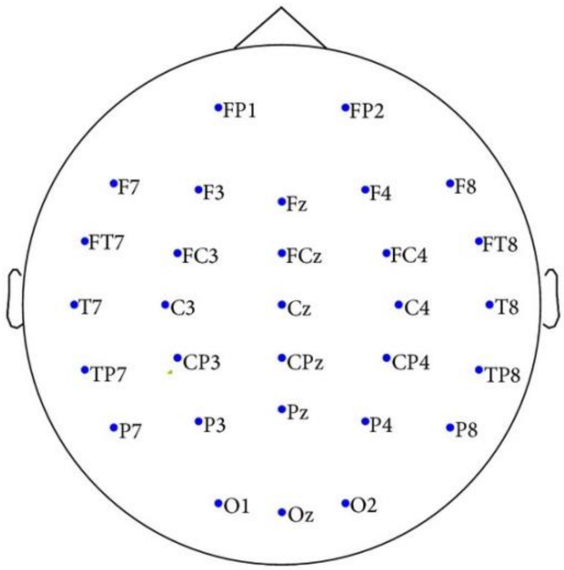

Figure 13. Electrode locations on the scalp.

Figure 13 is a drawing of an individual looking forward. Capital letters represent the row. This present study uses F (frontal), C (central), and P (parietal) electrodes. The numbers and the lower case “z” represent hemisphere. The midline is represented by “z” and odd numbers represent the left hemisphere, and even numbers represent the right hemisphere.

EEG Recording and Analysis: The EEG activity was recorded from the following electrode sites: F3, Fz, F4, C3, Cz, C4, P3, Pz, P4, T7, T8, Tp7, Tp8, P7, P8, O1, and O2. The vertical electrooculogram (VEOG) was recorded from electrodes above and below the middle of the left eye. The horizontal electrooculogram (HEOG) was recorded at the outer canthi of both eyes. Impedance of the electrodes was kept below

5 kΩ. Signals were amplified using the Synamps RT (Neuroscan) with a gain of 2000 and with a bandpass of 0.1-50 Hz. and the signals will be processed at 500 Hz. Data were cleaned by using a high-pass filter to the raw data (.1Hz). After scanning the data and removing abnormally noisy data due to clear artifacts, an Independent Components Analysis (ICA) was run to assist in artifact rejection. Components which are identified to be related or caused by blinking were removed. Data were then epoched starting a 200ms before stimulus onset, until 1000ms post-stimulus onset. The timeframe of 200ms pre-stimulus onset until stimulus onset was be used as a baseline. Once epoched, artifact rejection identified trials with abnormal values, abnormal trends, improbable data, abnormal distributions, and abnormal spectra (Lopez-Calderon & Luck, 2014).

2.2. *Procedure*

Before the experiment, participants signed an IRB approved informed consent form from The University of Akron. Older adults completed the Montreal Cognitive Assessment (MoCA) to scan for MCI. Older adults who scored at or above the threshold of 18 continued to the following parts of the experiment (all participants scored above the threshold). Next, the written measures were taken, this began with the Digit Symbol Substitution task, a measure of speed of processing and the Mill Hill Vocabulary Scale as a measure of vocabulary. Next, the EEG cap was prepared, this process took roughly 20-25 minutes. Participants then completed the recognition memory task, where they were asked to remember 100 words. Immediately after the study phase, the participant were tested on the recognition portion (part two) with electrophysiological data being collected (experiment 2 included a second recognition memory task, as mentioned before). Once participants finished the EEG session, they received a quick debriefing of the experiment before being thanked and compensated (older adult: $20, younger adult: course extra credit).

2.3. Instrumentation

A 32 channel neuroscan EEG system (Grael EEG) was used to collect data. Speakers were connected to the computer and made a soft beeping sound if the participant provided an incorrect response. The behavioral data was collected using E-Prime software.

2.4. Data Analysis

In the following analyses we used Age Group, Probe Type, Categorization Type and Recognition Type as factors. Age Group was used to separate the Older (ages 60+) and Younger Adults (ages 18-35). Probe Type separated old words which were previously shown in the study phase, from new words which were not shown during the study phase (measured as hit rate for old words and correct rejection rate for new words). Condition separated the single-category condition (positive words) from the four-category condition (animals, fruits, money and sports).

Accuracy was measured as percent correct, and data were analyzed using a 2 (age group: younger vs. older) x 2 (probe type: Old (hit-rate) vs. New (correct rejection-rate) ANOVA for Experiment 1. Experiment 2 used a 2 (age group: younger vs. older) x 2 (probe type: Old vs. New) x 2 (condition: one vs. four category) ANOVA was used to analyze the error data in Experiment 2. Response criterion (beta) was calculated using signal detection methods, and age differences tested using a two-sample t-test.

Behavioral Prediction: In Experiment 1, Age Group and Probe Type will interact. Where old probes will be more difficult for older adults (i.e., lower accuracy). In Experiment 2, Age group, Probe Type and Categorization Type will interact. This will be driven by older adults preforming similarly on new probes to younger adults, but less well on old probes in the more difficult single category condition. In the easier 4-category condition, we predicted that older adults will perform similarly to younger adults on both old and new probes.

ERP Analysis: The FN400 Recognition, LPC Recollection and P3 Recognition were measured by creating a difference wave by subtracting new items (correct rejections) from correctly recognized old items (hits; Curran, 2000). The "recognition below threshold" measures were calculated by the difference between misses and correct rejections (Correct Rejections – Misses). The below threshold set of measures provided an index of how much recognition was elicited by items which did not make the threshold to become a hit, compared to correct rejections (that should produce little to no recognition). In experiment 1, the recognition measures were analyzed in a 2 (Age Group: younger vs. older) x 2 (Recognition Type: Above vs. Below Threshold) x 3 (Column: Left Hemisphere vs. Central vs. Right Hemisphere) x 3 (Row: Frontal vs. Central vs. Parietal) mixed ANOVA. Experiment 2 included another within-subjects factor: Condition (1-category vs. 4-categories) making the ANOVAs 2x2x2x3x3.

The four ERP components were analyzed using one-sample, one-tailed t-tests to determine significance. They were considered significant if they were significantly less than zero (Curran, 2000).

ERP Prediction: For the recognition measures (Correct Rejections – Hits) we expected a main effect of age, where the FN400 Recognition and the P3 Recognition measures would be higher for younger adults, as is commonly found in electrophysiological investigations in age-related differences in recognition memory when words are used (Friedman et al., 2013; Wolk et al., 2009), indicating better overall word recognition. For the recognition below threshold measures (Correct Rejections – Misses) we expected a main effect of age, where recognition below threshold amplitudes would be stronger for older adults. This finding would be indicative of older adults displaying higher recognition for their misses than younger adults. This pattern is hypothesized to result from older adults using a more conservative response criterion, making moderately recognized material misses, where similarly recognized items for younger adults are "hits" due to their relatively more liberal response criterion. In experiment 2 we expected a main effect of Condition for FN400 Recognition, LPC Recollection and P3 Recognition, where greater amplitudes would be observed for the four-category condition, than the single-category condition. This prediction is due to the four-category test being as easier task due to a release from PI, and greater levels of recognition are predicted as a result. Condition and Age were also expected to interact, where older adults receive a greater release from PI compared to younger adults. This can be observed by a greater increase in amplitude by older adults in the four-category from the single-category condition relative to younger adults.

With the primary goal of better understanding age-related differences in recognition memory, the present study aimed to identify contributing factors leading to these differences. Experiment 1 used ERP and behavioral measures to assess whether the tendency of older adults to show a conservative response bias led to accuracy scores which underestimate older adults' recognition abilities. Additionally, we suggest that the age-related pattern of a more conservative response criterion with increased age would be due at least in part to greater levels of entropy in older adults. Specifically, increased neural noise would lead to less clear memory representations which would cause older adults to question themselves more. This effect would be seen in experiment 1 by a disproportionately greater number of "misses" for older adults and greater levels of familiarity below threshold (using the EEG measure), meaning that older adults need greater levels of familiarity to make a response indicating that a word was recognized. Experiment 2 examined the account that age-related differences in proactive interference contribute to differences in recognition memory. In this experiment we compared two theories which would produce markedly different hypotheses (as discussed later).

In Experiment 1 we predict that younger adults will have higher overall accuracy on the Old/New recognition task. This difference in accuracy will be due to higher "old word" recognition for younger adults. The present study aims to show that older adults recognize the "old words" better than previously thought, using the ERP method. If older adults adopt a more conservative response criterion, (meaning that stronger response confidence is necessary to elicit a response indicating recognition – which is likely instated to adjust for age-related increases in interference due to entropy) then older adults would be more likely to have more misses than younger adults when identifying "old words".

Critically, the ERP method allows us to index recognition levels before the response criterion stage in processing. This provides us novel information about recognition, unlike a single behavioral response that is affected by response criterion which occurs later in processing. It is predicted that ERP miss data will show greater levels of recognition for older adults than younger adults, because of the higher threshold for a recognition response for older adults. If the results are as expected, this study would provide evidence that older adults have better functioning recognition memory than previously thought because age-related differences in performance would be due at least in part to the response selection stage, and not only pure recognition memory processes.

Experiment 2 aimed to examine the role of proactive interference in recognition memory performance with age. The entropy theory would suggest that increased levels of neural noise lead to less clear memory representations. This would be especially impactful when learning similar items which occupy similar areas of psychological space (e.g. words in the same category). Thus, learning many words in a single category would create a more difficult task relative to learning from multiple lists of categories. The improvement from the single category condition to an easier multiple category condition is labeled release from PI and it should be greater for older adults as their relatively clearer memory representations will benefit more from this manipulation. This would be observed by and age by category interaction. The complexity/speed of processing model would not predict this interaction. To test this, a recognition memory task using a high proactive interference condition (100 words from the same category) and low proactive interference condition (25 words from 4 different categories) was completed in experiment 2. We predicted an Age by Category (1 category vs. 4 categories) interaction, where younger adults will more greatly benefit from the release from proactive interference. Meaning that the improvement in accuracy scores between the more difficult single-category condition, to the easier four-category condition will be greater for older adults, than for younger adults. These results would be congruent with the entropy theory.

CHAPTER III

RESULTS

As discussed in the Introduction, recognition memory was analyzed using behavioral and electrophysiological methods. Behavioral data were analyzed for response accuracy. Electrophysiological data measured the ERP components FN400, LPC and P3 which have previously been used to measure recognition memory (Curran, 2000; Strozak et al., 2016)

3.1 ERP Analysis:

As discussed in the Method section, all older adult participants were screened for mild cognitive impairment using the MoCA. No participants showed signs of mild cognitive impairment. All ERPs were time-locked to the presentation of the target word, with an epoch of 200ms before stimulus presentation to establish a baseline, to 1000ms after stimulus presentation. The FN400 ERP component was measured from 300-500ms post-stimulus presentation using frontal and central electrodes (F3, Fz, F4, C4, Cz and C4; Curran, 2000; Friedman, 2013), The LPC ERP component was measured from 500-800ms post-stimulus presentation using frontal and central and parietal electrode sites (F3, Fz, F4, C4, Cz, C4, P3, Pz and P4) and the P3 ERP Component was measured from 400-600ms post-stimulus presentation using frontal, central and parietal electrode sites (F3, Fz, F4, C4, Cz, C4, P3, Pz, P4, Mallik et al., in preparation.). The FN400, LPC and P3 recognition components were measured by calculating the difference of correct rejections to hits (Correct Rejections – Hits) and the FN400, LPC and P3 recognition below threshold components were measured by calculating the difference of correct rejections to misses (Correct Rejections – Misses). These measures were considered significant if their values were significantly less than zero. These recognition measures previously validated due to the common finding that correctly recognized probes (hits) exhibit a more positive voltage than correctly identified new probes (correct rejections; Curran, 2000; Friedman, 2013). The present study extends this finding into a novel application of this logic, where misses (incorrectly labeled old items) are used instead of hits. Thus, if misses are more positive than correct rejections, it is evidence of misses being recognized. It is hypothesized that misses will be more recognized than correct rejections. The difference between correct rejections and misses is labeled "recognition below threshold". If one uses a conservative response criterion in which very strong evidence is needed to produce a "hit" response, then they would show a greater recognition below threshold effect due to more recognition of "misses".

3.2 Behavioral Accuracy Experiment 1: Positive Words

These data were analyzed using a two-way, Age Group (Younger vs. Older) by Probe Type (Hit Rate vs. Correct Rejection Rate) ANOVA. No significant results were found as there was no main effect of either Age Group or Type and Age Group and Type did not interact ($p>0.25$; see table 1).

Table 1.

Behavioral Results from Experiment 1.

Age Group	Hit Rate	Hit Rate SE	Correct Rejection Rate	Correct Rejection Rate SE
Younger Adults	0.662	0.032	0.693	0.025
Older Adults	0.694	0.027	0.7	0.067

3.3 Experiment 1: Response Time

Response time was analyzed using a two-way, Age Group (Younger vs. Older) by Probe Type (Hit Rate vs. Correct Rejection Rate) ANOVA. This revealed a main effect of Age Group ($F(1,38) = 7.42$, $p < .001$), where younger adults had significantly faster response times (see figure 14). There was no main effect of type, and type and age did not interact.

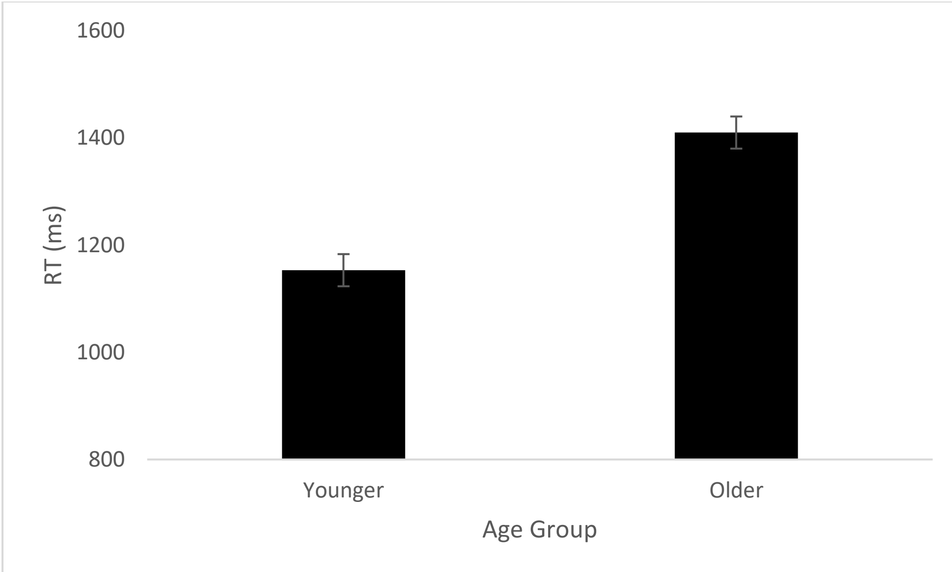

Figure 14. Response times of younger and older adults in Experiment 1.

3.4 Experiment 1: Response Bias

The present study measured response bias by using β'' which is a recommended way of analyzing response bias because it does not rely on the assumption of normal distributions of signal and noise as see in figure 11 (Pollack and Norman, 1964; Green and Moses 1966). It is calculated by the following equation:

$$\beta'' = [FA(1 – FA) – H (1 – H) / [FA(1 – FA) + H (1 – H)]$$

For this measure, zero indicates a neutral criterion, a positive number indicates a liberal criterion and a negative number represents a conservative criterion. Measures range between -1 and +1. A two-sample t-test revealed no significant age differences in β'' and one-sample t-tests showed that β'' did not significantly differ from zero (a neutral response bias) for either age group (see table 2).

Table 2.

Experiment 1: Response Bias

Age Group	β''	β'' SD
Younger Adults	-0.007	0.16
Older Adults	-0.0175	0.26

3.5 Experiment 1: Fn400

Experiment 1 included 40 subjects, 20 younger adults and 20 older adults. The older adults had significantly more years of education, than younger adults ($t(19)=-4.1$, $p<.001$). The older adults scored significantly better on the Mill Hill vocabulary test than younger adults ($t(19)=-4.2$, $p<.0001$). Younger adults scored significantly higher on the digit symbol substitution task than the older adults ($t(19)=7.7$, $p<.0001$). The FN400 ERP component has been used in previous research to index recognition (Curran, 2000). In this study it was both measured in the traditional fashion (Correct Rejections – Hits) to index recognition and in a novel way, labeled FN400 Recognition Below Threshold, (correct rejections – misses) to index the level of recognition in misses. We hypothesized that older adults will have less overall recognition, as seen with a lower FN400 for recognition, and older adults will have a larger FN400 below threshold due to a more conservative response criterion which leads to increased levels of misses, even on items with an ERP of high enough amplitude to suggest that it was familiar enough to be recognized. In the later

ANOVA, this would be expressed as an Age Group (Younger Vs. Older) by Recognition Type (FN400 Recognition vs. FN400 Recognition Below Threshold) interaction.

In line with the predictions, a one-sample t-test found a significant effect of FN400 for recognition (t= -3.19, DF=39, p= 0.0014), where the average voltage of correct rejections was 0.83 MV lower than hits in the measured time-frame (300-500ms), which is significantly less than zero, suggesting that hits were significantly more recognized than correct rejections (see figure 15 and figure 16).

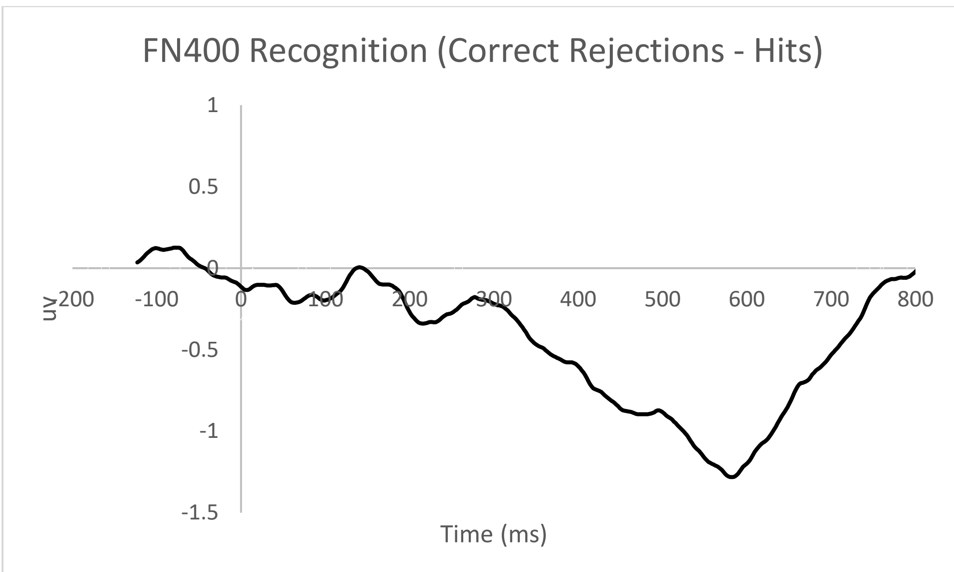

Figure 15. Experiment 1 FN400: Younger and Older adults combined.

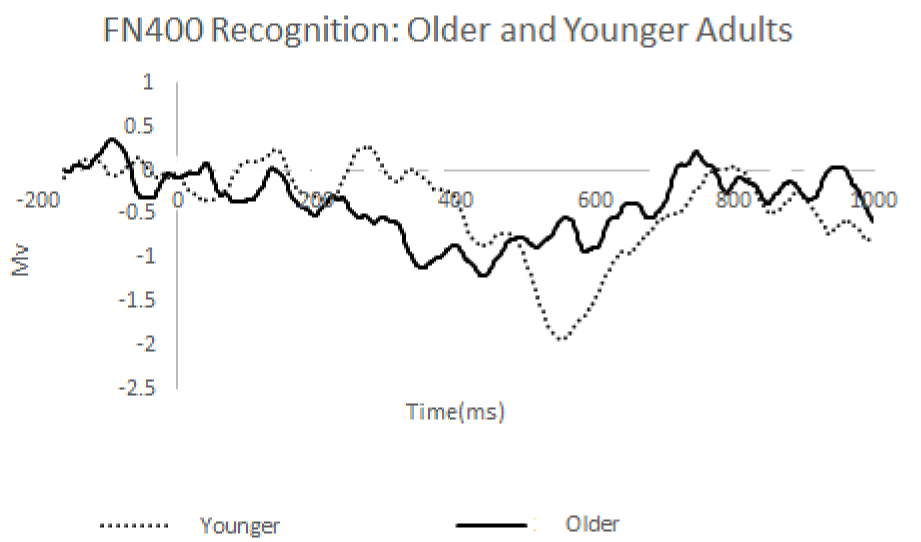

Figure 16. Experiment 1: FN400 Younger and Older Adults

Next, a 2 (Age Group: Younger vs. Older), x 2 (Type: Recognition vs. Recognition Below Threshold) x 3 (Column: Right Electrodes vs. Central Electrodes vs. Left Electrodes) x 3 (Row: Frontal vs. Central vs. Parietal) ANOVA was conducted. No significant results were obtained.

Contrary to expectations, there was no main effect of age for either FN400 type (Correct rejections – hits and correct rejections – misses) and age did not intact with either FN400 type, suggesting similar patterns between younger and older adults in recognition. The finding of no main effect of age for FN400 recognition suggests that recognition was not significantly different for either age group.

As predicted, older adults showed a significant FN400 Below Threshold (correct rejections – misses), with correct rejections being -0.65 MV lower than misses ($t= -1.74$, $DF=19$, $p= 0.049$). This indicates a significantly higher amplitude for miss responses than correct rejections. This provides evidence for a more conservative response criterion due to older adult's higher level of amplitude for misses than correct rejections. This pattern was not significant for younger adults (see figure 17).

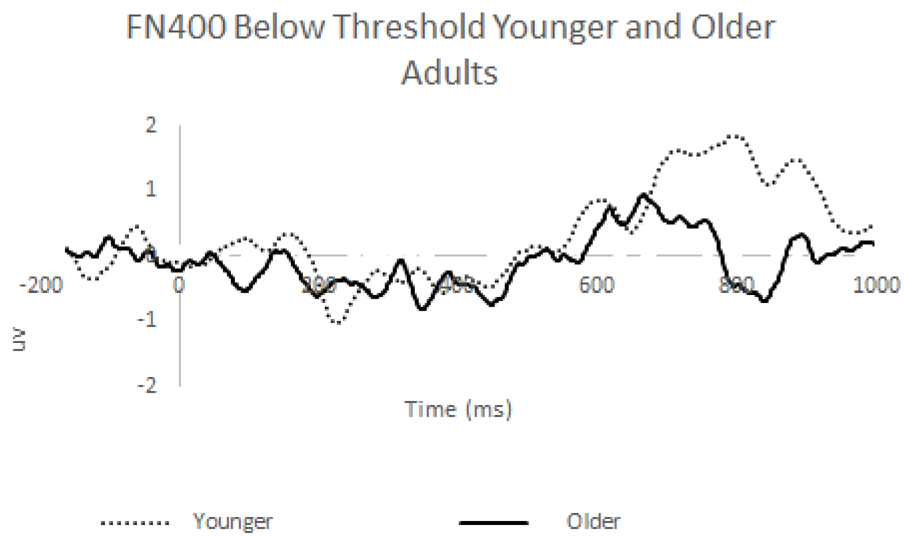

Figure 17. Experiment 1: FN400 Below Threshold for younger and older adults.

3.6 Experiment 1: P3

The P3 Recognition ERP component provides another measure of recognition. This component is analyzed similarly to the FN400 recognition component, in that recognition is measured by subtracting hits from correct rejections (Correct rejections – Hits) and was included to introduce a novel measure called P3 Below Threshold (Correct Rejections – Misses) to index the level of recognition for misses. We hypothesize that older adults will have less overall recognition, as seen with a smaller P3 recognition effect, and older adults will have a larger P3 Below Threshold due to a more conservative response criterion which leads to increased levels of misses, even on items which were sufficiently recognized (leading to an Age by Recognition Type interaction). First, we tested if P3

Recognition and P3 Recognition Below Threshold were significant by conducting one sample t-tests. After, we conducted a mixed design ANOVA.

As predicted, A main effect of P3 Recognition was found (t= -4.39, DF=39, p<.0001), where the difference between correct rejections and hits was -1.03MV. This indicates that the measure is sensitive to recognition, and that the participants recognized hits more than correct rejections (see figure 18).

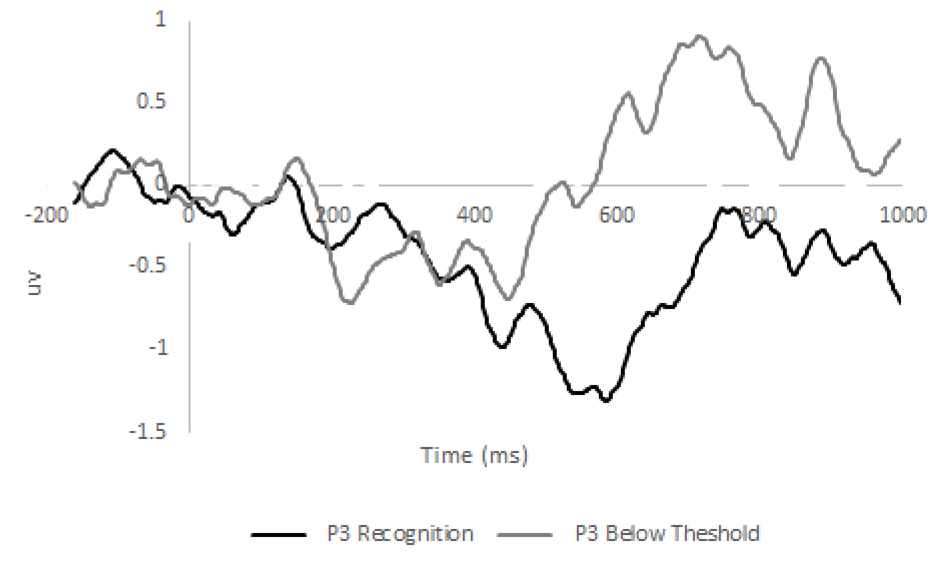

Figure 18. Experiment 1: P3 Recognition and P3 Recognition Below Threshold.

A significant P3 Recognition was found for both younger (M= -1.2Mv, t(19)= -3.32, p= 0.0018) and older adults (M= -0.86MV, t(19)= -2.83, p= 0.0054). The Categorization Below Threshold measure was insignificant for both younger and older adults.

A 2 (Age Group: Younger vs. Older), x 2 (Type: Categorization vs. Categorization Below Threshold) x 3 (Column: Right Electrodes vs. Central Electrodes vs. Left Electrodes) x 3 (Row: Frontal vs. Central vs. Parietal) ANOVA was conducted to examine within and between group differences. There was no main effect of group, meaning that the recognition measures were not significantly different between younger and older adults. There was a main effect of Type, where P3 Recognition was significantly more negative than P3 Recognition Below Threshold ($F(1,38)= 14.52$, $p< .001$), meaning that hits showed significantly higher amplitudes than misses. Type and Age Group did not interact ($p = 0.29$). Row and Column interacted, due to higher negative voltage in the right hemisphere frontal electrodes compared to the left hemisphere, and the opposite finding in the parietal electrodes which showed more negativity on the left hemisphere compared to the right hemisphere ($F(4,152) = 2.80$, $p = 0.047$; see table 3).

Table 3

Experiment 1: P3 Row by Column interaction.

Electrode	Voltage	Row	Column
F3	-0.16	Frontal	Left
Fz	-0.52	Frontal	Central
F4	-0.58	Frontal	Right
P3	-0.72	Parietal	Left
Pz	-0.74	Parietal	Central
P4	-0.28	Parietal	Right

3.7 Experiment 1 LPC

As predicted, A main effect of LPC Recognition was found ($t= -3.65$, $DF=39$, $p<.001$), where the difference between correct rejections and hits was -0.85MV. This indicates that the measure is sensitive to recognition, and that the participants recognized hits more than correct rejections (see figure 18).

A significant P3 Recognition was found for both younger ($M= -1.02$ Mv, $t(19)= --2.84$, $p= 0.0052$) and older adults ($M= -0.69$MV, $t(19)= -2.26$, $p= 0.0181$). The

Categorization Below Threshold measure was not statistically significant for either younger or older adults.

3.8 Experiment 1 Discussion:

Experiment 1 found significant ERP effects for recognition (P3, LCP and FN400). This means that the measures were sensitive to recognition. Critically the FN400 Below Threshold measure reached significance for older adults and trended toward significance for younger adults. This means that older adults showed significantly more recognition for misses than correct rejections. Surprisingly, there was no significant age-related difference in the difficult 100 positive word condition, which was featured in Experiment 1.

3.9 Experiment 2:

Experiment 2 contained two parts. One of which replicated Experiment 1 by providing a list of 100 positive words to remember, and then a separate condition which included a new list of 100 words that included words from four different categories instead of one. This manipulation was added to examine the role of interference in recognition memory. We expected older adults to be more susceptible to interference due to increased levels of randomness in their memory system. Proactive interference (the tendency for previous learning to hinder subsequent learning) tends to be higher when targets are more similar (Wickens, Born & Allen, 1963). As suggested by the SIMPLE model (Brown, Neath, & Chater, 2007), the closer items are in "psychological space", the more likely they are to be confused. In this case the TBR words are stored in semantic space. Words closer together in meaning are more likely to be confused, due to interference. Figures (19 and 20) display a theoretical manipulation of adding categories and its own on reducing interference between items. Items in the four-category condition are separated by more "semantic space" and thus are less likely to be confused with other items than the single category condition. We hypothesized that older adults would more greatly benefit from the release from proactive interference (reducing interference between items) than younger adults. Thus, we hypothesized an Age by Condition (1 category vs. 4 categories) interaction. Experiment 2 included 40 subjects, 20 younger adults and 20 older adults. The older adults scored significantly better on the Mill Hill vocabulary test than younger adults ($t(19)=-3.9$, $p<.001$). Younger adults scored significantly higher on the digit symbol substitution task than the older adults ($t(19)=7.3$, $p<.001$). The older adults had significantly more years of education, than younger adults ($t(19)=-4.2$, $p<.001$). Vocabulary and years of education were later run as covariates in two separate one-way ANCOVAs (Analysis of Covariance). Each of these analyses failed to yield support for the influence of these covariates (F's < 1).

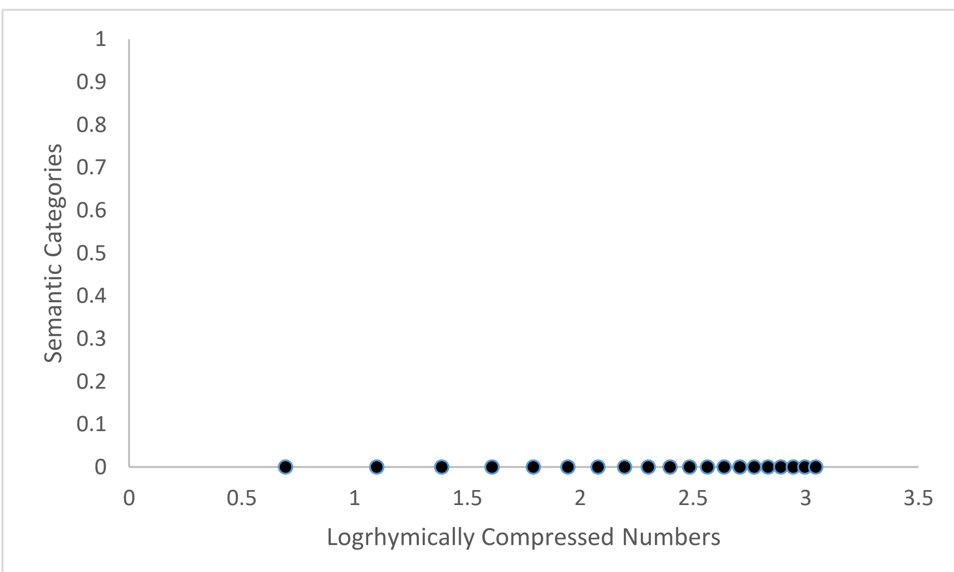

Figure 19. Twenty positive words

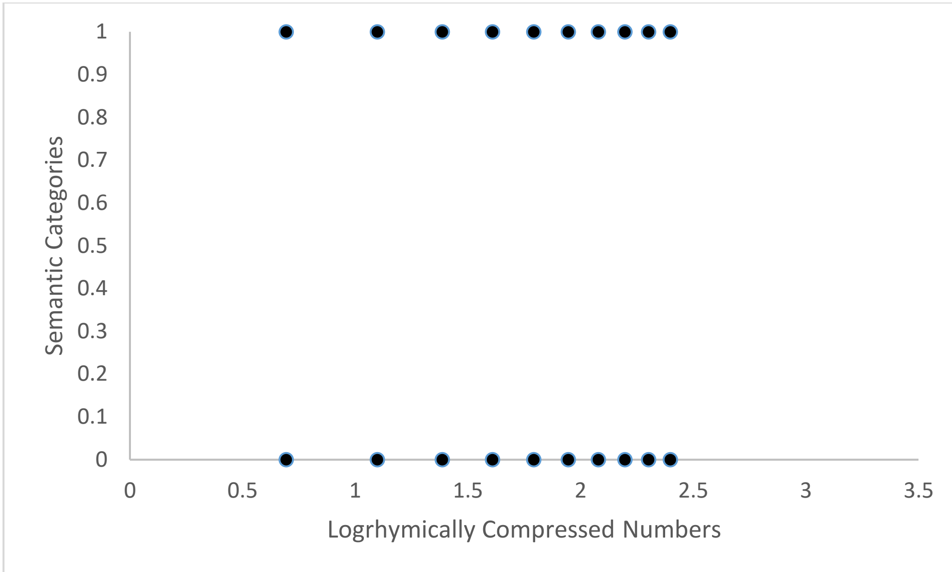

Figure 20. Ten positive words and ten negative words

3.10 Behavioral Accuracy Experiment 2

A three-way Age Group (Younger vs. Older) by Probe Type (Hit Rate vs. Correct Rejection Rate) By Condition (Positive Words vs. Categories) ANOVA was conducted which revealed a main effect of Condition ($F(1,38)= 35.81$, $p< .0001$). Accuracy in the Category condition was 7.8% higher than the Positive word condition (Category average = 0.736, Positive average = 0.657; see figure 21). No other effects were significant, meaning that there was no main effect of Age and that Age and Condition did not interact (see tables 4 and 5).

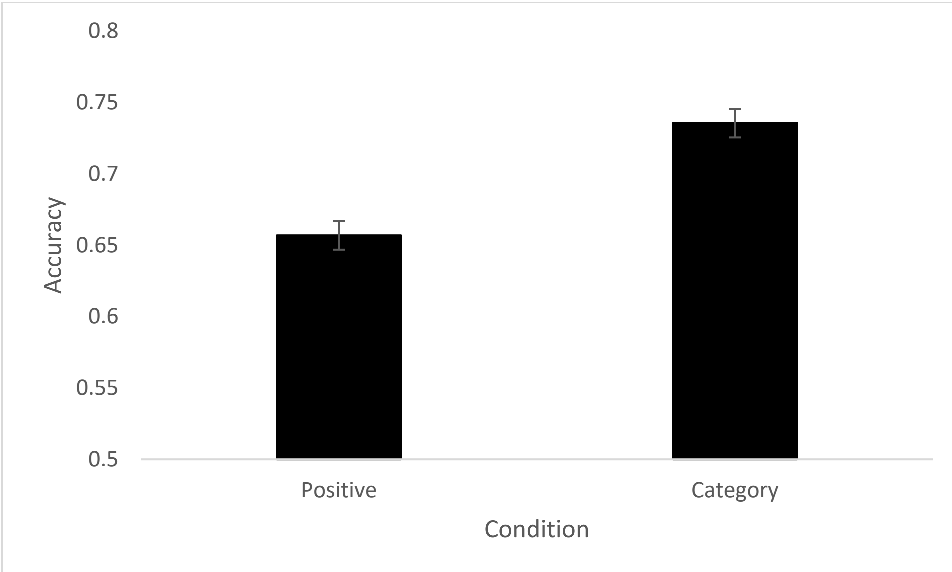

Figure 21. Experiment 2: Main effect of behavioral condition

Table. 4

Experiment 2: Behavioral Results, Younger Adults.

Condition	Hit Rate	Hit Rate SE	Correct Rejection Rate	Correct Rejection Rate SD
Positive Words	0.655	0.030	0.674	0.027
Categories	0.684	0.0564	0.774	0.034

Table. 5

Experiment 2: Behavioral Results, Older Adults.

Condition	Hit Rate	Hit Rate SE	Correct Rejection Rate	Correct Rejection Rate SD
Positive Words	0.623	0.040	0.677	0.031
Categories	0.718	0.039	0.766	0.040

3.11 Experiment 2: Response Time

Response time in Experiment 2 was analyzed using A three-way Age Group (Younger vs. Older) by Probe Type (Hit Rate vs. Correct Rejection Rate) By Condition (Positive Words vs. Categories) ANOVA. This revealed a main effect of Group, Probe Type and Condition, while no interactions were significant. The main effect of Age Group was driven by Younger Adults responding faster than Older Adults ($F(1,38)= 10.75$, $p= 0.002$, see figure 22). The main effect of condition was due to faster responses from the four-category condition ($F(1,38)= 4.36$, $p= 0.045$, see figure 23). The main effect of probe type was due to faster responses for old-probes, relative to new-probes ($F(1,38) = 12.4$, $p= 0.001$, see figure 24).

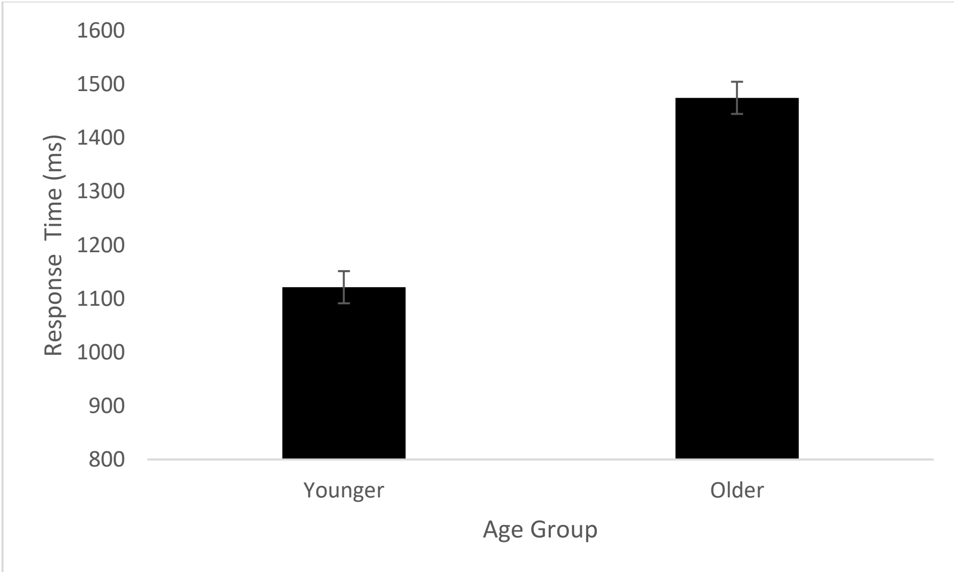

Figure 22. Experiment 2: Response time.

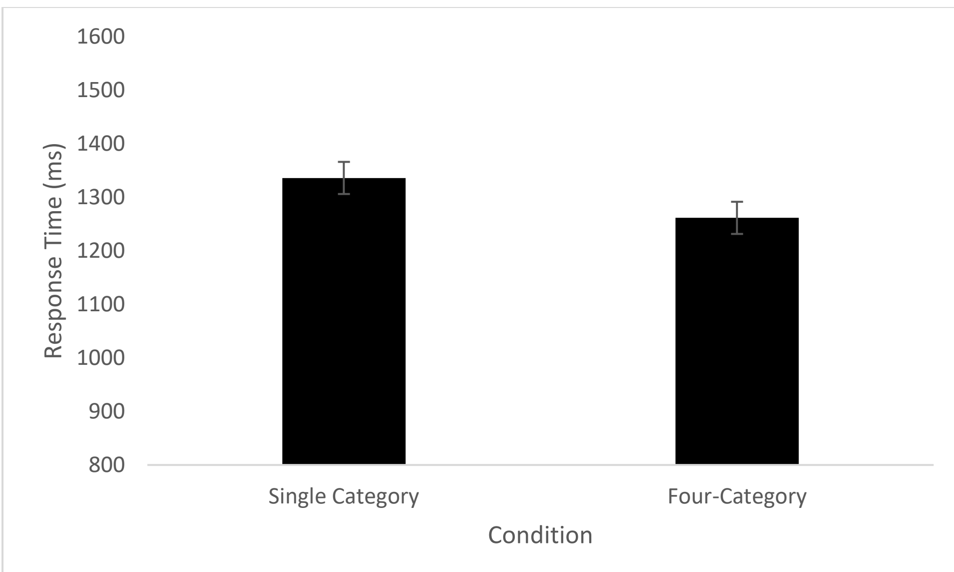

Figure 23. Experiment 2: Condition.

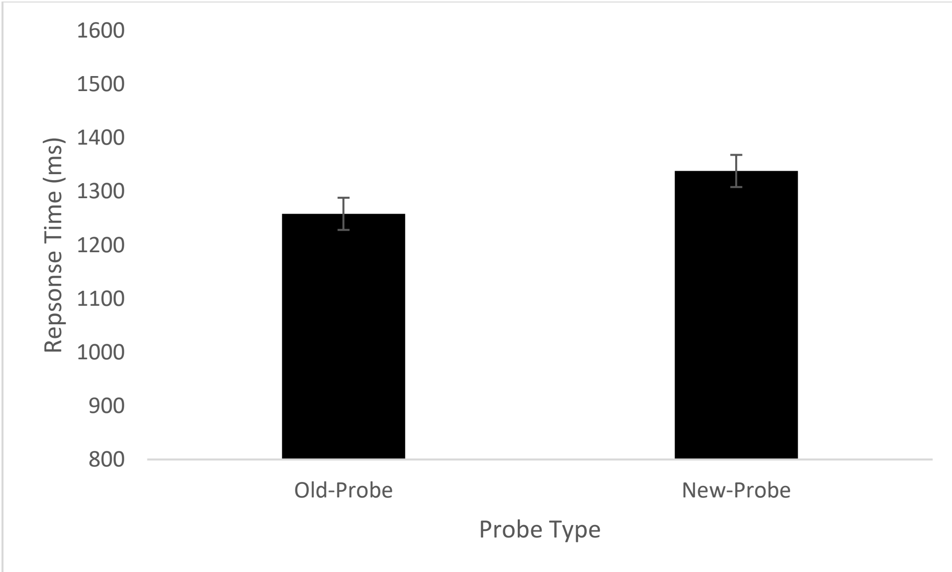

Figure 24. Experiment 2: Probe-Type differences.

3.12 Experiment 2: Response Bias

A 2 (Age Group: Younger vs. Older Adults) by 2 (Condition: single-category vs. four-category ANOVA) was conducted to analyze age-related differences in β''. No significant effects were found in this model. A one-sample t-test showed that in the four-category condition, a negative response bias approached significance ($t(39) = -1.6$, $p = 0.058$). Table 6 shows the group means and standard deviations

Table 6.

Experiment 2: Response Criterion.

Age Group	Positive Word Condition β''	Positive Word Condition β'' SD	Category Word Condition β''	Category Word Condition β'' SD
Younger Adult	-0.005	0.172	-0.071	0.31
Older Adult	-0.044	0.244	-0.0825	0.2964

3.13 Experiment 2: FN400- Positive word and Categorical Word Conditions

The second experiment used a within-subjects design and we hypothesized there would be higher levels of recognition in the categorical word condition relative to the positive word condition due to lower levels of interference between similar words. We further predicted that younger adults would show better recognition as indexed my larger recognition ERPs and that older adults would show better recognition for misses than younger adults, due to a more conservative response criterion as shown by greater below threshold measures. It was also predicted that older adults would benefit to a greater extent from the four-category group and that this would be seen as an Age Group by Condition interaction.

A 2 (Age Group: Younger vs. Older), x 2 (Condition: Positive Words vs. Categories) x 2 (Type: Recognition vs. Recognition Below Threshold) x 3 (Column: Right Electrodes vs. Central Electrodes vs. Left Electrodes) x 3 (Row: Frontal vs. Central vs. Parietal) ANOVA was conducted. The hypothesis of increased FN400 Recognition in the four-category condition failed to receive support, as there was not main effect of condition. Additionally, Age Group and Type did not interact, which does not support the hypothesis of different patterns for each age group in the FN400 Recognition and FN400 Recognition Below Threshold ERPs. Age Group and Column interacted, where older adults had the smallest recognition effects in the left hemisphere (M= -0.12MV) and younger adults had the smallest recognition effects in the right hemisphere (M= -0.13; see table 7).

Table 7.

Experiment 2 FN400: Age Group by Column Interaction.

Electrodes	Voltage MV	Age Group	Hemisphere
F3 and C3	-0.12	Older Adult	Left
Fz and Cz	-0.3	Older Adult	Central
F4 and C4	-0.39	Older Adult	Right
F3 and C3	-0.26	Younger Adult	Left
Fz and Cz	-0.31	Younger Adult	Central
F4 and C4	-0.13	Younger Adult	Right

There was a three-way interaction of Type of recognition (FN400 Recognition vs. FN400 Below Threshold), Row of electrodes (Frontal vs. Central) and Age Group (Older vs. Younger Adults) where older adults showed more recognition below threshold in frontal regions and younger adults showed more recognition below threshold in central regions ($F(1,38)= 4.45$, $p= 0.0414$; see table 8).

Table 8.

Experiment 2 FN400: Type by Row by Age Group Interaction.

Electrodes	Voltage MV	Age Group	Recognition Type	Row
F3, Fz and F4	-0.47	Older Adult	Recognition	Frontal
C3, Cz and C4	-0.49	Older Adult	Recognition	Central
F3, Fz and F4	-0.13	Older Adult	Below Threshold	Frontal
C3, Cz and C4	0.02	Older Adult	Below Threshold	Central
F3, Fz and F4	-0.42	Younger Adult	Recognition	Frontal
C3, Cz and C4	-0.41	Younger Adult	Recognition	Central
F3, Fz and F4	0.04	Younger Adult	Below Threshold	Frontal
C3, Cz and C4	-0.15	Younger Adult	Below Threshold	Central

There was also a 3-way interaction between Type (FN400 Recognition vs. FN400 Below Threshold), Column (Left Hemisphere vs. Central vs. Right Hemisphere) and Age Group (Younger vs. Older Adults; $F(1,38)= 3.75$, $p= 0.04$). This interaction was driven by the Age and Column interaction, where older adults showed a stronger recognition effect that was 0.28 MV more negative on the right than in the left hemisphere and younger adults showed the opposite pattern where the left hemisphere was 0.13 MV more negative than the right. This effect remained for older adults in both frontal and central regions, as the right frontal region was 0.18 MV more negative than the left and the right central region was 0.36 MV more negative than the left. The effect of increased negativity in the left hemisphere was not found in frontal locations for younger adults (-0.03) but appears in the central regions as the left hemisphere was 0.24 MV more negative than the right (see table 9).

Table 9.

Experiment 2 FN400: Type by Column by Age Group Interaction

Electrodes	Older Adult Voltage MV	Younger Adult Voltage MV	Hemisphere	Row
F3	-0.19	-0.22	Left	Frontal
Fz	-0.33	-0.18	Central	Central
F4	-0.38	-0.19	Right	Frontal
C3	-0.04	-0.31	Left	Central
Cz	-0.26	-0.45	Central	Frontal
C4	-0.41	-0.07	Right	Central

3.14 Experiment 2: P3- Positive Word and Categorical Word Conditions

A 2 (Age Group: Younger vs. Older), x 2 (Condition: Positive Words vs. Categories) x 2 (Type: Recognition vs. Recognition Below Threshold) x 3 (Column: Right Electrodes vs. Central Electrodes vs. Left Electrodes) x 3 (Row: Frontal vs. Central vs. Parietal) ANOVA was conducted to analyze the P3 component. This test revealed a main effect of Type, where P3 Recognition was 0.71 MV more negative than P3 Below Threshold ($F(1,38)= 6.06$, $p= 0.0185$; see figure 25).

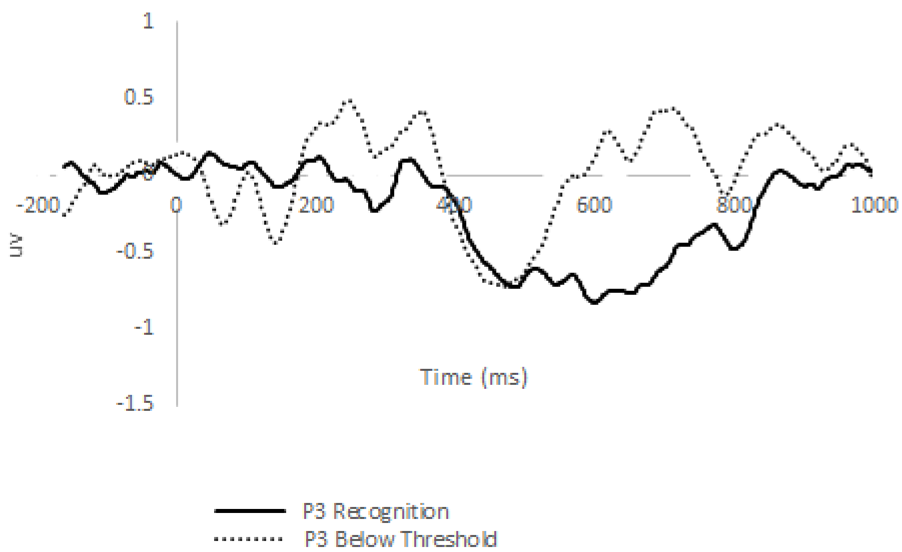

Figure 25. Experiment 2: P3 Recognition Type

Condition (Positive vs. Category) and Row (Frontal vs. Central vs. Parietal) interacted, where greater negativity was found in parietal regions for the positive condition relative to other regions. The Category showed the least amount of negativity in the parietal region (see table 10).

Table 10.

Experiment 2 P3: Row by Condition Interaction.

Electrodes	Positive Word Condition UV	Category Word Condition UV
Frontal	-0.31	-0.51
Central	-0.29	-0.44
Parietal	-0.5	-0.25

There was a three-way interaction between Recognition Type, Electrode Row and Age Group ($F(2,76)= 4.82$, $p= 0.0142$). This interaction was driven by a relatively larger effect of type for younger adults than older adults (-0.91MV vs. -0.52MV respectively) and older adults showing stronger below threshold recognition in frontal and central electrode locations, while younger adults showed a larger effect in the parietal region (see table 11).

Table 11

Experiment 2 P3: Age Group by Row by Recognition Type.

Row	Older Adult Voltage MV	Younger Adult Voltage MV	Recognition Type
Frontal	-0.81	-0.56	Recognition
Central	-0.86	-0.63	Recognition
Parietal	-0.86	-0.70	Recognition
Frontal	0.15	-0.40	Recognition Below Threshold
Central	0.18	-0.14	Recognition Below Threshold
Parietal	-0.14	0.2	Recognition Below Threshold

There was a three-way interaction between Age Group, Hemisphere and Condition ($F(2,76)= 4.26$, $p= 0.031$). This effect was driven by older adults having a smaller recognition effect in the left hemisphere for the positive condition, and a larger recognition effect in the left hemisphere for the category condition, and the opposite being true for younger adults who had their largest effect on the left side for the positive condition, and their smallest effect on the left side for the category condition (see table 12).

Table 12.

Experiment 2 P3: Age Group by Hemisphere by Condition Interaction

Hemisphere	Older Adult Voltage MV	Younger Adult Voltage MV	Condition
Left	-0.14	-0.53	Positive
Central	-0.31	-0.47	Positive
Right	-0.40	-0.35	Positive
Left	-0.64	-0.09	Category
Central	-0.34	-0.56	Category
Right	-0.4	-0.35	Category

3.15 Experiment 2: Positive and Categorical Words LPC

A 2 (Age Group: Younger vs. Older), x 2 (Condition: Positive Words vs. Categories) x 2 (Type: Recognition vs. Recognition Below Threshold) x 3 (Column: Right Electrodes vs. Central Electrodes vs. Left Electrodes) x 3 (Row: Frontal vs. Central vs. Parietal) ANOVA was conducted to analyze the LPC component. This test revealed a main effect of Type, where LPC Recognition was 0.75 MV more negative than P3 Below Threshold ($F(1,38)= 5.59$, $p= 0.0234$; see figure 25).

3.16 Experiment 2: Positive Words – FN400

As hypothesized there was a significant FN400 of recognition (Correct Rejections – Hits) ($M= -0.45$, $t(39) = -1.74$, $p = 0.04$). Which suggests that hits showed significantly higher amplitude and were better recognized that correct rejections (see figure 26).

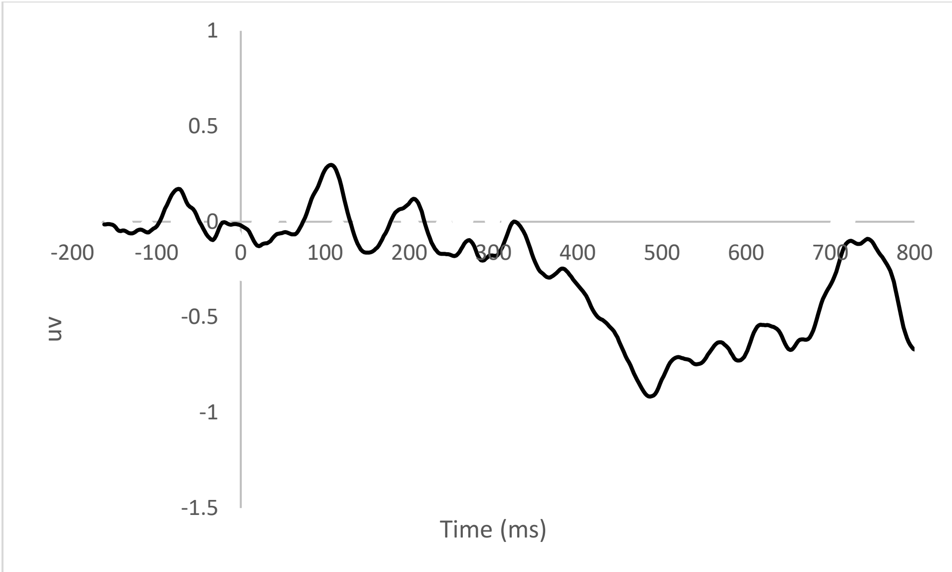

Figure 26. Experiment 2: Positive words: FN400

The group t-tests revealed a significant FN400 Recognition component for older adults (M= -0.64, t(19)= -1.88, p= 0.0377), but not younger adults (M= -0.6, t(19)= -1.14, p= 0.13; see table 13).

Table 13.

Experiment 2 Positive Words FN400: Amplitude

	Hits (Mv)	Correct Rejections (Mv)	FN400 Recognition (Mv)
Younger	0.88	0.63	-0.26
Older	1.76	1.12	-0.64*

FN400 was calculated as CR-Hits. Asterisks indicate significant effects (p<.05).

Next, a 2 (Age Group: Younger vs. Older), x 2 (Type: Recognition vs. Recognition Below Threshold) x 3 (Column: Right Electrodes vs. Central Electrodes vs. Left Electrodes) x 3

(Row: Frontal vs. Central vs. Parietal) ANOVA was conducted. This revealed a Column by Group interaction (F(2,76) = 3.81, p= 0.039; see table 14). This interaction was driven by younger adults having a stronger recognition effect in left hemisphere, compared to the right (0.177 MV) and older adults having a stronger recognition effect in the right hemisphere, compared to the left (0.374 MV). No other effects were significant.

Table 14.
Experiment 2 Positive Words FN400: Column by Group interaction

Electrodes	Voltage MV	Age Group	Hemisphere
F3 and C3	-0.15	Older Adult	Left
Fz and Cz	-0.4	Older Adult	Central
F4 and C4	-0.53	Older Adult	Right
F3 and C3	-0.52	Younger Adult	Left
Fz and Cz	-0.44	Younger Adult	Central
F4 and C4	-0.35	Younger Adult	Right

3.17 Experiment 2: Positive Words – P3

As predicted, a one-sample t-test revealed a significant effect of P3 categorization (M= -0.6, t(39)= -2.20, p= 0.017), where the ERP component was significantly less than zero. Hits were 0.6 Mv higher in amplitude than correct rejections (see figure 27).

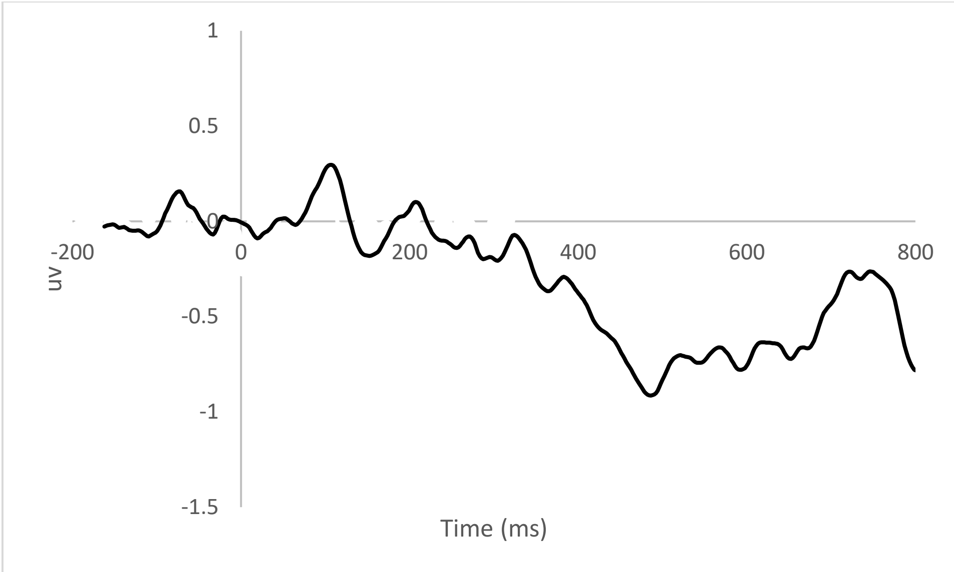

Figure 27. Experiment 2: Positive words P3 Recognition

The P3 Recognition component was significant for older adults (M= -0.54, t(19)= -1.74, p = 0.049) and approached significance for younger adults(M= -0.66, t(19)= -1.44, p = 0.08; see figure 28).

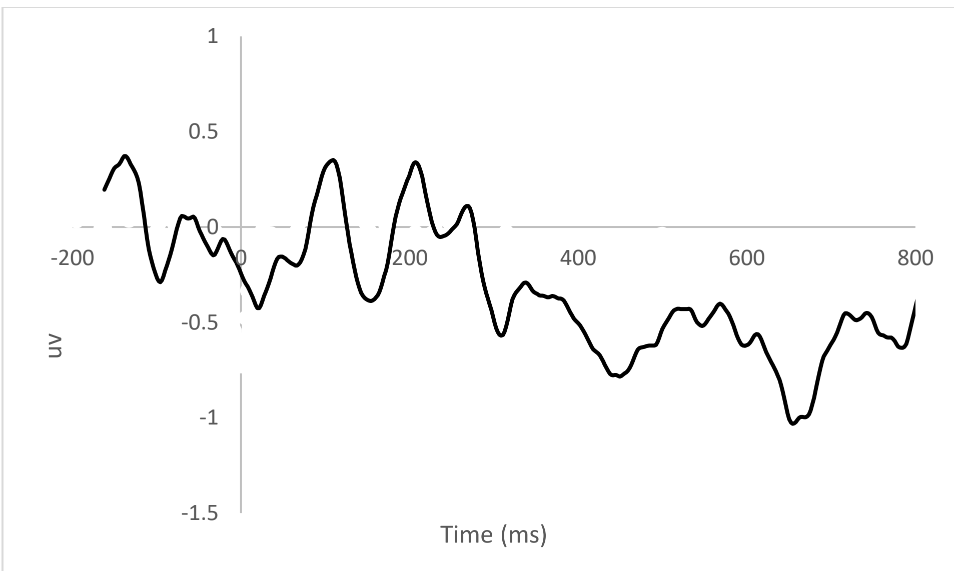

Figure 28. Experiment 2: P3 Recognition type by age

The below threshold measures were not significant, nor were the significance test from a 2 (Age Group: Younger vs. Older), x 2 (Type: Recognition vs. Recognition Below

Threshold) x 3 (Column: Right Electrodes vs. Central Electrodes vs. Left Electrodes) x 3 (Row: Frontal vs. Central vs. Parietal) ANOVA.

3.18 Experiment 2: Positive Words – LPC

As hypothesized there was a significant LPC of recollection (Correct Rejections – Hits) (M= -0.399, t(39) = -1.74, p = 0.045). Which suggests that hits showed significantly higher amplitude and were better recognized that correct rejections (see figure 27).

3.19 Experiment 2: Categorical Words – FN400

The categorical words condition was hypothesized the lead to greater recognition, due to less interference with other words on the list. Words from this listed consisted of 25 words in the following categories: Animals, Kitchen Items, Money and Sports.

The FN400 Recognition component approached significance (M= -0.386, t(39)= -1.59, p= 0.06). As can be seen from the figure, it appears that the effect is happening later, beginning at roughly 400ms and finishing at approximately 600ms post-stimulus presentation, which is more in line with the P3 time window, compared to the FN400 time window which is between 300 and 500ms post-stimulus presentation (see figure 29).

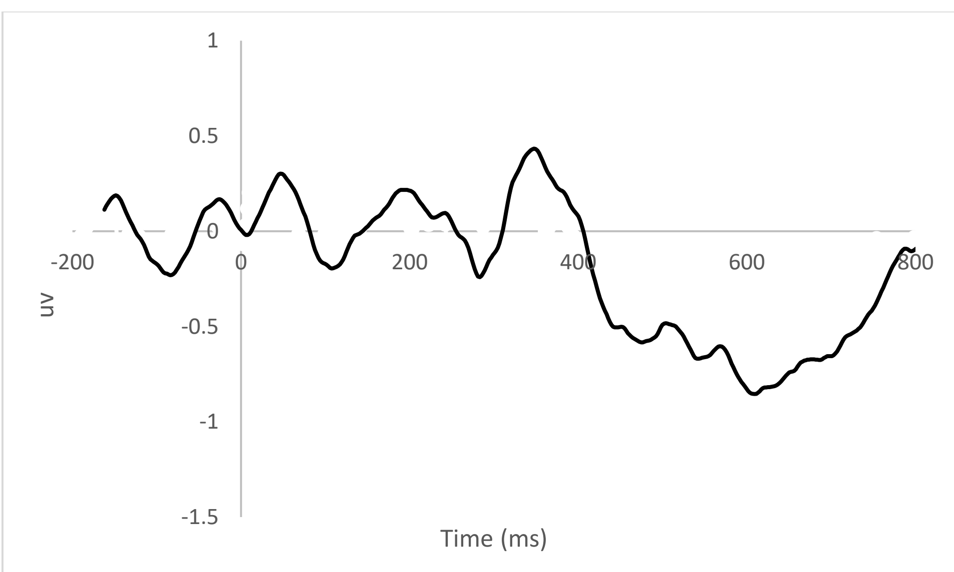

Figure 29. Experiment 2: Categorical words FN400

Next, a 2 (Age Group: Younger vs. Older), x 2 (Type: Recognition vs. Recognition Below Threshold) x 3 (Column: Right Electrodes vs. Central Electrodes vs. Left Electrodes) x 3 (Row: Frontal vs. Central vs. Parietal) ANOVA was conducted which revealed a main effect of Type ($F(1,38) = 4.30$, $p = 0.045$). The FN400 Recognition component exhibited a significantly stronger effect than the FN400 Below Threshold component (see figure 30). No other effects were significant.

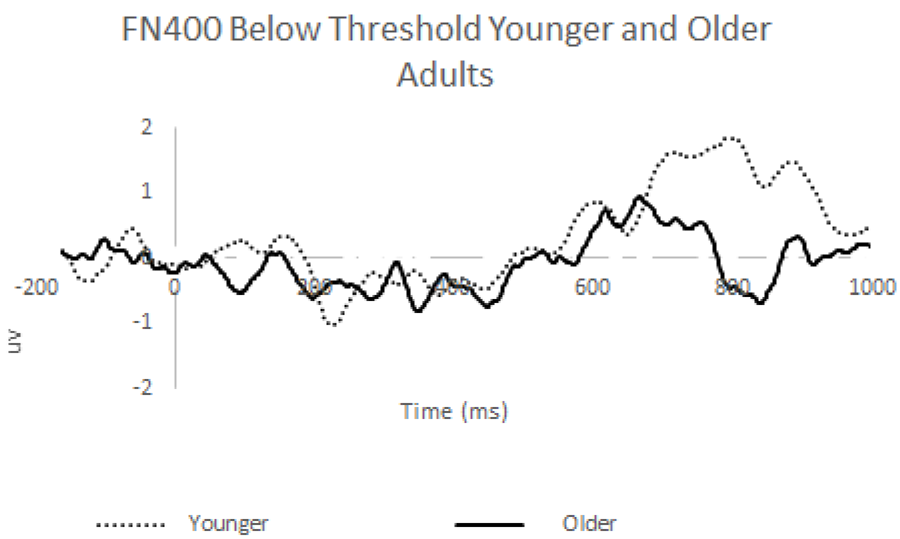

Figure 30. Experiment 2: Categorical Words FN400 Recognition Type

3.20 Experiment 2: Categorical Words – P3

As predicted, one-sample t-tests revealed a significant P3 Recognition component ($M = -0.88$, $t(39) = -3.64$, $p < 0.001$). This effect was also found for both younger ($M = -1.05$, $t(19) = -2.43$, $p = 0.013$) and older adults ($M = -0.71$, $t(19) = -3.17$, $p = 0.0025$; see figure 31). The P3 Below Threshold did not reach significance ($M = -0.35$, $t(19) = -0.96$, $p = 0.17$).

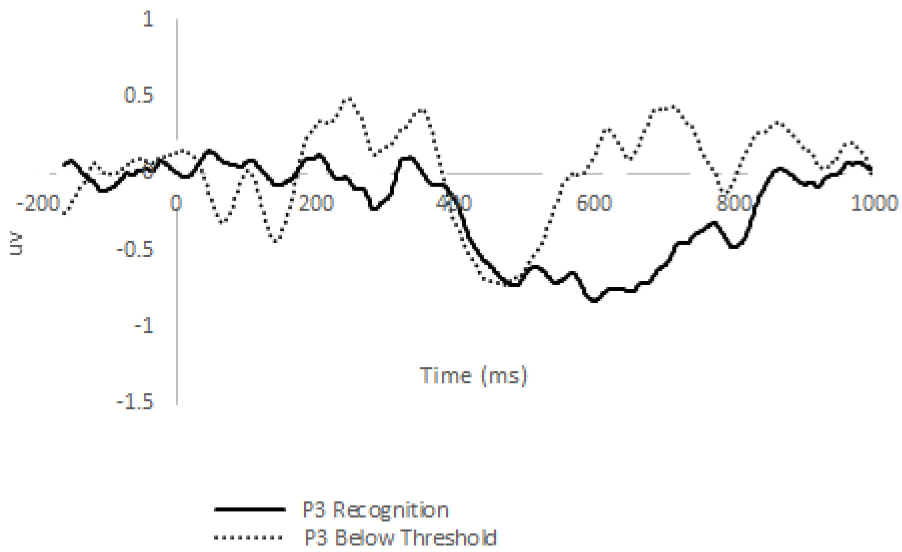

Figure 31. Experiment 2: Categorical Words P3 Recognition

Next, a 2 (Age Group: Younger vs. Older), x 2 (Type: Recognition vs. Recognition Below Threshold) x 3 (Column: Right Electrodes vs. Central Electrodes vs. Left Electrodes) x 3 (Row: Frontal vs. Central vs. Parietal) ANOVA was conducted which revealed that no other effects were significant, although a main effect of type approach significance ($F(1,38) = 3.20$, $p= 0.08$), where the effect of P3 Recognition trended as a stronger effect than P3 Below Threshold.

3.21 Experiment 2: Categorical Words – LPC

The LPC of recollection approached significance (Correct Rejections – Hits) ($M= -0.35$, $t(39) = -1.68$, $p = 0.051$).

3.22 Below Threshold Measures and Performance

This study offers the first method of analyzing recognition below threshold. With the rationale that having too conservative of a response criterion leads to decreased performance due to a selection bias. That is, items which are sufficiently recognized will be a hit for individuals with a non-biased response criterion, but for those with a more conservative response criterion, some of those hits will become misses due solely to the response selection process (not recognition). We predict that below threshold measure will positively correlate to accuracy scores, but more specifically to hit rate, because a more conservative response criterion is predicted to lower the number of hits and increase the number of misses.

3.23 FN400 Below Threshold

In attempt to validate the FN400 Below Threshold measure, behavioral accuracy scores were correlated to FN400 Below Threshold scores. The FN400 was positively correlated to Hit Rate ($r = 0.188$, $n=120$, $p= 0.02$; see figure 29). Additionally, the frontal electrodes of the FN400 was correlated to accuracy rate ($r = 0.152$, $n=120$, $p= 0.048$; see figure 32).

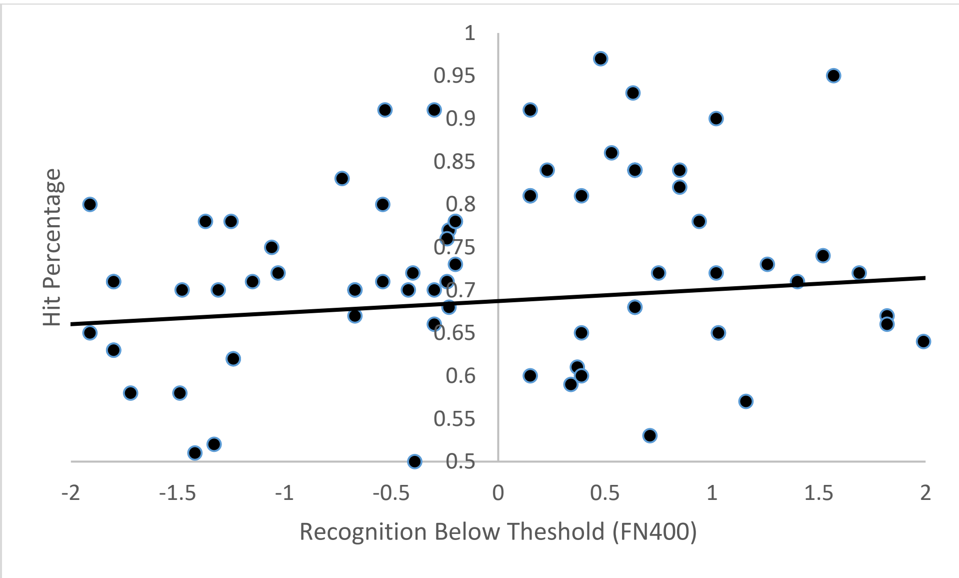

Figure 32. Hit and FN400 Recognition Below Threshold.

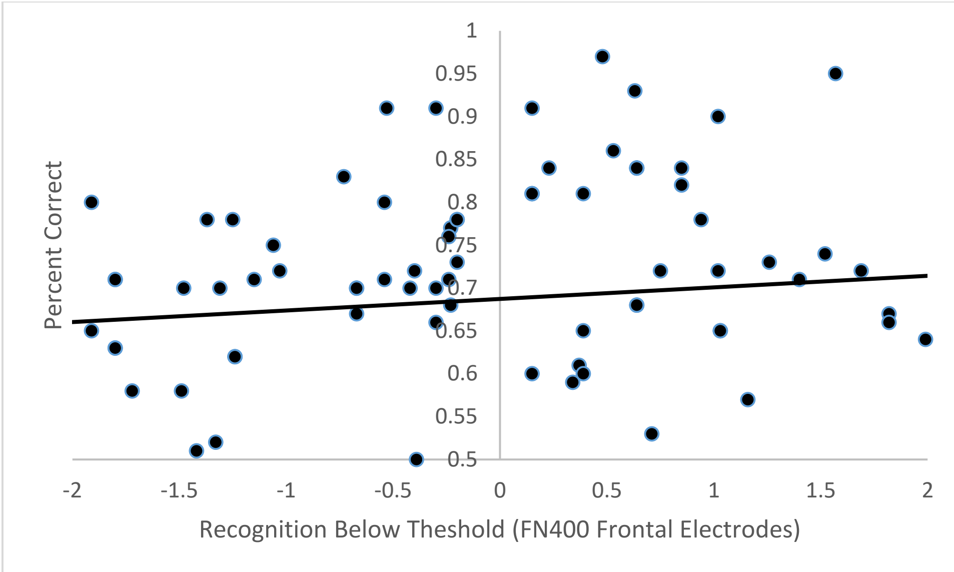

Figure 33. Accuracy and FN400 Frontal Recognition Below Threshold

In the recognition condition, the central electrodes of the FN400 Recognition positively correlated with hit percentage (Person one-tail correlation .151, p= 0.049; see figure 33).

3.24 P3 Recognition Below Threshold

No significant correlations between P3 Recognition Below Threshold and behavioral performance were found.

3.25 LPC Recognition Below Threshold

No significant correlations between LPC Recognition Below Threshold and behavioral performance were found.

3.26 Experiment 2 Discussion

Experiment 2 included an additional four-category condition in attempt to reduce PI. As expected, accuracy was higher for the four-category condition than the single-category condition. The release from PI (meaning the benefit from switching from the single-category to four-category conditions) was approximately equal for both groups. It was expected that older adults would disproportionally benefit from the release from PI.

Accuracy did not significantly differ between groups for either the more difficult single-category condition (replicating the results from Experiment 1) or the easier four-category condition. Additionally, contrary to expectations, respond criterion did not differ between age groups. As expected, younger adults had faster response times than older adults.

CHAPTER IV

GENERAL DISCUSSION

The present study aimed to explain two common findings in the field of human episodic memory. First was to provide a potential causal mechanism of age-related differences in human memory (e.g entropy), and second to describe and examine the role of response bias on recognition memory accuracy scores. Two Experiments were conducted to provide insight into these phenomena. Experiment 1 examined age-related differences in recognition memory with the goal of better understanding the role of response criterion on recognition memory test outcomes. The experiment consisted of 100 to-be-remembered positive words and 100 positive new words. Recognition memory was measured behaviorally by hit-rate and correct rejection-rate, also electrophysiologically through the FN400, LPC and P3 Recognition components. The role of response criterion was analyzed through SDT measures and a new ERP measure to index the recognition of "misses", these measures were called FN400 Recognition Below Threshold, P3 Recognition Below Threshold and LPC Recognition Below Threshold, which were measured by subtracting misses from correct rejections.

Experiment 1 did not provide evidence for age-related differences in recognition memory accuracy. The present finding of non-significant age differences was observed with behavioral accuracy scores and ERPs (FN400 Recognition, LPC Recollection and P3

Recognition). Age and Type (Hit-rate vs. Correct Rejection-rate) did not interact, suggesting that response criterion did not differ between age group in terms of behavioral accuracy. The response time measure showed faster responses for younger adults. T-tests revealed that ERP amplitude for hits were significantly higher than correct rejections for both age groups, meaning that hits had significantly greater amplitude than correct rejections. Interestingly, the FN400 Below Threshold measure showed that misses were significantly more positive than correct rejections for older, but not younger adults. Younger adults trended in that direction, thus an age by recognition type interaction was not significant.

Experiment 2 aimed to replicate Experiment 1 and introduce a new condition to show the effects proactive interference on recognition memory. It was hypothesized that due to entropy (increased randomness in a physical system) that older adults would be more prone to memory errors for items that held closer distances in "semantic space". Experiment 1 used 200 positive words and is considered a relatively difficult recognition task because the words carry similar meaning, thus their memory representations are more likely hold closer distances in "semantic space" relative to the words in Experiment 2 which held four different categories (as opposed to one in Experiment 1. Experiment 2 consisted of two parts, the first used the same 200 positive words, and the second part replicated the task using words from the following four categories: Sports, Animals, Kitchen Items and Money. This condition was thought to be easier, because less items would be in each semantic space, leading to less proactive interference between items (e.g. release from PI). It was hypothesized that older adults would benefit to a greater magnitude relative to the positive-word condition than younger adults. This is because it was hypothesized that older adults will be more sensitive to PI due to increased levels of entropy. This would be expressed as an Age by Condition interaction. This finding was not supported by either the ERP, accuracy or response time data. Both groups observed relatively equal increases in behavioral performance when comparing the new four-category condition to the single-category condition that was used in Experiment 1 (overall accuracy increased by 7.8% in the four-category condition, and responses were 74.5ms faster). This suggests the both groups benefited equally from the release from PI. Overall the age groups performed similarly, as there was no main effect of age. Surprisingly there was no main effect of condition using the electrophysiological measures. We predicted that the release from PI that was afforded by the increase of categories and the behavioral increase in accuracy would have shown an increased amplitude in the four-category condition.

As expected, the FN400 Recognition ERP component was positively correlated with hit-rate. Meaning, participants who averaged higher amplitudes for hits, relative to correct rejections scored better than those who had lower hit amplitudes. This provides additional evidence that the FN400 was measuring recognition. Critically, the novel measure FN400 Below Threshold was also positively associated with hit-rate and the frontal electrodes of the FN400 Below Threshold was positively correlated to overall behavioral accuracy. Meaning, that those who recognized misses more than correct rejections performed worse than those who did not recognize their misses. This suggests that a more conservative response criterion is related to lower performance. This is the first time to our knowledge that response criterion has been analyzed through electrophysiological measures of recognition. The Below Threshold measures shed light into the decision-making process and allows for a more detailed analysis of recognition that is not biased by response criterion.

Experiment 1 and Experiment 2 failed to replicate previous literature on two age-related differences in commonly found in recognition memory (Ally et al., 2008a; Craik & Schloerscheidt, 2011- experiment 1a; Coyne, Allen & Wickens, 1986; Danziger, 1980; Nessler et al., 2007; Poon & Fozard, 1980; Ratcliff, Thapar & McKoon, 2004 Wolk et al., 2009). First, the present study found no age-related differences in recognition memory for accuracy scores. Second, the study found no evidence of age-related differences in response criterion. The present study aimed to explain these common age-related findings in recognition memory, by proposing that increased levels of entropy in the older adult's system were responsible for these changes. While this study cannot make these conclusions due to null age-related results, the same theory still applies to human memory as a whole. As predicted, the release from PI (difference in behavioral performance between the positive word condition and the multiple category condition in experiment two) was a significant and exhibited a relatively large effect (accuracy was increased by 7.8%, response time was 74.5ms faster). This finding is in line with other studies that suggest that interference plays an important role in remembering information.

The present study introduced recognition below threshold measures by measuring recognition-related amplitude differences between misses and correct rejections. This measure was significant for the FN400 component but not for the P3 component. The FN400 was further validated by showing a positive correlation with hit-rate and overall behavioral accuracy. The correlation between the FN400 below threshold component and accuracy scores trended towards significance in both Experiment 1 and Experiment 2 and only reached significance when the results from both studies were combined. Theoretically the result of a small effect of response criterion on behavioral performance makes sense, as response bias is one of many factors that are involved in recognition memory performance. Future studies would be needed to further validate this ERP component.

The word stimuli chosen may have influenced the results. In Experiment 1, older adults may have disproportionately aided by the choice to use positive words. Older adults have been shown to remember positive words better than negative or neutral words (Mather & Carstensen, 2005), while this is not necessarily true for younger adults. However, the choice to choose positive words cannot explain why older adults did comparably well to younger adults in the four-category condition. The single-category and four-category conditions were counter-balanced on word length and frequency of use but were not counter-balanced on concreteness. The categories condition contained 92% concrete nouns, while the single-category condition only contained 32% concrete nouns. It is possible that the increase in accuracy between the conditions could be partially due to word concreteness.

Perhaps the most unexpected finding was the lack of age-related differences in recognition memory. This could have occurred due to a variety of sources. First, but quite unlikely is that this study may have fell victim to a type II error, where true population group differences exist, but due to random sampling and random effects, null results were obtained. Previous meta-analysis shows a small, but reliable decline in recognition memory with age (Koen & Yonelinas, 2014). While some studies have found age related differences in recognition memory (Ally et al., 2008a; Craik & Schloerscheidt, 2011-experiment 1a; Nessler et al., 2007; Wolk et al., 2009), others have not (Ally et al., 2008b;

Craik & Schloerscheidt, 2011- experiment 1b). Although this study used an acceptable level of power (0.8), there is still a 20% chance of obtaining insignificant results in an experiment, even when group means are different. It is less likely, but still possible to report two studies with null results even when true effects exist, and the studies contain adequate power (0.2 x 0.2 = 0.04 or 4%). However, this may be even less likely as an additional two studies in our laboratory using a longer retention interval also observed no adult age differences in recognition memory (Allen et al., in press, Experiments 2 and 3). Additionally, across Experiment 1 and Experiment 2 older adults scored 0.6% higher than younger adults, meaning that the effect size is in the opposite direction than predicted.

Another possibility is that these effects could have been due to a selection bias, where the present sample does not differ in recognition memory, but the true population does. Due to the quasi-experimental nature of cross-sectional aging research, it is not possible to randomly assign an important independent variable (age). As a result, aging researchers must be particularly wary of selection effects, as it is possible that their groups may vary systematically in important qualities that are related to the dependent variable. In this study, three age-related differences between the younger and older adults stood out. First, older adults performed significantly better on the Mill-Hill vocabulary scale. It is possible that this sample of older adults had particularly good vocabularies relative to their peers and that this may have aided their performance. The second is older adults possessed more years of education than younger adults. Years of education have previously been linked to less cognitive decline (Springer, McIntosh, Winocur & Grady, 2005) and could have influenced the results. Finally, younger adults displayed greater speed of processing, as displayed by the Digit-Symbol Substitution Task, this may have benefited younger adults. Because older adults did better than expected, vocabulary and years of education were run as covariates in two separate one-way ANCOVAs (Analysis of Covariance). Each of these analyses failed to yield support for the influence of these covariates (F's < 1).

Another possibility is that the null age-related findings may be due to age-differences (the difference in recognition performance between present-day younger vs. older adults) instead of measuring age-changes (the changes in an individual's ability over time). Cross-sectional designs such as the present study are susceptible to detecting (or not detecting) age-related differences in a cohort's ability, instead of an individual's ability. Previous studies have documented that cohorts can vary in ability (Flynn, 2007). The Flynn effect was named to show a general trend of intelligence scores becoming higher for subsequent cohorts. More recent findings have found the opposite "a reverse Flynn effect" (Dutton, Linden & Lynn, 2016). It is possible that a longitudinal design would have shown different age patterns. Future studies may consider replicating previous aging research in efforts to understand older adults are improving, or if younger adults are not scoring as well on memory tasks, as they once did. Lastly, the null age-related findings may be due to a speed-accuracy tradeoff. Future studies may consider methods to assure similar response times for each group.

The present study found no age-related differences in recognition memory. This may be at least partially due to an emerging trend of older adults performing better compared to younger adults than they have in the past (Dutton, Linden & Lynn, 2016). The manipulation of increasing interference equally affected each age group. The largest theoretical addition that this study provides is a new electrophysiological index of the recognition of misses. The below threshold technique allows for insight into recognition decision-making that was previously unexamined.

REFERENCES

Allen, P. A. (1991). On age differences in processing variability and scanning speed. *Journal of gerontology, 46(5),* 191-201.

Allen, P. A., Kaufman, M., Smith, A. F., & Propper, R. E. (1998). Age differences in entropy: Primary versus secondary memory. *Experimental aging research, 24(4),* 307-336.

Allen, P. A., Kaufman, M., Smith, A. F., & Propper, R. E. (1998). A molar entropy model of age differences in spatial memory. Psychology and aging,13(3), 501.

Allen, P. A., Kaut, K., Baena, E., Lien, M. C., & Ruthruff, E. (2011). Individual differences in positive affect moderate age-related declines in episodic long-term memory. *Journal of Cognitive Psychology, 23(6),* 768-779.

Allen, P. A., Kaut, K. P., Lord, R. G., Hall, R. J., Grabbe, J. W., & Bowie, T. (2005). An emotional mediation theory of differential age effects in episodic and semantic memories. *Experimental Aging Research, 31(4),* 355-391.

Allen, P. A., Lien, M. C., & Jardin, E. (2015). Age-related emotional bias in processing two emotionally valenced tasks. *Psychological research,* 1-20.

Allen, P. A., Sliwinski, M., & Bowie, T. (2002). Differential age effects in semantic and episodic memory, Part II: Slope and intercept analyses. *Experimental Aging Research*, *28*(2), 111-142.

Allen, P. A., Smith, A. F., Jerge, K. A., & Vires-Collins, H. (1997). Age differences in mental multiplication: Evidence for peripheral but not central decrements. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 52(2),* 81-90.

Angel, L., Fay, S., Bouazzaoui, B., Granjon, L., & Isingrini, M. (2009). Neural correlates of cued recall in young and older adults: an event-related potential study. *Neuro report, 20(1),* 75-79.

Angel, L., Fay, S., Bouazzaoui, B., & Isingrini, M. (2011). Two hemispheres for better memory in old age: role of executive functioning. *Journal of Cognitive Neuroscience*, *23(12)*, 3767-3777.

Baltes, P. B. (1987). Theoretical propositions of life-span developmental psychology: On the dynamics between growth and decline. *Developmental psychology, 23(5),* 611.

Bernstein, L. J., Beig, S., Siegenthaler, A. L., & Grady, C. L. (2002). The effect of encoding strategy on the neural correlates of memory for faces. *Neuropsychologia, 40(1*), 86-98.

Born, J., Hitzler, V., Pietrowsky, R., Pauschinger, P., & Fehm, H. L. (1988). Influences of cortisol on auditory evoked potentials (AEPs) and mood in humans. *Neuropsychobiology, 20(3),* 145-151.

Buckner, R. L., & Petersen, S. E. (1996, February). What does neuroimaging tell us about the role of prefrontal cortex in memory retrieval?. *In Seminars in Neuroscience* 8(1), 47-55.

Cabeza, R., Anderson, N. D., Locantore, J. K., & McIntosh, A. R. (2002). Aging gracefully: compensatory brain activity in high-performing older adults. *Neuroimage, 17(3),* 1394-1402.

Cerella, J. (1985). Information processing rates in the elderly. *Psychological bulletin, 98(1)*, 67.

Cohen, G., & Faulkner, D. (1986). Does 'elderspeak' work? The effect of intonation and stress on comprehension and recall of spoken discourse in old age. *Language & Communication, 6(1-2),* 91-98.

Coyne, A. C., Allen, P. A., & Wickens, D. D. (1986). Influence of adult age on primary and secondary memory search. *Psychology and Aging, 1(3),* 187.

Craik, F. I., & Jennings, J. M. (1992). *Human memory.*

Craik, F. I., & Lockhart, R. S. (1972). Levels of processing: A framework for memory research. *Journal of verbal learning and verbal behavior, 11(6), 671-684.*

Craik, F. I., & Tulving, E. (1975). Depth of processing and the retention of words in episodic memory. *Journal of experimental Psychology: general,104(3),* 268.

Curran, T. (2000). Brain potentials of recollection and familiarity. *Memory & Cognition, 28(6),* 923-938.

Czernochowski, D., Fabiani, M., & Friedman, D. (2008). Use it or lose it? SES mitigates age-related decline in a recency/recognition task. *Neurobiology of aging, 29(6),* 945-958.

Danckert, S. L., & Craik, F. I. (2013). Does aging affect recall more than recognition memory?. Psychology and aging, 28(4), 902-909.

Danziger, W.L. (1980). Measurement of response bias in aging research. In L. W. Poon (Ed.), Aging in the 1980s: Psychological Issues, 552-557.

De Renzi, E., Liotti, M., & Nichelli, P. (1987). Semantic amnesia with preservation of autobiographic memory. A case report. *Cortex, 23(4),* 575-597.

Duarte, A., Ranganath, C., Trujillo, C., & Knight, R. T. (2006). Intact recollection memory in high-performing older adults: ERP and behavioral evidence. *Journal of Cognitive Neuroscience, 18(1),* 33-47.

Dunlosky, J., Hertzog, C., & Powell-Moman, A. (2005). The contribution of mediator-based deficiencies to age differences in associative learning. *Developmental Psychology, 41(2),* 389.

Dutton, E., van der Linden, D., & Lynn, R. (2016). The negative Flynn effect: A systematic literature review. *Intelligence, 59, 163-169*.

Düzel, E., Yonelinas, A. P., Mangun, G. R., Heinze, H. J., & Tulving, E. (1997). Event-related brain potential correlates of two states of conscious awareness in memory. *Proceedings of the National Academy of Sciences,94(11)*, 5973-5978.

Eichenbaum, H. (2003). Memory systems. *Handbook of psychology*.

Farewell, L. A., & Donchin, E. (1991). The truth will out: interrogative polygraphy ('lie detection') with event-related potentials. Psychophysiology, 28, 531-547.

Flynn, J. R. (2007). What is intelligence?: Beyond the Flynn effect. *Cambridge University Press*.

Friedman, D. (2013). The cognitive aging of episodic memory: a view based on the event-related brain potential. *Frontiers in behavioral neuroscience*, 7, 111.

Gold, P. E., & Van Buskirk, R. B. (1975). Facilitation of time-dependent memory processes with posttrial epinephrine injections. *Behavioral biology,13(2),* 145-153.

Hasher, L., & Zacks, R. T. (1988). Working memory, comprehension, and aging: A review and a new view. *Psychology of learning and motivation, 22,* 193-225.

Haxby, J. V., Ungerleider, L. G., Horwitz, B., Maisog, J. M., Rapoport, S. I., & Grady, C. L. (1996). Face encoding and recognition in the human brain. *Proceedings of the National Academy of Sciences, 93(2),* 922-927.

Hayama, H. R., Johnson, J. D., & Rugg, M. D. (2008). The relationship between the right frontal old/new ERP effect and post-retrieval monitoring: specific or non-specific?. *Neuropsychologia, 46(5),* 1211-1223.

Howard, M. W., Bessette-Symons, B., Zhang, Y., & Hoyer, W. J. (2006). Aging selectively impairs recollection in recognition memory for pictures: evidence from modeling and receiver operating characteristic curves. *Psychology and aging, 21(1),* 96.

Jack, C. R., Petersen, R. C., Xu, Y., O'brien, P. C., Smith, G. E., Ivnik, R. J., & Kokmen, E. (2000). Rates of hippocampal atrophy correlate with change in clinical status in aging and AD. *Neurology, 55(4),* 484-490.

Jacoby, L. L. (1999). Deceiving the elderly: Effects of accessibility bias in cued-recall performance. *Cognitive Neuropsychology, 16(3-5),* 417-436.

Jacques, P. S., & Levine, B. (2007). Ageing and autobiographical memory for emotional and neutral events. *Memory, 15(2),* 129-144.

Jacques, P. S., Dolcos, F., & Cabeza, R. (2010). Effects of aging on functional connectivity of the amygdala during negative evaluation: a network analysis of fMRI data. *Neurobiology of aging, 31(2),* 315-327.

Janowsky, J. S., Shimamura, A. P., & Squire, L. R. (1989). Source memory impairment in patients with frontal lobe lesions. *Neuropsychologia, 27(8),* 1043-1056.

Jennings, J. M., & Jacoby, L. L. (1997). An opposition procedure for detecting age-related deficits in recollection: telling effects of repetition. *Psychology and aging, 12(2),* 352.

Kliegl, R., Smith, J., & Baltes, P. B. (1990). On the locus and process of magnification of age differences during mnemonic training. *Developmental Psychology, 26(6),* 894.

Lien, M. C., Allen, P., & Martin, N. (2014). Processing visual words with numbers: Electrophysiological evidence for semantic activation. *Psychonomic bulletin & review, 21(4),* 1056-1066.

Lopez-Calderon, J., & Luck, S. J. (2014). ERPLAB: An open-source toolbox for the analysis of event-related potentials. *Frontiers in human neuroscience, 8*, 213.

Mitchell, D. B. (1989). How many memory systems? Evidence from aging. Journal of Experimental Psychology: *Learning, Memory, and Cognition,15(1),* 31-49.

Moscovitch, M. (1992). Memory and working-with-memory: A component process model based on modules and central systems. *Journal of cognitive neuroscience, 4(3),* 257-267.

Naveh-Benjamin, M. (2000). Adult age differences in memory performance: tests of an associative deficit hypothesis. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26(5),* 1170.

Naveh-Benjamin, M., Brav, T. K., & Levy, O. (2007). The associative memory deficit of older adults: the role of strategy utilization. *Psychology and aging, 22(1)*, 202.

Naveh-Benjamin, M., & Craik, F. I. (1995). Memory for context and its use in item memory: comparisons of younger and older persons. *Psychology and aging, 10(2),* 284.

Pachella, R. G. (1974). The interpretation of reaction time in information processing research. In B. Kantowitz (Ed.), Human information processing: Tutorials in performance and cognition (pp. 41-82). Hilldale, NJ: Erlbaum.

Paller, K. A., Voss, J. L., & Boehm, S. G. (2007). Validating neural correlates of familiarity. *Trends in cognitive sciences, 11(6),* 243-250.

Perfect, T. J., & Dasgupta, Z. R. (1997). What underlies the deficit in reported recollective experience in old age? *Memory & Cognition, 25(6),* 849-858.

Polich, J., & Kok, A. (1995). Cognitive and biological determinants of P300: an integrative review. *Biological psychology*, *41*(2), 103-146.

Poon, L. W., & Fozard, J. L. (1980). Age and word frequency effects in continuous recognition memory. Journal of Gerontology, 35(1), 77-86.

Ratcliff, R., Thapar, A., Gomez, P., & McKoon, G. (2004). A diffusion model analysis of the effects of aging in the lexical-decision task. Psychology and aging, 19(2), 278-289.

Raz, N., Lindenberger, U., Rodrigue, K. M., Kennedy, K. M., Head, D., Williamson, A., & Acker, J. D. (2005). Regional brain changes in aging healthy adults: general trends, individual differences and modifiers. *Cerebral cortex, 15(11),* 1676-1689.

Rees, L. (1953). Psychological concomitants of cortisone and ACTH therapy. *The British Journal of Psychiatry, 99(416),* 497-504.

Roberts, S., & Sternberg, S. (1993). The meaning of additive reaction-time effects: Tests of three alternatives. Attention and performance XIV: *Synergies in experimental psychology, artificial intelligence, and cognitive neuroscience, 14,* 611-653.

Rönnlund, M., Nyberg, L., Bäckman, L., & Nilsson, L. G. (2005). Stability, growth, and decline in adult life span development of declarative memory: cross-sectional and longitudinal data from a population-based study. Psychology and aging, 20(1), 3-18.

Rosenbaum, R. S., Köhler, S., Schacter, D. L., Moscovitch, M., Westmacott, R., Black, S. E., ... & Tulving, E. (2005). The case of KC: contributions of a memory-impaired person to memory theory. *Neuropsychologia, 43(7),* 989-1021.

Raz, N., Rodrigue, K. M., Head, D., Kennedy, K. M., & Acker, J. D. (2004). Differential aging of the medial temporal lobe a study of a five-year change. *Neurology, 62(3),* 433-438.

Salthouse, T. A. (1979). Adult age and the speed-accuracy trade-off. Ergonomics, 22(7), 811-821.

Sutton, S., Braren, M., Zubin, J., & John, E. R. (1965). Evoked-potential correlates of stimulus uncertainty. Science, 150(3700), 1187-1188.

Schaie, K. W. (1996). Intellectual development in adulthood: The Seattle longitudinal study. *Cambridge University Press.*

Schroots, J. J. F. (1988). On growing, formative change and aging. *In Emergent theories of aging*, 299-329.

Schroots, J. J., & Yates, F. E. (1999). On the dynamics of development and aging. *Handbook of theories of aging*, 417-433.

Shimamura, A. P. (2002). Memory retrieval and executive control. Principles of frontal lobe function, 210-220.

Shimamura, A. P. (2000). The role of the prefrontal cortex in dynamic filtering. *Psychobiology, 28(2),* 207-218.

Springer, M. V., McIntosh, A. R., Winocur, G., & Grady, C. L. (2005). The relation between brain activity during memory tasks and years of education in young and older adults. *Neuropsychology, 19(2),* 181-192.

Stern, Y. (2002). What is cognitive reserve? Theory and research application of the reserve concept. *Journal of the International Neuropsychological Society, 8(3),* 448-460.

Sullivan, E. V., Pfefferbaum, A., Swan, G. E., & Carmelli, D. (2001). Heritability of hippocampal size in elderly twin men: equivalent influence from genes and environment. *Hippocampus, 11(6),* 754-762.

Tulving, E. (1972). Episodic and semantic memory 1. *Organization of Memory. London: Academic, 381(4),* 382-404.

Van Hooff, J. C., Brunia, C. H., & Allen, J. J. (1996). Event-related potentials as indirect measures of recognition memory. International Journal of Psychophysiology, 21(1), 15-31.

Verhaeghen, P. (2003). Aging and vocabulary score: A meta-analysis.*Psychology and aging, 18(2), 332.*

Verhaeghen, P., Marcoen, A., & Goossens, L. (1993). Facts and fiction about memory aging: A quantitative integration of research findings. *Journal of gerontology, 48(4),* 157-171.

Verhaeghen, P., Marcoen, A., & Goossens, L. (1992). Improving memory performance in the aged through mnemonic training: a meta-analytic study. *Psychology and* aging, 7(2), 242.

Verhaeghen, P., & Cerella, J. (2002). Aging, executive control, and attention: A review of meta-analyses. *Neuroscience & Biobehavioral Reviews, 26(7),* 849-857.

Verhaeghen, P., & Marcoen, A. (1993). Memory aging as a general phenomenon: Episodic recall of older adults is a function of episodic recall of young adults. *Psychology and Aging, 8(3),* 380-388.

Voss, J. L., & Paller, K. A. (2006). Fluent conceptual processing and explicit memory for faces are electrophysiologically distinct. *The Journal of Neuroscience, 26(3),* 926-933.

West, R. L. (1996). An application of prefrontal cortex function theory to cognitive aging. *Psychological bulletin, 120(2),* 272-300.

Wickens, D. D. (1970). Encoding categories of words: An empirical approach to meaning. Psychological Review, 77(1), 1-15.

Wood, S., & Kisley, M. A. (2006). The negativity bias is eliminated in older adults: age-related reduction in event-related brain potentials associated with evaluative categorization. *Psychology and Aging, 21(4),* 815-822.

Yates, F. E., & Benton, L. A. (1995). Biological senescence: Loss of integration and resilience. *Canadian Journal on Aging, 14(1),* 106-120.

Yonelinas, A. P. (2002). The nature of recollection and familiarity: A review of 30 years of research. *Journal of memory and language, 46(3),* 441-517.

APPENDIX

Appendix A: Word Stimuli

Positive Word	Length	Log Frequency	POS	Categorical Word	Length	Log Frequency	POS
silly	5	9.98	Other	tree	4	10.21	Noun
yum	3	7.86	Other	orchid	6	7.78	Noun
adore	5	6.97	Other	plant	5	10.14	Noun
calm	4	8.75	Noun	rose	4	9.87	Noun
fit	3	10.66	Other	horse	5	10.08	Noun
glad	4	10.15	Other	moss	4	8.22	Noun
holy	4	10.21	Other	flower	6	8.75	Noun
love	4	12.02	Noun	seed	4	9.01	Noun
joke	4	9.92	Noun	grass	5	8.9	Noun
bloom	5	8.24	Noun	oak	3	8.77	Noun
bonus	5	9.59	Noun	eel	3	7.79	Noun
dream	5	7.03	Noun	maple	5	8.31	Noun
learn	5	11.18	Other	pine	4	8.98	Noun
vim	3	0	Noun	bush	4	9.3	Noun
zest	4	5.66	Noun	pig	3	8.76	Noun
hot	3	10.85	Other	cedar	5	8.01	Noun
cure	4	9.05	Noun	hamster	7	6.83	Noun
light	5	11.48	Noun	peacock	7	6.88	Noun
focus	5	10.22	Noun	gorilla	7	7.2	Noun
friend	6	11.3	Noun	monkey	6	8.49	Noun
glow	4	6.54	Noun	coyote	6	7.32	Noun
glamor	6	4.37	Noun	weasel	6	7.33	Noun
herod	5	5.5	Noun	beaver	6	7.45	Noun
mirth	5	5.93	Noun	butterfly	9	7.49	Noun
comely	6	4.66	Other	dog	3	10.97	Noun
scenic	6	7.23	Other	rhino	5	7.55	Noun
boon	4	7.73	Noun	squirrel	8	7.6	Noun

perky	5	5.87	Noun	cardinal	8	7.74	Noun
vivid	5	7.57	Other	redwood	7	7.56	Noun
favor	5	7.94	Noun	goat	4	7.85	Noun
gleam	5	5.92	Other	ant	3	7.93	Noun
clarity	7	8.03	Noun	viper	5	8.1	Noun
feat	4	7.99	Noun	owl	3	8.26	Noun
divine	6	5.7	Other	crow	4	8.45	Noun
nifty	5	8.55	Other	cougar	6	7.24	Noun
polite	6	8.82	Other	deer	4	8.5	Noun
sparkling	9	6.53	Other	snake	5	8.56	Noun
thrilling	9	6.33	Other	lizard	6	8.65	Noun
accepted	8	10.43	Other	rabbit	6	8.66	Noun
champion	8	9.02	Noun	forest	6	9.75	Noun
constant	8	9.8	Noun	bat	3	8.77	Noun
dazzling	8	6.14	Other	elephant	8	8.86	Noun
endorsed	8	7.69	Other	cow	3	8.89	Noun
esteemed	8	6.66	Other	rat	3	8.91	Noun
fabulous	8	8.15	Other	buffalo	7	9.03	Noun
friendly	8	9.77	Other	chicken	7	9.35	Noun
gorgeous	8	8.13	Other	fox	3	9.54	Noun
handsom e	8	7.84	Other	bear	4	10.07	Noun
innovate	8	5.48	Other	tulip	5	6.11	Noun
luminous	8	6.17	Other	cat	3	10.56	Noun
pleasant	8	8.82	Other	spoon	5	7.87	Noun
positive	8	10.23	Noun	microwave	9	8.38	Noun
prepared	8	9.99	Other	knife	5	8.87	Noun
reliable	8	9.74	Other	sink	4	9.06	Noun
skillful	8	6.2	Other	coffee	6	9.82	Noun
terrific	8	8.27	Other	stove	5	7.52	Noun
thriving	8	6.75	Other	counter	7	9.7	Noun
truthful	8	7.09	Other	eggs	4	9.01	Noun
angelic	7	7.94	Other	pot	3	9.49	Noun
awesome	7	9.04	Other	cup	3	10.23	Noun
believe	7	12.25	Other	pan	3	9.22	Noun
delight	7	8.07	Noun	towel	5	8.13	Noun
elegant	7	8.15	Other	nut	3	8.4	Noun

genuine	7	8.88	Other	cookie	4	9	Noun
healing	7	9.1	Noun	blender	7	6.88	Noun
learned	7	10.25	Other	tong	4	7.12	Noun
perfect	7	10.64	Other	opener	6	7.3	Noun
quality	7	11.28	Noun	roast	5	7.3	Other
rejoice	7	6.78	Other	table	5	10.93	Noun
soulful	7	5.43	Other	kettle	6	7.31	Noun
success	7	10.52	Noun	freezer	7	7.35	Noun
bubbly	6	5.48	Other	island	6	10.71	Noun
divine	6	9.46	Other	grill	5	7.31	Noun
genius	6	8.77	Noun	toaster	7	7.57	Noun
hearty	6	6.45	Other	cookbook	8	7.78	Noun
jovial	6	7.43	Other	plastic	7	10.18	Noun
lovely	6	9.01	Noun	spice	5	7.85	Noun
pretty	6	11.78	Other	mixer	5	7.89	Noun
secure	6	9.56	Other	basket	6	7.94	Noun
simple	6	11.35	Other	cookie	6	7.99	Noun
agree	5	11.55	Other	jar	3	7.99	Noun
brave	5	8.62	Other	tray	4	8.13	Noun
champ	5	7.84	Other	boil	4	8.25	Other
fresh	5	9.65	Other	oven	4	8.27	Noun
great	5	12.47	Noun	jug	3	6.73	Noun
ideal	5	9.75	Noun	sauce	5	8.66	Noun
lucid	5	8.34	Other	cabinet	7	8.77	Noun
merit	5	8.62	Noun	juice	5	8.94	Noun
quick	5	10.54	Other	salt	4	9.63	Noun
ready	5	10.69	Other	glasses	7	9.05	Noun
smile	5	9.42	Other	recipe	6	9.23	Noun
super	5	10.25	Other	plate	5	9.25	Noun
cute	4	9.31	Other	bowl	4	9.28	Noun
good	4	13.35	Other	fork	4	9.33	Noun
keen	4	8.14	Other	garbage	7	9.44	Noun
kind	4	11.79	Noun	cook	4	9.51	Other
open	4	11.88	Other	platter	7	6.84	Noun
tops	4	8.28	Noun	china	5	10.42	Noun
fun	3	11.23	Noun	sponge	6	7.38	Noun
cake	4	9	Noun	refrigerator	12	7.52	Noun

hope	4	11.92	Noun	dividend	8	7.34	Noun
win	3	11.08	Noun	nickel	6	7.59	Noun
play	4	11.92	Other	wallet	6	7.74	Noun
care	4	11.56	Noun	dime	4	7.85	Noun
give	4	12.35	Other	donate	6	7.99	Noun
kiss	4	8.36	Other	capitalism	10	8.57	Noun
amaze	5	6.69	Other	borrow	6	8.35	Other
idea	4	11.8	Noun	deposit	7	8.38	Other
aid	3	9.83	Noun	portfolio	9	8.39	Noun
dance	5	10.17	Noun	mortgage	8	8.47	Noun
create	6	11.2	Other	margin	6	8.51	Noun
elate	5	3	Other	penny	5	8.56	Noun
glee	4	6.45	Noun	cent	4	8.75	Noun
vigor	5	6.57	Noun	discounted	10	7.72	Noun
spry	4	6.63	Other	bonds	5	8.96	Noun
ally	4	7.96	Noun	invest	6	8.98	Other
alive	5	9.9	Other	estate	6	9.15	Noun
bright	6	9.53	Other	bankruptcy	10	7.75	Noun
free	4	12.41	Other	currency	8	9.18	Noun
fine	4	11.62	Other	rent	4	9.28	Noun
grow	4	10.12	Other	quarter	7	9.37	Noun
blithe	6	5.28	Other	earn	4	9.39	Other
inspire	7	7.27	Other	surplus	7	8.31	Noun
frolic	6	5.16	Other	debt	4	9.56	Noun
awed	4	5.58	Other	fund	4	9.78	Noun
jocund	6	0	Other	profit	6	9.9	Noun
merry	5	7.54	Other	economy	7	9.99	Noun
pep	3	6.76	Noun	dollar	6	10.08	Noun
agile	5	6.45	Other	loss	4	10.31	Noun
fantastic	9	9.29	Other	income	6	10.49	Noun
eager	5	8.06	Other	exchange	8	10.5	Noun
honor	5	7.88	Noun	splurge	7	4.98	Noun
full	4	6.3	Other	inherit	7	7.58	Noun
fair	4	7.53	Other	rich	4	10.51	Noun
swell	6	6.67	Noun	barter	6	6.67	Noun
excite	6	9.6	Other	receipt	7	8.74	Other
rewarding	9	7.73	Other	overdraft	9	4.17	Noun

spiritual	9	9.68	Other	receipt	7	8.74	Noun
adorable	8	6.84	Other	broke	5	9.55	Noun
affluent	8	6.47	Other	earnings	8	8.42	Noun
charming	8	7.89	Other	loan	4	9.16	Noun
creative	8	9.86	Other	inflation	9	8.86	Noun
ecstatic	8	6.78	Other	recession	9	7.71	Noun
engaging	8	8.04	Other	lend	4	8	Other
exciting	8	9.58	Other	poverty	7	8.93	Noun
familiar	8	10.2	Other	tariff	6	6.91	Noun
generous	8	8.44	Other	influx	6	6.8	Noun
grace	5	6.8	Noun	shortage	8	7.84	Noun
heavenly	8	7.82	Other	finance	7	9.53	Noun
jubilant	8	4.08	Other	coin	4	8.76	Noun
paradise	8	9.31	Noun	speed	5	11.42	Noun
polished	8	7.59	Other	score	5	10.05	Other
powerful	8	10.38	Other	win	3	11.08	Other
progress	8	9.91	Noun	net	3	11.67	Noun
restored	8	8.37	Other	fast	4	11.25	Noun
stunning	8	7.72	Other	field	5	11.29	Noun
thorough	8	8.47	Other	quarterback	11	6.73	Noun
tranquil	8	5.51	Other	basketball	10	9.19	Noun
amazing	7	10.13	Other	score	5	10.05	Noun
approve	7	8.51	Other	foot	4	10.09	Noun
beaming	7	6.33	Other	bowler	6	7.17	Noun
classic	7	10.2	Noun	athlete	7	7.2	Noun
earnest	7	7.27	Noun	aerobic	7	7.23	Other
ethical	7	8.67	Other	darts	4	7.41	Noun
glowing	7	7.6	Other	canoe	5	7.45	Noun
healthy	7	9.5	Other	boxer	5	7.46	Noun
natural	7	10.72	Noun	diver	5	7.46	Noun
popular	7	10.63	Other	rugby	5	7.68	Noun
refined	7	7.48	Other	tackle	6	7.71	Other
skilled	7	8.51	Other	sled	4	7.79	Noun
special	7	11.57	Other	fencing	7	8.02	Noun
admire	6	8.06	Other	football	8	9.79	Noun
cheery	6	5.56	Other	fitness	7	8.38	Noun
famous	6	9.77	Other	runner	6	8.41	Noun

giving	6	10.69	Other	bicycle	7	8.52	Noun
honest	6	10	Other	sweat	5	8.53	Noun
lively	6	7.54	Other	helmet	6	8.66	Noun
poised	6	7.05	Other	surf	4	8.69	Noun
reward	6	8.58	Noun	tennis	6	8.77	Noun
seemly	6	3.58	Other	soccer	6	8.92	Noun
superb	6	8.23	Other	offense	7	8.99	Noun
bliss	5	7.7	Noun	compete	7	9.05	Other
bravo	5	7.77	Noun	stadium	7	9.06	Noun
clean	5	10.5	Other	softball	8	6.79	Noun
funny	5	10.51	Other	coach	5	9.08	Noun
happy	5	11.17	Other	golf	4	9.25	Noun
laugh	5	9.51	Noun	hockey	6	9.41	Noun
lucky	5	9.79	Other	gym	3	8.17	Noun
proud	5	9.72	Other	baseball	8	9.82	Noun
quiet	5	9.48	Noun	archery	7	6.88	Noun
right	5	12.87	Other	umpire	6	6.96	Noun
sunny	5	8.39	Other	jump	4	10.2	Other
cool	4	10.81	Noun	throw	5	10.25	Other
easy	4	11.45	Other	target	6	10.3	Noun
grin	4	9.08	Noun	defense	7	10.36	Noun
neat	4	9.38	Other	ball	4	10.56	Noun
nice	4	11.64	Other	race	4	10.75	Noun
safe	4	10.41	Noun	Frisbee	7	6.47	Noun
hug	3	8.24	Other	racket	6	6.51	Noun
joy	3	9.37	Noun	swimmer	7	6.46	Noun