AGE RELATED CHANGES IN PREPARATION OF ENCODING

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AGE RELATED CHANGES IN PREPARATION OF ENCODING

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

SUMMARY

A hallmark of aging is a decline in episodic memory. These memory impairments in older adults may be related to a shift away from proactive control strategies. Previous research, with young adults, suggests proactive processes can benefit memory encoding. The dual mechanisms of control model suggests changes in the recruitment of proactive and reactive control strategies will influence behavioral outcomes. The current study used EEG to investigated proactive control in episodic memory in aging. Both young and old adults completed a subsequent memory task with audio and visual items. Each item was preceded by a modality consistent cue. Participants also completed the AX-CPT, which is sensitive to the use of proactive strategies. We found both younger and older adults recruited proactive processes only for audio trials. Both groups exhibited proactive patterns of performance on the AX-CPT. Post-stimulus EEG suggests younger and older adults recruited different strategies for processing audio items. Visual items did not show subsequent memory effects in the pre-stimulus time period, but both groups showed post-stimulus effects. These results suggest younger and older adults are able to flexibly recruit proactive strategies that benefit memory performance.

CHAPTER 1

INTRODUCTION

A hallmark of aging is a deterioration of memory, but not all types of memory decline with age. Episodic memory, the memory for specific autobiographical events, shows a deficit while other forms of memory such as semantic (e.g. names and facts) and procedural memory (e.g. riding a bike) do not drastically decline with age (Mitchell, 1989). In a recent review by Craik and Rose (2012), it is suggested that age-related errors in episodic memory vary with task demands and are related to specific forms of episodic memory use. The authors also argue that memory errors may be substantially related to a deficit in older adults ability to self-initiate semantic operations leading to a failure of encoding (Craik & Rose, 2012). Previous research has suggested that age differences in memory can be reduced when older adults are instructed to use deeper semantic tasks (Troyer, Hafliger, Cadieux, & Craik, 2006).

1.1 Encoding Processes

A common way to assess the neural correlates of memory encoding are with the subsequent memory paradigm. This paradigm uses an encoding and retrieval phase (i.e. study and test), where participants are presented items and later asked to differentiate those items (old) from additional items (new). The average neural signal from subsequently remembered items are subtracted from those subsequently forgotten (Paller & Wagner, 2002; Sanquist, Rohrbaugh, Syndulko, & Lindsley, 1980). Any post-stimulus neural differences between the subsequently remembered from the subsequently forgotten items are known as ‘Dm’, difference due to memory. Electrophysiological (EEG) Dm effects commonly show more positive-going activity for subsequently remembered than forgotten items, this is particularly evident when the encoding phase requires elaborative processing (Friedman, Nessler, & Johnson, 2007; Paller, Kutas, & Mayes, 1987). Dms with the reverse pattern (Forgotten > Remembered) are uncommon but have been occasionally reported (Guo, Voss, & Paller, 2005). Dm effects are sensitive to the conditions and context during encoding. For example, in face name pairs the Dm differs according to the memory for faces, names, and the association between them (Guo et al., 2005), additionally the Dm varies by the depth of the encoding task, such as deep vs shallow encoding (Otten & Rugg, 2001). While the Dm is mediated by the encoding conditions, how memory is assessed at retrieval also reveal encoding differences. These retrieval based differences are likely related to confidence or the extent of contextual detail that was originally encoded (Friedman, 2000; Gutchess, Ieuji, & Federmeier, 2007).

Research investigating age differences in Dm with EEG are rather limited. One study found no significant Dm effects for the old (Friedman, Ritter, & Snodgrass, 1996). By contrast, a later study from the same group using the Remember/Know/New recognition task found a Dm for the old that did not differ between remember and know trials while the young adult Dm was greater for subsequent remember than know trials, suggesting that the Dm correlates with subsequent recollection, in the young (Friedman & Trott, 2000). In Friedman et al. (1996) participants were not told about the subsequent memory test (i.e. incidental encoding) and the Dm was based on encoding trials in which there was no orienting task. But, in Friedman et al. (2000), participants read sentences and were instructed to remember the nouns, which may have recruited elaborative encoding strategies. Friedman and colleagues suggested that the discrepancy between the older adult Dm in those studies may be related to the use of elaborative encoding. Similar findings have been found with picture stimuli, where young and older adults show similar Dm effects for items remembered with high confidence vs items subsequently forgotten. For young, but not older adults, Dm effects also distinguished items subsequently remembered with high vs. low confidence (Gutchess et al., 2007).

Consistent with previous work showing that Dm effects in the old are insensitive to the quality or quantity of subsequent memory. Taken together these results suggests young and old adults utilize similar processing strategies when elaborative encoding is explicit, but the old adults may not encode as much contextual detail.

1.2 Prestimulus Subsequent Memory Effect

Most research on subsequent memory effects at encoding have focused on the Dm and the various manipulations it is sensitive to. More recently, the time period before an item is presented at encoding has shown sensitivity to subsequent memory. These pre-stimulus subsequent memory effects (preSME) are found for semantic but not orthographic orienting tasks (Otten, Quayle, Akram, Ditewig, & Rugg, 2006), are sensitive to reward incentives (Gruber & Otten, 2010), the type of semantic orienting task (Padovani, Koenig, Brandeis, & Perrig, 2011), but not stimulus modality (Otten, Quayle, & Puvaneswaran, 2010). For encoding tasks involving semantic decisions (e.g. Animacy, Relative Size), a frontal negative going preSME (subsequent forgotten > subsequent remember) was found (Otten et al., 2006; Otten et al., 2010; Padovani et al., 2011), that did not differ by visual or audio stimuli (Otten et al., 2010). Although, one study failed to find a preSME in audio items (Otten et al., 2006). A different pattern of results has been found for encoding tasks where an emotional decision was made, this elicited a central positive preSME (subsequent remember > subsequent forgotten) (Padovani et al., 2011). Further evidence suggests pre-stimulus processes are under voluntary control, for example, orthographic (alphabetical order of first and last letter in a word) tasks have been shown to not elicit a preSME (Otten et al., 2006). But, when the same items are given a high monetary value, for remembering them on a subsequent memory test, a widespread central positive preSME was found (Gruber & Otten, 2010).

These studies highlight the variable nature of the preSME and suggests that task related preparation benefits memory performance.

It is possible that the preSME is related to task switching. If it is we would expect to see differences between stay (repeat trial type) and switch (change trial type) trials. In one study, no task switching differences were found between different stimulus modalities (i.e. visual, audio) (Otten et al., 2010), but they used the same orienting task for encoding. If the preSME is related to the early recruitment of task specific processes then there may be task related differences when switching tasks. For example, when switching (or staying) between emotional and semantic tasks, a frontal negativity (subsequent remember < subsequent forgotten) was found for both stay and switch trials. The time course of this negativity differed between stay and switch. The stay preSME happened earlier than the switch preSME (Padovani, Koenig, Eckstein, & Perrig, 2013). This suggests that updating the task goals, but not modality, changes the time course of the preSME, which again highlights the flexible, task driven, nature of this preparatory process.

Similar to the young adult Dm studies discussed previously, those investigating the preSME also found a memory gradient (Remember > Know >= Forgotten). Only correct old items given high confidence, or remember, judgments were reliably different from those items forgotten. Correct old items with low confidence, or know, judgments were not significantly different from forgotten items. Thus, preparatory processes may benefit memory performance for only the stronger, or more detailed, memories.

Currently, we know of no published studies investigating age differences in the preSME. The similarities between the types of task manipulations that effect the Dm and the preSME suggest that elderly adults will show similar patterns to the young adults, between correct high confident items and those forgotten. Taken all together previous research suggests there are multiple ways in which preparation may facilitate memory performance, and it is at least partially under voluntary control. For example, older adults may not self-initiate pre-stimulus elaborative encoding strategies but they may recruit other preparatory processes that assist in memory formation, such as inhibiting internal or external distraction.

1.3 Dual Mechanism of Control

If the preSME reflects early recruitment and implementation of the orienting (encoding) task goals, then the underlying process is likely tied to cognitive control. Cognitive control represents the ability to act in a goal driven manner and requires the ability to flexibly update, maintain, and execute behaviors in accordance with internal desires (Miller, 2000).

The Dual Mechanisms of Control (DMC) model (Braver, 2012) provides a framework for when task processes are brought online. The DMC posits two forms of control: proactive and reactive. Proactive control encompasses task related activity that precedes an event of interest, for example, getting into the exit lane when you pass the sign for your exit on the highway. Reactive control defines task related activity that happens in response to the event of interest, for example, swerving away from a car that hit its brakes right in front of you. These processes are not mutually exclusive, and it is likely that some situations require both proactive and reactive control. They can be thought of as early selection and late correction, respectively (Braver, 2012).

The AX variant of a continuous performance task (Beck, Bransome, Mirsky, Rosvold, & Sarason, 1956) has been used to assess proactive and reactive control strategies across various populations such as children (Chatham, Frank, & Munakata, 2009), schizophrenics (Barch et al., 2001), and the elderly (Barch et al., 2001; Braver, Satpute, Rush, Racine, & Barch, 2005). In this paradigm participants are sequentially presented pseudo randomized letters (‘A’, ‘B’, ‘Y’, ‘X’) one at a time that are ordered in cue-probe pairs (‘A-Y’, ‘A-X’, ‘B-Y’, ‘B-X’). The target letter is ‘X’ only when it is proceeded by an ‘A’, and participants are asked to indicate for each letter if it is a target or a non-target. Target trials are over represented to create a prepotent response. By investigating error rates and reaction times it is possible to assess the use of proactive or reactive strategies. Those using proactive strategies should have higher error rates and longer reaction times for ‘A-Y’ pairings than for ‘B-X’ pairings. Those using reactive strategies would show the opposite pattern; more errors and longer reaction times for ‘B-X’ pairings than ‘A-Y’ pairings. The idea is that a proactive strategy will setup the upcoming response during the “A” or “B”, which will have to be overridden in the ‘A-Y’ pairing but not in the ‘B-X’ pairing. A reactive strategy sets up the response for each letter once that letter appears; when the ‘X’ appears (in the ‘B-X’ pairing) the prepotent response needs to be over ridden by recalling the previous letter (‘B’). Braver et al. (2005) found a strong positive correlation between age and ‘B-X’ trial reaction times, as well as a negative correlation between age and ‘A-Y’ trial reaction times. Additionally, this pattern of activity held when only older adults were included in the analysis. Further evidence for this proactive and reactive delineation comes from the negative correlation between ‘A-Y’ and ‘B-X’ reaction times. These behavioral results are corroborated by an imaging study which found young adults show overall greater prefrontal cortex activation than elderly adults during the cue period. This pattern was reversed during the probe period, which found greater overall prefrontal cortex activation for the old adults compared to the young (Paxton, Barch, Racine, & Braver, 2008). This suggests similar cognitive control processes are recruited in both young and older adults, but the time course, or initializing event (cue vs. probe), is different.

In an interesting manipulation Braver and colleagues found they could, within participants, shift young adults to use reactive strategies and old adults to use proactive strategies. The authors initiated these shifts in the young by penalizing errors, while the older adults were given additional training (calling specific attention to the cue). These behavioral shifts corresponded to activation shifts in areas of the prefrontal cortex (Braver, Paxton, Locke, & Barch, 2009). Taken together, these results suggest elderly adults are more prone to use reactive strategies than young adults, but this may ultimately be dependent on task conditions.

1.4 Current Study

The use of preparation in episodic encoding has not been previously studied in older adults. EEG is especially suited for this study due to its high temporal resolution, which is important for investigating the temporal dynamics of control strategy during encoding. Participants completed an incidental memory paradigm with a semantic orientation task (relative size judgment) and performed a subsequent testing phase with confidence judgments (i.e. "Old High Confidence", "Old Low Confidence", "New Low Confidence", and "New High Confidence"). They also completed an AX-CPT task, similar to Braver et al. (2005), describe above, which served to indicate each participant's dominant control strategy (i.e. proactive or reactive). By collecting both a cognitive control task with producible indices of proactive and reactive control and an episodic memory paradigm in the same participants we hoped to investigate the direct role of cognitive control in episodic memory encoding in the young and old. We predict the following:

1. Elderly adults will show an attenuated preSME, while young adults will show a frontal negative going preSME in both visual and audio trials.
2. Elderly adults will use a reactive strategy on the AX-CPT task, while young adults will use proactive strategies (Braver et al., 2005).
3. If preparation during encoding benefits memory performance, we expect a positive correlation between control strategy and memory performance.
4. Previous research suggests only remembered items given high confidence (or "Remember" ratings) found a reliable preSME. Thus, we predict the preSME will be modulated by subsequent successful memory confidence.

5. The relationship between the preSME and Dm remains elusive. As discussed previously the Dm may reflect effortful encoding strategies, and the preSME may represent the successful preparation of task networks associated with effortful encoding strategies. This early preparation could alter how an item is encoded and we would expect a relationship to emerge between them.

CHAPTER 2

METHOD

2.1 Participants

Participants were recruited from the Georgia Institute of Technology and the surrounding community. Forty-four young adults participated for pay or course credit. Thirty-seven older adults participated for pay. All compensation was paid at a rate of $10 per hour for each hour of participation. All participants were right-handed. Participants with neurological conditions, including Alzheimer's disease, stroke, ADHD, untreated depression, schizophrenia, and epilepsy were excluded. All participants signed an Institutional Review Board (IRB) approved consent form prior to participation.

Participants were additionally excluded if they received a MOCA score under 21, if they performed near ceiling or chance on the memory or AX-CPT task, or for excessive noise in the EEG such that a minimum of 13 trials per condition was available for ERP analysis. After participant rejection eighteen younger adults and nineteen older adults were included in the analysis. Details of participant exclusion are listed in **Table 1,** and demographics are listed in **Table 2**.

Table 1: Participants Excluded

Participants	Young Adults	Old Adults
Total Ran	44	37
Didn't Complete	1	2
MOCA < = 20	0	1
Performance to High	4	0
At Chance: behavioral Pr < .1	2	2
Over 50% of bad trials	0	2
EEG Recording Issues	10	4
Low AXCPT performance	0	1
Less than 13 trials Post Processing	9	6
Total Used	18	19

Table 2: Used Participant Demographics

Demographics	Young Adults		Old Adults	
	Mean[STD]	Range	Mean[STD]	Range
Age	21.28[3.32]	18 – 32	66.68[4.28]	60 – 78
Years of Education	14.44[1.50]	12 – 18	16.26[2.38]	12 – 21
MOCA	28.22[1.52]	25 – 30	27.05[2.32]	22 – 30
Male	9	50%	8	42%
Female	9	50%	11	58%

* Standard deviations in brackets.

2.2 Equipment

2.2.1 Stimulus Presentation

A Dell desktop computer running Psychtoolbox 3 (Kleiner, Brainard, & Pelli, 2007) and MATLAB 2012b for UNIX were used for stimulus presentation. Visual stimuli were presented on a 19 inch CRT monitor and participants were seated two feet away. Audio stimuli were presented through an external computer speaker adjusted for participant comfort. All responses were collected using a numerical keypad.

2.2.2 EEG Acquisition

Scalp-recorded EEG data was collected from 32 Ag-AgCl electrodes using an ActiveTwo amplifier system (BioSemi, Amsterdam, Netherlands). Electrode position follows the extended 10-20 system (Nuwer et al., 1998). External left and right mastoid electrodes were used for referencing offline. Two electrodes placed superior and inferior to the right eye recorded vertical electrooculogram (VEOG), and two additional electrodes recorded horizontal electrooculogram (HEOG) at the lateral canthi of the left and right eyes. EEG was sampled at 1024 Hz with 24 bit resolution.

2.3 Design

An incidental memory paradigm was used with the study and test period separated by a 30 minute delay. During the delay participants completed the AX-CPT task. Response side (left or right) was counter balanced across participants. All participants received a short practice (study: 20, test: 30, AX-CPT: 15) before each respective part of the experiment. Practice trials continued for each participant until they fully understood the task. All older participants were run on the Montreal Cognitive Assessment (MoCA) to screen out possible mild cognitive impairment (Nasreddine et al., 2005).

2.3.1 Incidental Memory Task

Stimuli. A pool of 480 concrete nouns was used to create the study and test lists. Approximately half of each list consisted of items conceptually bigger or smaller than a standard computer monitor. The nouns were selected from the MRC Psycholinguistic Database (Wilson, 1988) with a written frequency of 10 – 50 occurrences per million (Kučera & Francis, 1967), a length of 3 – 12 letters, concrete range of 350 – 700, and image ability range of 500 – 700 (Coltheart, 1981). If multiple nouns had the same phonetic representation (e.g. “mail”, “male”), only one was retained. Each noun had an equal likelihood of being in the study or test list, as well as an equal likelihood of being presented as an audio or visual item. Auditory stimuli were created with the software program Audacity (http://audacity.sourceforge.net/). All words were spoken by the same female voice and normalized (mean duration: 592 milliseconds (ms), range 250 – 1120 ms). All visual presentation occurred on a black background. Visually presented items were displayed in the center of the screen for 590 ms with white letters (Helvetica font, size 36). A white fixation cross was present on the screen at all times except during the period of visual cue and word presentation. The visual cue consisted of the fixation cross turning red for 250 ms, and the auditory cue was a 500Hz tone for 250 ms.

Study. A schematic of the study period is presented in **Figure 1**. The study period consisted of four blocks with 60 trials each. Each block contained an equal number of words to be presented in each modality (visual and auditory). Trials were pseudo-randomized with the requirement that the stimulus modality change after a maximum of 4 trials and an equivalent number of stay and switch trials in the whole stimulus set. Each trial began with a fixation cross randomly jittered between 300ms and 700ms by intervals of 50 ms. Jitter was included in order to reduce expectancy related activity (i.e., CNV) prior to the cue onset, as this could introduce noise into the cue period. After the jitter, a cue was presented for 250 ms (a red cross for visual trials, and a 500 Hz tone for auditory trials). Following the cue, the white fixation cross stayed on the screen for 1500 ms. During visual trials the fixation cross changed to the target word for 590 ms before changing back to a white fixation cross. In auditory trials, the fixation cross stayed on the screen and the word was presented through the computer speaker. For each item the participant made a semantic judgment by responding with a left or right button press, as to whether or not the word presented was bigger or smaller than a standard computer monitor. A one second delay followed the participant's response before the start of the next trial. If the participant did not respond within 3 seconds, the trial continued to the next trial.

Participants were instructed with the following information: (1) They will be making judgments on the relative size of a word's referents, which will be presented either on the computer monitor or through the computer speaker. (2) For each item a cue will indicate which presentation modality the item will be in, with these cues being a tone for auditory trials and a red fixation cross for visual trials. (3) The cue will always indicate the modality of the upcoming word stimuli, and the time between cue and word is the same for all trials. (4) Once the word has been presented they are to make a right or left button response to indicate if the word's referent is bigger or smaller than a standard computer monitor as perceived by them. (5) Using the cue to prepare for the upcoming trials was encouraged.

Test. The testing stage used the same procedure as the study phase, **Figure 1**, with the exception of the judgment the participant makes**.** This was done to allow for an examination of preparatory processes at test in a subsequent manuscript. The test period consisted of all 480 items (240 from the study list, and 240 new). The test period was divided into 6 blocks with each block containing an equal number of old visual, old auditory, new visual and new auditory, along with equal items from each bigger/smaller list. Test items were randomly assigned to each block. As with the study period, each block was pseudo randomized for a maximum of 4 trials in the same modality, and an equivalent number of stay and switch trials. Each studied item presented during testing was in the same modality as it was during study. For each item, the participant made an old/new decision with the following response options: "Old High Confidence", "Old Low Confidence", "New Low Confidence", and "New High Confidence". Additionally, they could respond with another button for an error response of: "no idea", "missed the item presentation", etc. The trial proceeded one second after the subject response or, if no response is made, after five seconds. Participants respond by pressing one of four keys on a number pad (7, 4, 1, and 0) oriented to a horizontal plane. Old and new judgments were counterbalanced between participates on the left and right side of the number pad. The number pad key corresponding to the number 3 on the response pad was used for an error response.

Participants were instructed with the following information: (1) They will be presented all the items they saw in the first part of the experiment plus new items. They need to decide for each item if it was in the first part of the experiment (i.e. study phase). (2) All previous words will be in the same modality as previously presented. (3) For each item, a cue will indicate which presentation modality the item will be in, with a tone for auditory trials and a red fixation cross for visual trials. (4) The cue will always indicate the modality of the upcoming word stimuli, and the time between cue and word is the same for all trials. (5) Once the word has been presented, they are to press the button that corresponds to their choice (i.e. Old High, Old Low, New Low, and New High). (6) Using the cue to prepare for upcoming trials was not brought up.

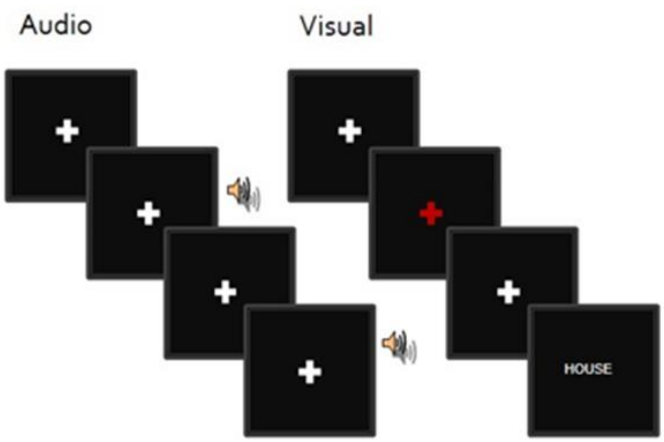

Figure 1: Memory Paradigm

2.3.2 AX-CPT

Stimuli. All stimuli were presented on a black screen in white lettering. Target trials ('A-X') consisted of the cue 'A' and the probe 'X'. Non-target letters can be any other letter in the alphabet, with the exception of 'Y' and 'K' (due to visual similarities to the letter 'X'). All Stimuli were presented center screen in size 36 Helvetica font. In each block, 70% of the trials were target trials ('A-X') the three non-target conditions ('A-Y','B-X','B-Y') had 10% of the trials in a block, these trials were pseudo randomized with at least one target trial in between non-target trials. Each block had 50 trials and there were 6 blocks.

Task. A schematic of the paradigm is in **Figure 2**. Participants were presented each letter for 500ms before it disappears, then a blank screen for 1500ms before proceeding to the next letter, and must respond to each letter as a target ('X' that was preceded by an 'A') or non-target (any other letter). Left and right responses for targets and non-targets were counterbalanced across subjects. Using the previous trial to prepare for an upcoming response was not mentioned.

Participants were instructed with the following information: (1) On the screen they will be presented a letter and for each letter they will make a response. (2) If the letter is an 'X' and it was preceded by (or follows) an 'A' they will make a target response; if it is any other letter or an 'X' not proceeded by an 'A' then press the non-target button.

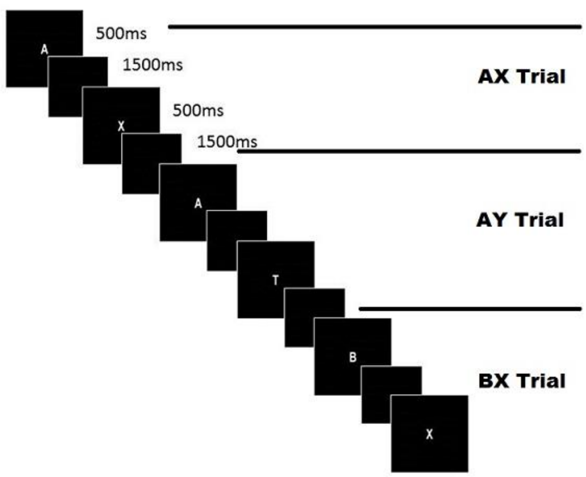

Figure 2: AX-CPT Paradigm

2.4 Behavioral Analysis

Behavioral performance from the memory task was assessed on measures of recognition, Pr (Hits – False Alarms), and response bias, Br (false alarms / (1 – Pr)) (Snodgrass & Corwin, 1988), for audio and visual trials separately. Trials were also separated on whether they were a switch or stay trial at study (stay trial: previous trial in same modality, switch trial: previous trial in different modality). Accuracy at test was assessed for visual, audio, stay at study, and switch at study. Reaction times at test were not assessed since finger-button mappings were not established for all 5 possible responses. Encoding related accuracy responses were not assessed do to the subjective nature of the orienting task. Reaction times for study items were compared for visual and audio items separately and assessed based on subsequent performance.

AX-CPT performance was assessed for accuracy and reaction times. Reaction times and accuracy was used to assess the use of proactive and reactive strategies. Accuracy and raw latency was assessed for both young and old groups. As in Braver et al. (2005), we controlled for general response slowing in older adults by also assessing a within subject z-score transformation of reaction times (Faust, Balota, Spieler, & Ferraro, 1999). This should allow for a more interpretable correlation (and index) of AY and BX reaction time measures. Proactive indices were calculated, (AY-BX)/ (AY + BX), for both accuracy and reaction times (Braver et al., 2009). SPSS version 22 and MATLAB were used to calculate behavioral statistics. All values Huynh Feldt corrected were appropriate, and indicated by the degrees of freedom.

2.5 EEG Analysis

2.5.1 EEG Preprocessing

EEG data analysis utilized MATLAB and EEGLAB (Delorme & Makeig, 2004) for all offline data analysis. Raw data was re-referenced to the average of the left and right mastoid electrodes, then filtered with a bandpass of .01 – 40 Hz. Cue and stimulus periods were epoched separately. Study data was epoched 200 ms pre-cue to 1800 ms post-cue, and 200 ms pre-stimulus to 2000 ms post-stimulus, in order to assess both cue and stimulus subsequent memory effects. Epochs were baseline corrected to the 200 ms pre-cue or pre-stimulus time period. After epoching, manual artifact rejection was used to remove epochs with artifacts not associated with ocular activity (Blinks, Horizontal Eye Movements). After artifact rejection, independent component analysis (ICA) was run on the remaining epochs. Additional information for using ICA in artifact rejection can be found in Delorme, Sejnowski, and Makeig (2007). Ocular artifact components were removed, and a second pass of manual artifact rejection was used to remove any remaining artifacts. Participants with less than 13 epochs in a condition of interest were rejected from further analysis. The subject average waveforms were digitally smoothed with a low-pass filter of 12 Hz.

2.5.2 ERP analysis

Encoding data was sorted into epoch conditions of high confident hits, low confident hits, and misses for each stimulus condition (Visual, Audio, Stay, Switch). Grand averages were created for both the pre-stimulus epochs (Cue – Stimulus), and the post stimulus epoch (stimulus – 2000 ms). Due to the low numbers of subsequent misses and low confident hits, these trial types were combined to make a "forgotten" condition and high confident hits were used for the remembered condition. In order to establish the reliability of the preSME, age groups and modalities were assessed separately. Three spatial location factors(see **Figure 3**) were created using 24 electrodes(Fp1, AF3, F7, F3, FC5, FC1, Fp2, AF4, F8, F4, FC6, FC2, O1, PO3, P7, P3, CP5, CP1, O2, PO4, P8, P4, CP6, CP2) resulting in a 2 (Accuracy: Remembered, Forgotten) X 2 (Chain: Anterior, Posterior) X 2 (Hemisphere: Left, Right) X 6 (Locations: A, B, C, D, E, F) omnibus ANOVA. Only the main effect or interactions with Accuracy are relevant for determining the preSME. Significant results were followed up with subsequent F tests. Time windows were picked based on visual inspection of the waveforms; resulting in 4 visual cue (200 - 400ms, 400 - 800ms, 800 - 1400ms, and 1400 - 1750ms), 3 audio cue (200 - 600ms, 600 - 1200ms, and 1200 - 1750ms), and 4 post-stimulus (visual and audio: 200 - 600ms, 600 - 1000ms, 1000 - 1400ms, and 1400 - 2000ms) mean amplitude time windows. Younger and older adult difference waves (Remembered minus Forgotten) were assessed for amplitude differences and submitted to a vector length method rescaling(McCarthy & Wood, 1985). Vector normalization allows for the comparison of topographic differences between conditions or groups by removing amplitude differences while keeping the same voltage pattern. Both raw amplitude and vector normalized data were subjected to a 2 (Chain: Anterior, Posterior) X 2 (Hemisphere: Left, Right) X 6 (Locations: A, B, C, D, E, F) X 2 (Group: YA, OA) ANOVA for each modality separately in the same time windows used for the within subject ANOVAs. Only main effects or interactions with Group were assessed. EEG statistics were run on the 'R' programming language with package ezANOVA. All p values are Huynh Feldt corrected were appropriate and indicated in the degrees of freedom.

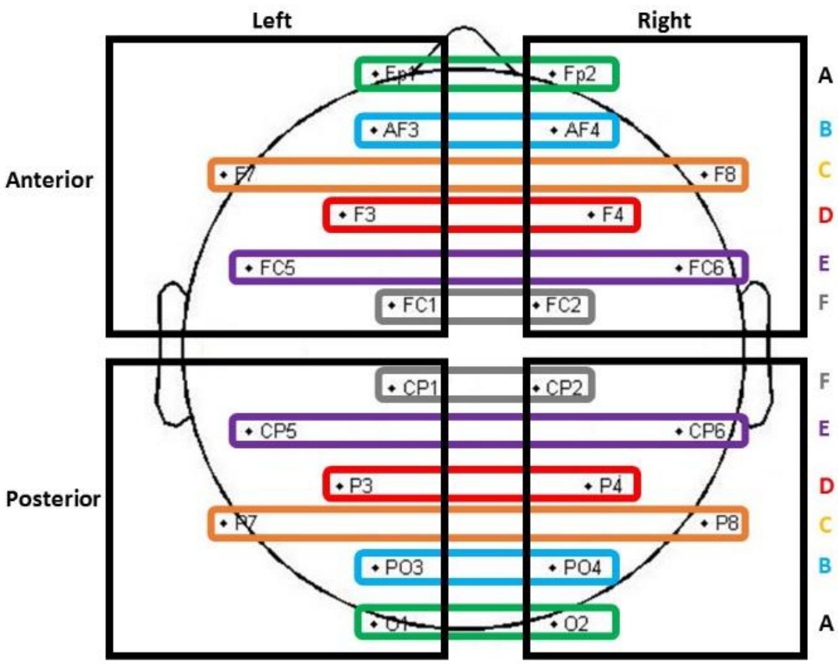

Figure 3: EEG ANOVA Spatial Factors

CHAPTER 3

RESULTS

3.1 Behavioral Results

3.1.1 Memory Task

Memory accuracy was assessed with corrected recognition (Pr) for both visual and audio items. Pr takes into account an individual subject's false alarm rate (misclassifying a new item as an old item), which makes the 'at chance' rate equal to zero. Mean Pr and Br values are listed in **Table 3.** Pr was assessed with a 2(Modality: Visual, Audio) X 2(Group: YA, OA) ANOVA, which only revealed a main effect of modality [F (1, 35) = 6.429, p = 0.016], neither Group nor a Modality by Group interaction was significant [F's < 1.7, p's > 0.2]. The same analysis for response bias (Br) revealed no significant effects [All F's < 1.7, p's > 0.2].

Table 3: Corrected Recognition (Pr) and Response Bias (Br)

Memory Task: Mean[STD]	Young Adults	Old Adults
Visual Pr	0.477[0.173]	0.461[0.136]
Audio Pr	0.456[0.177]	0.395[0.139]
Visual Br	0.491[0.179]	0.407[0.181]
Audio Br	0.500[0.145]	0.444[0.191]

* Standard Deviations in brackets

Confidence proportions are reported in **Table 4**. Separate 2 (Modality: Visual, Audio) X 2 (Confidence: High, Low) X 2(Group: YA, OA) ANOVAs were run for hits, misses, correct rejections, and false alarms. Significant main effects of Confidence were observed for hits and correct rejections [F (1, 35)'s > 6.988, p's < 0.012]. Only the correct rejection ANOVA found a main effect of Modality [F (1, 35) = 4.124, p = 0.05] that was modified by an interaction with Confidence [F (1, 35) = 5.788, p = 0.022]. As can be seen in **Table 4**, the proportion of high confidence correct rejections was greater for visual than auditory trials. There were no other significant effects [all F's < 3.384, p's > 0.06].

Table 4: Memory Accuracy

Hits	Young Adults			Older Adults		
	Mean[STD]	% High	% Low	Mean[STD]	% High	% Low
Visual	0.745[0.098]	0.762	0.238	0.687[0.115]	0.784	0.216
Audio	0.737[0.090]	0.759	0.241	0.665[0.142]	0.767	0.233
Switch	0.737[0.101]	0.772	0.228	0.672[0.129]	0.777	0.223
Stay	0.745[0.082]	0.751	0.249	0.680[0.123]	0.771	0.229
Misses	**Young Adults**			**Older Adults**		
	Mean[STD]	% High	% Low	Mean[STD]	% High	% Low
Visual	0.255[0.098]	0.437	0.563	0.313[0.115]	0.576	0.424
Audio	0.263[0.090]	0.442	0.558	0.335[0.142]	0.513	0.487
Switch	0.263[0.101]	0.442	0.558	0.328[0.129]	0.525	0.475
Stay	0.255[0.082]	0.436	0.564	0.320[0.123]	0.562	0.438
New Items	**Young Adults**			**Older Adults**		
	Mean[STD]	% High	% Low	Mean[STD]	% High	% Low
CR: Visual	0.732[0.140]	0.547	0.453	0.774[0.133]	0.665	0.335
CR: Audio	0.719[0.134]	0.543	0.457	0.730[0.147]	0.595	0.405
FA: Visual	0.268[0.140]	0.448	0.552	0.226[0.133]	0.543	0.457
FA: Audio	0.281[0.134]	0.429	0.571	0.270[0.147]	0.511	0.489

* Standard Deviations in brackets

Reaction times are reported in **Table 5**, and were assessed during encoding with modality separate 2 (Accuracy: Hits, Miss) X 2 (Confidence: High, Low) X 2 (Group: YA, OA) ANOVAs. One YA did not have a low confidence visual response, and one OA did not have any low visual or audio responses. Those participants were removed for this analysis. The reaction time ANOVA for visual items only revealed a main effect

Confidence [F (1, 33) = 8.883, p = 0.005], while the reaction time ANOVA for audio items found an Accuracy by Confidence interaction [F (1, 33) = 5.682, p = 0.023]. Subsequent analysis revealed reaction times for high confidence hit items had longer response times than for low confidence hit items [F (1, 33) = 10.313, p = 0.003]. No other significant effects of reaction time for visual or audio trials were found [All F's < 2.820, p's > 0.1].

Reaction times for stay and switch trials were submitted to a 2 (Trial Type: Switch, Stay) X 2 (Accuracy: Hits, Miss) X 2 (Confidence: High, Low) X 2 (Group: YA, OA) ANOVA. Only a main effect of Trial Type was found [F (1, 33) = 8.448, p = 0.006], indicating responses to switch trials took longer. No other significant effects of reaction time were found for stay and switch trials [All F's < 3.564, p's > 0.068].

These results suggest that the audio items were more difficult than the visual items, and there were more high confident responses for items correctly judged as old or new. Reaction time results revealed high confident items took longer for visual items than reaction times for low confidence items. In the audio condition only correctly classified old item reaction times for high confident items was greater than reaction times for low confidence items. Reaction times for trials with a modality switch took longer than those where the modality stayed the same, suggesting evidence of a switching cost.

Table 5: Reaction Times at Encoding

Hits (ms)	Young Adults		Older Adults	
Mean[STD]	High	Low	High	Low
Visual	1110[217]	1089[221]	1163[181]	1099[228]
Audio	1404[195]	1371[221]	1464[162]	1368[194]
Switch	1276[213]	1248[236]	1331[165]	1272[220]
Stay	1234[197]	1203[189]	1284[158]	1208[168]
Misses (ms)	**Young Adults**		**Older Adults**	
Mean[STD]	High	Low	High	Low
Visual	1154[286]	1078[206]	1125[197]	1067[200]
Audio	1371[260]	1363[268]	1427[216]	1424[220]
Switch	1267[245]	1207[251]	1322[213]	1309[223]
Stay	1241[318]	1242[234]	1239[153]	1243[242]

* Standard Deviations in brackets, time in milliseconds

3.1.2 AX-CPT

Error rate was used instead of accuracy in the AX-CPT for ease of interpretation, and values are presented in **Table 6**, and **Figure 4**. For example, an increase in 'A-Y' errors would indicate an increase in proactive control while an increase in 'B-X' errors indicates an increase in reactive control. Error rate was calculated (1 – accuracy) for each subject. Target trials 'A-X' were assessed separately from non-target trials ('A-Y', 'B-X', 'B-Y'). Error rates for non-target trials were submitted to a 3 (Trial Type: 'A-Y', 'B-X', 'B-Y') X 2 (Group: YA, OA) ANOVA which revealed a main effect of Trial Type [$F(1.441, 50.444) = 18.536$, $p < 0.001$], a marginal effect of Group [$F(1, 35) = 3.870$, $p = 0.057$], but no interaction [$F(1.441, 50.444) < 1$]. Follow up t-tests revealed that both 'A-Y' [$t(36) = 6.284$, $p < .001$] and 'B-X' [$t(36) = 5.993$, $p < .001$] were significantly different from 'B-Y' trials, but not each other [$t(36) = -1.404$, $p = .169$]. Target error rate was significantly lower for older adults [$t(35) = 2.243$, $p = .031$].

Table 6: AXCPT Error Rates

Mean[STD]	**Young Adults**	**Old Adults**
Targets		
AX	0.043[0.024]	0.026[0.023]
Non-Targets		
AY	0.141[0.110]	0.101[0.120]
BX	0.107[0.087]	0.067[0.076]
BY	0.010[0.021]	0.002[0.008]

* Standard deviations in brackets.

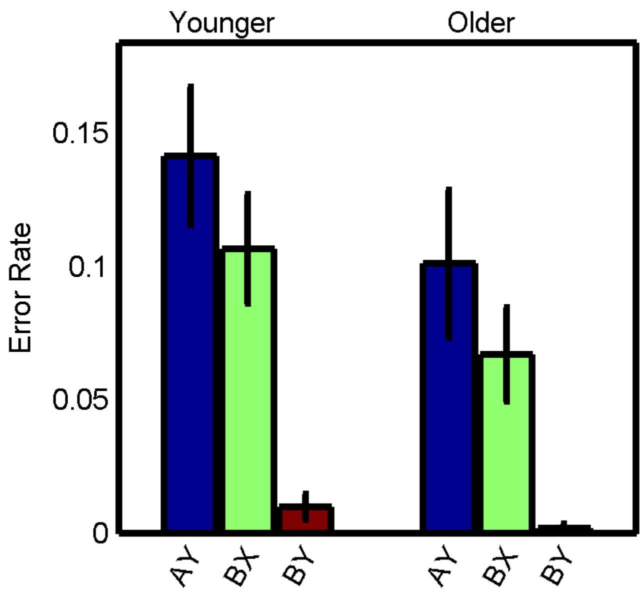

Figure 4: AXCPT Non-Target Error Rates

*Error bars = 1 SEM

Raw reaction times are listed in **Table 7**, and **Figure 5**. As with error rates, target trials were assessed separately from non-target trials. Non-target reaction times were assessed with a 3 (Trial Type: 'A-Y', 'B-X', 'B-Y') X 2 (Group: YA, OA) ANOVA, which revealed a main effect of Trial Type [F (1.220, 42.690) = 26.2, p < 0.001] and Group [F (1, 35) = 5.026, p < 0.031] with no Trail Type by Group interaction [F (1.220, 42.690) < 1]. Subsequent t-tests revealed all trial types significantly differed from each other ['A-Y' – 'B-X': t (36) = 2.657, p = .012; 'A-Y' – 'B-Y': t (36) = 17.043, p < .001;

'B-X' – 'B-Y': t (36) = 3.543, p = .001]. Raw reaction time to target trials did not significantly differ between groups [t (35) = 1.536, p = .134].

Table 7: AXCPT Raw Reaction Times

Mean[STD]	**Young Adults**	**Old Adults**
Targets		
AX	391[78]	431[80]
Non-Targets		
AY	497[71]	583[86]
BX	450[132]	527[186]
BY	396[80]	455[82]

*Standard deviations in brackets, time in milliseconds.

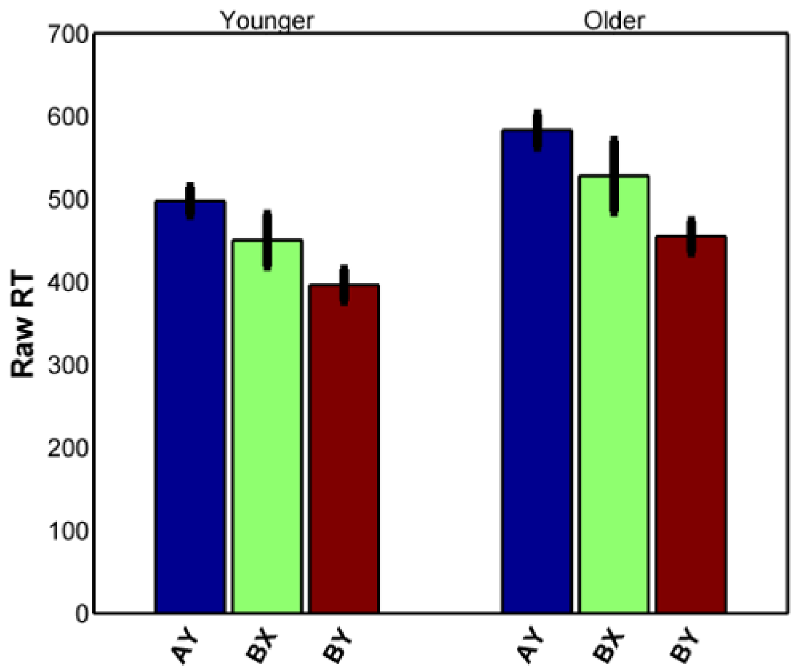

Figure 5: AXCPT Non-Target Raw Reaction Times

*Reaction times in milliseconds. Error bars = 1 SEM

Due to the possible effects of age related slowing, reaction times were also assessed using a within subject Z-score transformation (Braver et al., 2005). The Z-score transformed reaction times are presented in **Table 8**. A 3 (Trial Type: 'A-Y', 'B-X', 'B-Y') X 2 (Group: YA, OA) ANOVA was run on the Z-score transformed reaction times for non-target trials and found similar results as the raw reaction time data. A significant main effect of Trial Type [$F (1.397, 48.906) = 35.947$, $p < 0.001$], a marginal main effect of Group [$F (1, 35) = 3.351$, $p = 0.076$], and no interaction [$F (1.397, 48.906) = 0.108$, $p < 0.826$]. Subsequent t-tests on Trial Type found significant differences between all trial types ['A-Y' – 'B-X': $t (36) = 3.978$, $p < .001$; 'A-Y' – 'B-Y': $t (36) = 11.950$, $p < .001$; 'B-X' – 'B-Y': $t (36) = 3.760$, $p = .001$].

Table 8: AXCPT Z-Score Reaction Times

Mean[STD]	**Young Adults**	**Old Adults**
Targets		
AX	-0.085[0.087]	-0.126[0.194]
Non-Targets		
AY	0.789[0.470]	0.950[0.477]
BX	0.236[0.415]	0.415[0.511]
BY	-0.071[0.304]	0.016[0.443]

*Standard deviations in brackets.

Results from the AX-CPT data suggest that older adults made fewer errors overall but showed the same pattern of error rates as the young. Reaction time results suggest that older adults respond slower than younger adults but the patterns of behavior are the same between them. Taken together both young and older adults show patterns of behavior in the AX-CPT reflective of proactive control.

3.1.3 Cross Task Correlations

We calculated proactive indices for accuracy and reaction times and correlated these indices with memory performance (Pr, hit rate, and false alarm rate). Marginally significant interactions were only found in young adults for visual hit rate (Proactive

Index (Accuracy) x Visual Hits: R (18) = 0.43, p = 0.075) and audio hit rate (Proactive Index (Accuracy) x Audio Hits: R (18) = 0.434, p = 0.072). Older adult proactive indices showed no correlations with memory performance.

3.2 EEG Results

Each time period assessed was submitted to a 2 (Accuracy: Remembered, Forgotten) X 2 (Chain: Anterior, Posterior) X 2 (Hemisphere: Left, Right) X 6 (Locations: A, B, C, D, E, F) omnibus ANOVA. Only p values less than 0.10 are reported for main effects or interactions with Accuracy. Omnibus ANOVA results of each mean amplitude time window are listed in **Table 9** (visual items), and **Table 10** (audio items).

3.2.1 Visual Items: Young adults

The young adult visual preSME ANOVA revealed an interaction between Accuracy, Chain, and Hemisphere in the 200 – 400 ms window. Subsequent analysis of this interaction failed to find significant effects of Accuracy.

Young adult visual Dm ANOVA revealed marginally significant main effects of Accuracy in the 600 – 1000 ms and the 1400 – 2000 ms time windows. As can be seen in **Figure 6** the young adult Dm was widely distributed and showed more positive-going activity for subsequent remembered than forgotten trials.

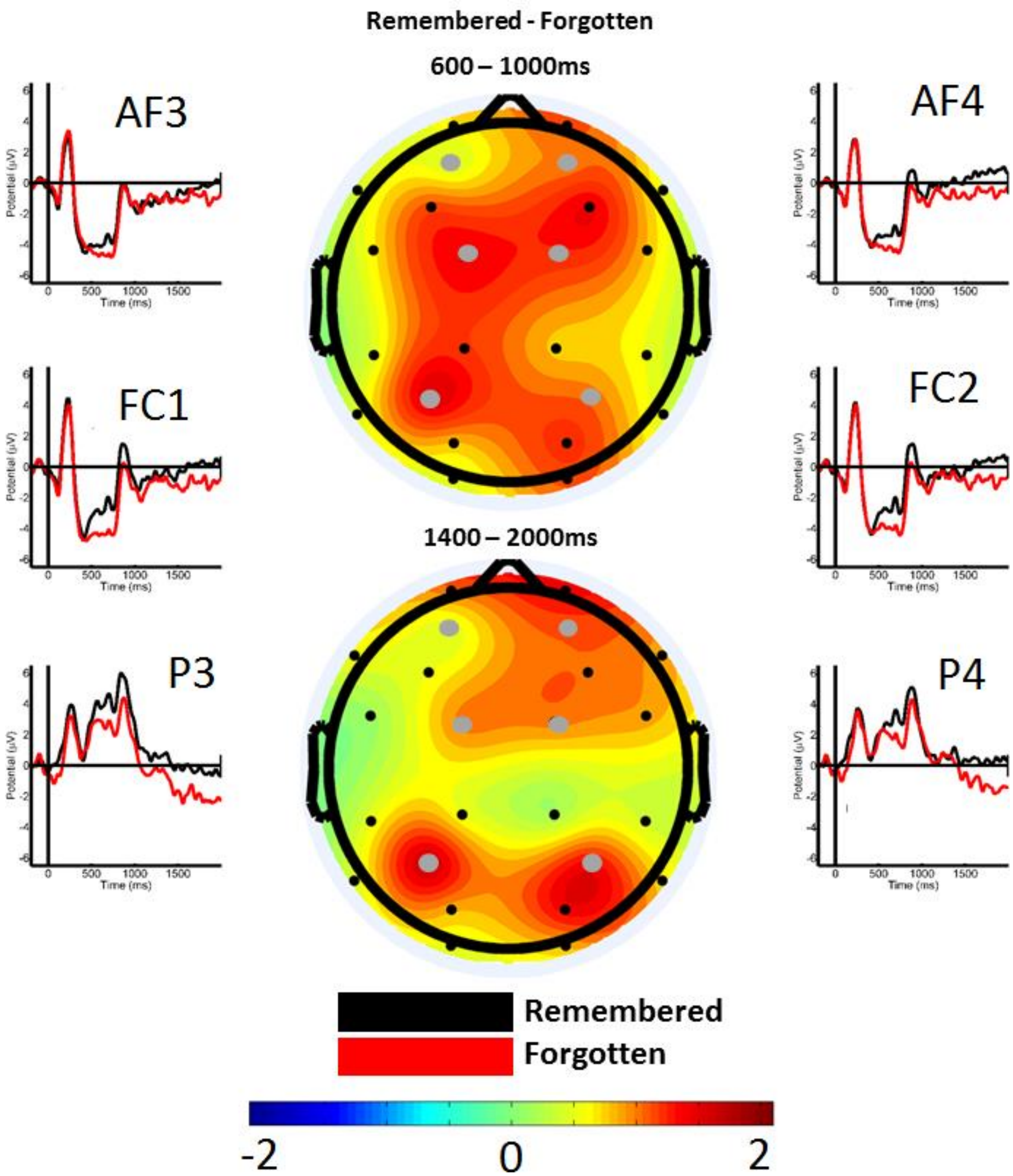

Figure 6: Young adult visual stimulus (Dm)

*Electrodes in gray are represented as wave forms. Word onset at 0ms. Amplitude in microvolts.

3.2.2 Visual Items: Old adults

The older adult visual preSME ANOVA found a significant Accuracy by Chain by Hemisphere interaction was found in the 200 to 400ms window. Subsequent analyses did not find effects of Accuracy, however.

The visual Dm ANOVA for older adults found a main effect of Accuracy in the 200 – 600 ms time window, and a marginally significant Accuracy by Chain interaction in the 600 – 1000 ms time period. Both the 1000 – 1400 ms and 1400 – 2000 ms time windows revealed significant Accuracy by Chain by Location interactions. Follow up ANOVAs in the 600 – 1000 ms range found a significant Accuracy by Location interaction in both anterior [$F(5, 90) = 2.731$, $p = 0.024$] and posterior electrode [$F(5, 90) = 2.413$, $p = 0.043$] sites, and a main effect of Accuracy over anterior sites at location D (F3, F4). The 1000 - 1400 ms time period revealed an Accuracy by Location interaction for anterior electrode sites only [$F(5, 90) = 3.392$, $p = 0.007$]. The 1400 – 2000 ms time range did not reveal any significant effects with Accuracy. As can be seen in **Figure 7**, the older adult Dm starts early as a wide spread positivity (remembered > forgotten) and this positivity shifts to focal anterior electrode sites over the time course.

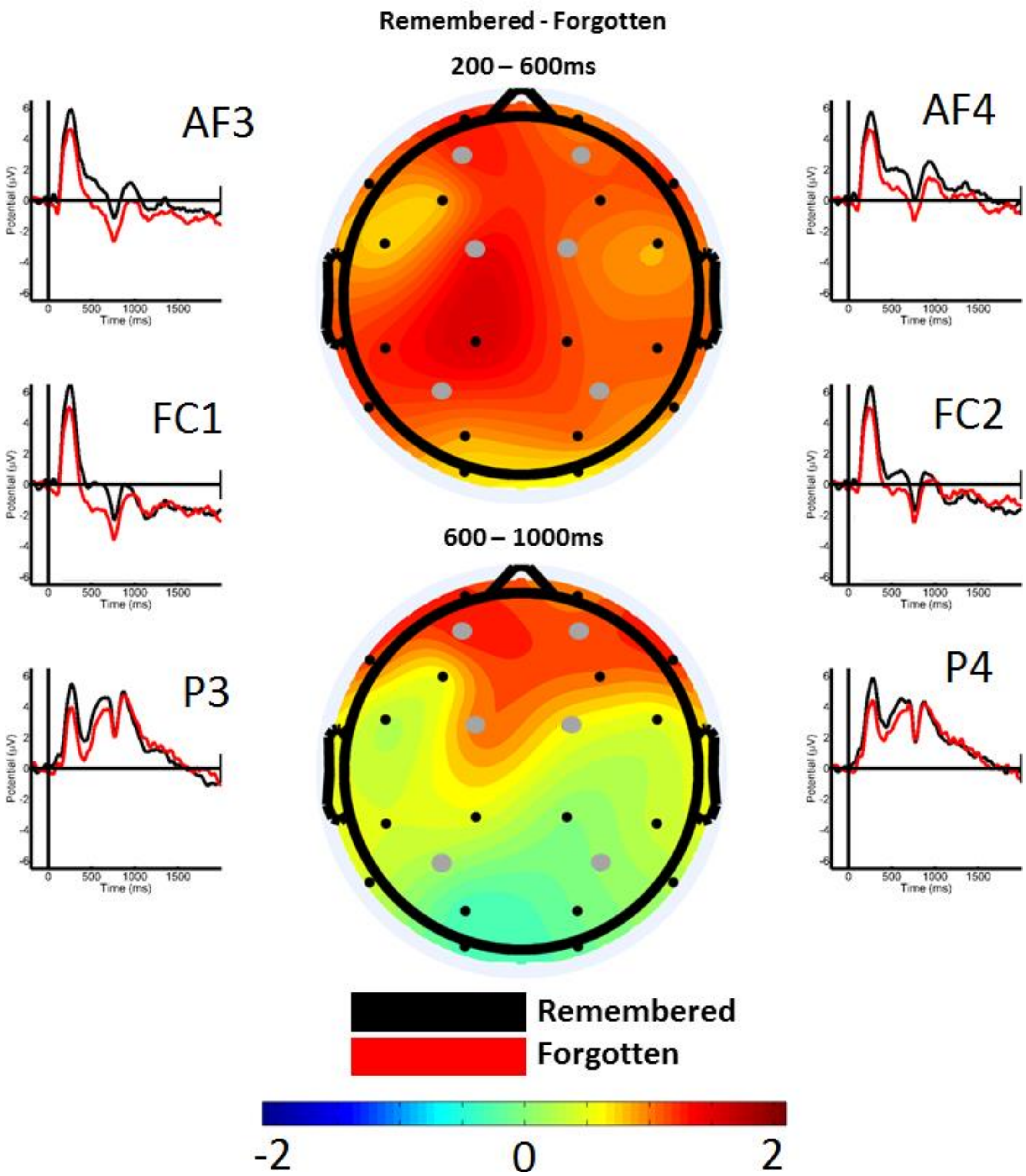

Figure 7: Older adult visual stimulus (Dm)

*Electrodes in gray are represented as wave forms. Word onset is at 0ms. Amplitude in microvolts.

3.2.3 Visual Items: Group Differences

Young adult and older adult difference waves (Remembered – Forgotten) were submitted to a 2 (Chain: Anterior, Posterior) X 2 (Hemisphere: Left, Right) X 6 (Locations) X 2 (Group: YA, OA) ANOVA for the same time windows as the within subject analysis.

3.2.3.1 Raw Amplitude Group Analysis

The ANOVA revealed no visual preSME main effects or interaction between the amplitudes of the age groups.

For visual Dm effects the ANOVA found a Group by Chain by Location interactions for both 600 – 1000 ms [$F(5, 175) = 4.562$, $p = 0.001$] and 1000 – 1400 ms [$F(4.435, 155.225) = 3.156$, $p = 0.013$] time windows. Although, subsequent analyses did not reveal further effects of Group in either time window.

3.2.3.2 Topographic Group Analysis (Vector Normalized Data)

The visual preSME ANOVA revealed no main effects or interactions between the age groups for the vector normalized data.

The visual Dm ANOVA revealed a Group by Chain by Location interaction in the 600 – 1000 ms time range [$F(4.345, 152.075) = 3.193$, $p = 0.013$], but subsequent analyses failed to find Group differences.

3.2.3.3 Summary

In summary neither younger nor older adults showed a reliable preSME for visual items but both groups had positive going Dm effects. Amplitude differences failed to reveal any main effect of group. The vector normalized difference waves for the visual Dm found did not reveal any significant differences in topography.

Table 9: EEG Omnibus ANOVAs - Visual Items

Omnibus		200 to 400		400 to 800		800 to 1400		1400 to 1750	
YA Visual Cue	**df**	**F**	**p**	**F**	**p**	**F**	**p**	**F**	**p**
A	(1,17)	-	-	-	-	-	-	-	-
A x C	(1,17)	-	-	-	-	-	-	-	-
A x H	(1,17)	-	-	-	-	-	-	-	-
A x L	(5,85)	-	-	-	-	-	-	-	-
A x C x H	(1,17)	3.81	0.068	-	-	-	-	-	-
A x C x L	(5,85)	-	-	-	-	-	-	-	-
A x H x L	(5,85)	-	-	-	-	-	-	-	-
A x C x H x L	(5,85)	-	-	-	-	-	-	-	-
OA Visual Cue									
A	(1,17)	-	-	-	-	-	-	-	-
A x C	(1,17)	-	-	-	-	-	-	-	-
A x H	(1,17)	-	-	-	-	-	-	-	-
A x L	(4.47,80.46)	-	-	-	-	2.01	0.093	-	-
A x C x H	(1,17)	6.2	0.023	-	-	-	-	-	-
A x C x L	(5,85)	-	-	-	-	-	-	-	-
A x H x L	(5,85)	-	-	-	-	-	-	-	-
A x C x H x L	(5,85)	-	-	-	-	-	-	-	-
Omnibus		**200 to 600**		**600 to 1000**		**1000 to 1400**		**1400 to 2000**	
YA Visual Stimulus	**df**	**F**	**p**	**F**	**p**	**F**	**p**	**F**	**p**
A	(1,17)	-	-	4.129	0.058	-	-	3.643	0.073
A x C	(1,17)	-	-	-	-	-	-	-	-
A x H	(1,17)	-	-	-	-	-	-	-	-
A x L	(5,85)	-	-	-	-	-	-	-	-
A x C x H	(1,17)	-	-	-	-	-	-	-	-
A x C x L	(5,85)	-	-	-	-	-	-	-	-
A x H x L	(5,85)	-	-	-	-	-	-	-	-
A x C x H x L	(5,85)	-	-	-	-	-	-	-	-
OA Visual Stimulus									
A	(1,17)	10.244	0.005	-	-	-	-	-	-
A x C	(1,17)	-	-	4.286	0.053	-	-	-	-
A x H	(1,17)	-	-	-	-	-	-	-	-
A x L	(5,85)	-	-	-	-	-	-	-	-
A x C x H	(1,17)	-	-	-	-	-	-	-	-
A x C x L	(3.53,63.54)	2.675	0.046	5.181	0.001	4.94	0.002	2.581	0.031
A x H x L	(5,85)	-	-	-	-	-	-	-	-
A x C x H x L	(5,85)	-	-	-	-	-	-	-	-

*A = Accuracy (Hit, Miss); C = Chain (Anterior, Posterior); H = Hemisphere (Right, Left); L = Location; Only p < 0.1 reported.

3.2.3 Audio Items: Young Adults

As seen in **Table 10**, the ANOVA for the preSME in young adults found significant Accuracy by Chain, and Accuracy by Chain by Location interactions during the 200 – 600 ms time window. Subsequent analyses revealed a marginally significant main effect of Accuracy over posterior electrodes in the 200 – 600 ms time window [$F(1, 17) = 3.951$, $p = 0.063$] and a significant Accuracy by Location interaction over anterior electrodes [$F(5, 85) = 2.763$, $p = 0.023$]. The 600 – 1200 ms ANOVA revealed a marginally significant preSME with an Accuracy by Hemisphere by Location interaction. Follow up analysis did not reveal any effect or interaction with Accuracy in the 600 – 1200 ms time window. As presented in **Figure 8** the young adult preSME started early with a posterior maximal negativity (forgotten > remembered) that was reduced in later time windows.

The young adult Dm ANOVA found a significant four way interaction in the early 200 – 600 ms, and a trend toward a main effect of Accuracy in the 1000 – 1400 ms window. Follow up analysis of the 200 – 600 ms window did not reveal any effects or interactions with Accuracy. As shown in **Figure 9** the young adult audio Dm manifested as a wide spread positivity (remembered > forgotten) in the 1000 – 1400 ms time window.

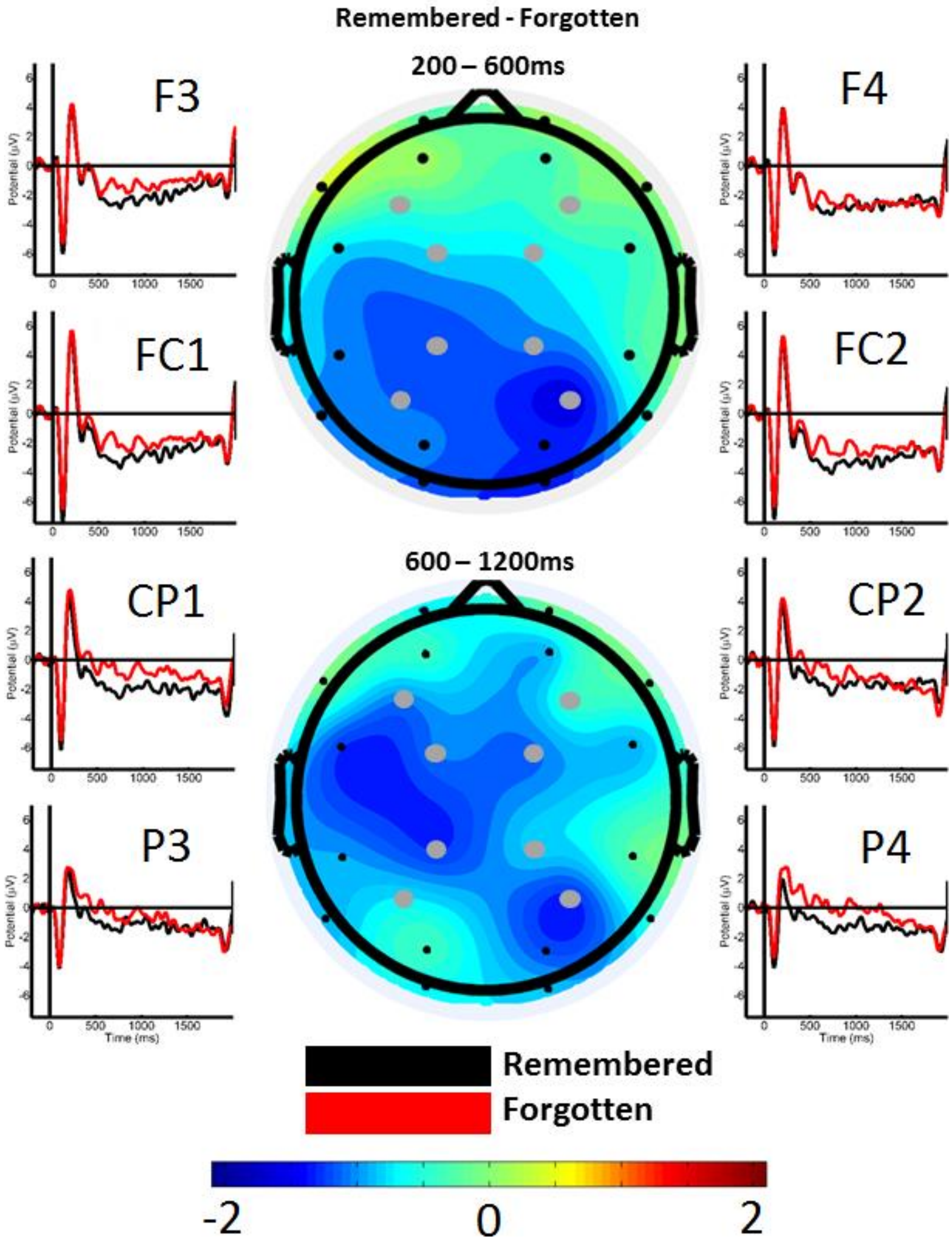

Figure 8: Young adult audio cue (preSME)

*Electrodes in gray are represented as wave forms. Cue onset at 0ms, word onset at 1750ms. Amplitude in microvolts.

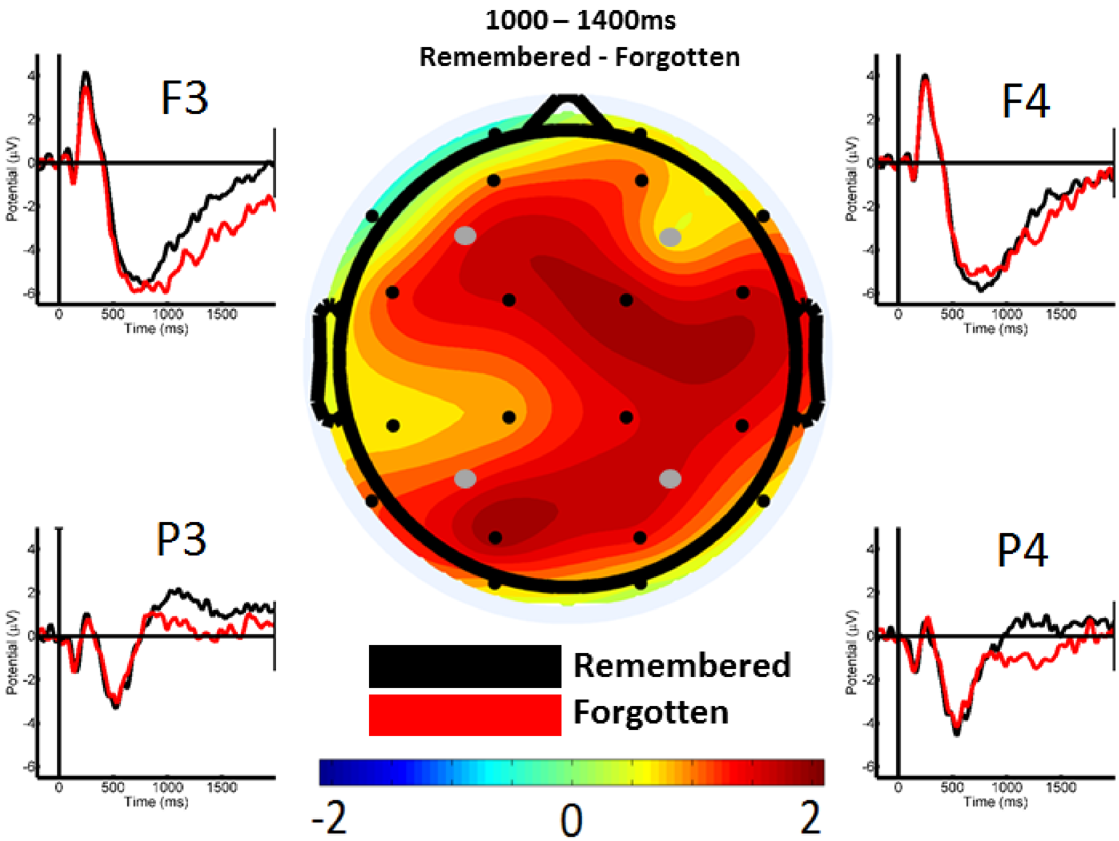

Figure 9: Young adult audio stimulus (Dm)

*Electrodes in gray are represented as wave forms. Word onset at 0ms. Amplitude in microvolts.

3.2.3 Audio Items: Older Adults

The ANOVA for the older adults' audio preSME resulted in a significant main effect of Accuracy in the 600 – 1200 ms time window, and a marginally significant Accuracy by Chain by Hemisphere interaction in the 1200 – 1750 ms time range. Subsequent analyses in the 1200 to 1750ms time window found a significant Accuracy by Location interaction for anterior electrode sites [$F(4.11, 73.98) = 2.518$, $p = 0.047$]. As seen in **Figure 10** the older adult audio preSME starts as widespread negativity in the middle time period and becomes less robust in the later time window.

The ANOVA for older adult Dm effects found a significant main effect of Accuracy in the 1000 – 1400 ms time window, and an Accuracy by Location interaction during the 1400 – 2000 ms range. Follow up analysis in the 1400 – 2000 ms range revealed a significant main effect of Accuracy at location B ($F(1, 18) = 4.846$, $p = 0.041$) and an Accuracy by Chain interaction at Location C ($F(1, 18) = 4.565$, $p = 0.047$). **Figure 11** shows the older adult Dm, which manifested as a widespread negativity in the 1000 – 1400 ms time range, and narrows in the later time window**.**

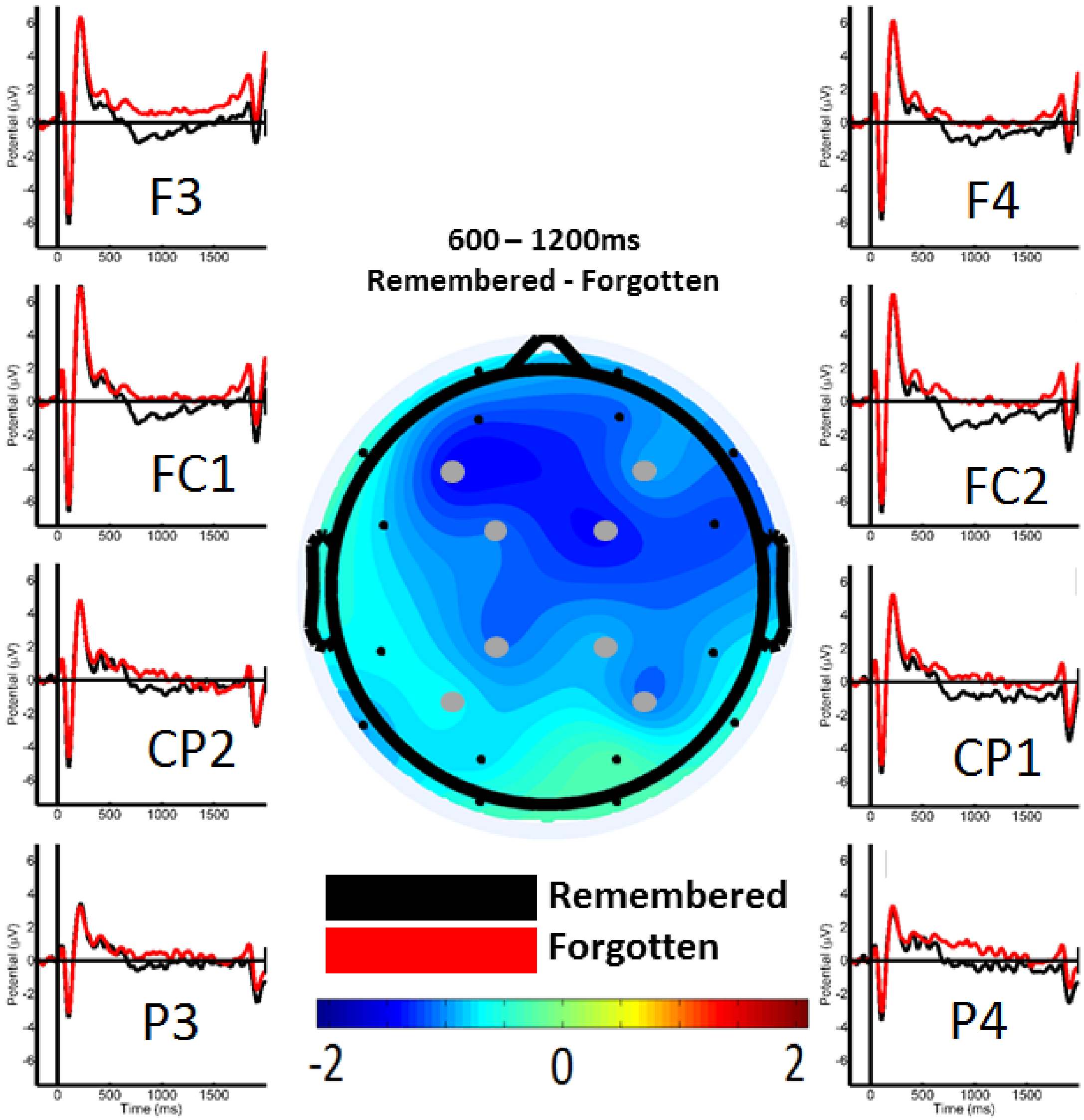

Figure 10: Older adult audio cue (preSME)

*Electrodes in gray are represented as wave forms. Cue onset at 0ms, word onset at 1750ms. Amplitude in microvolts.

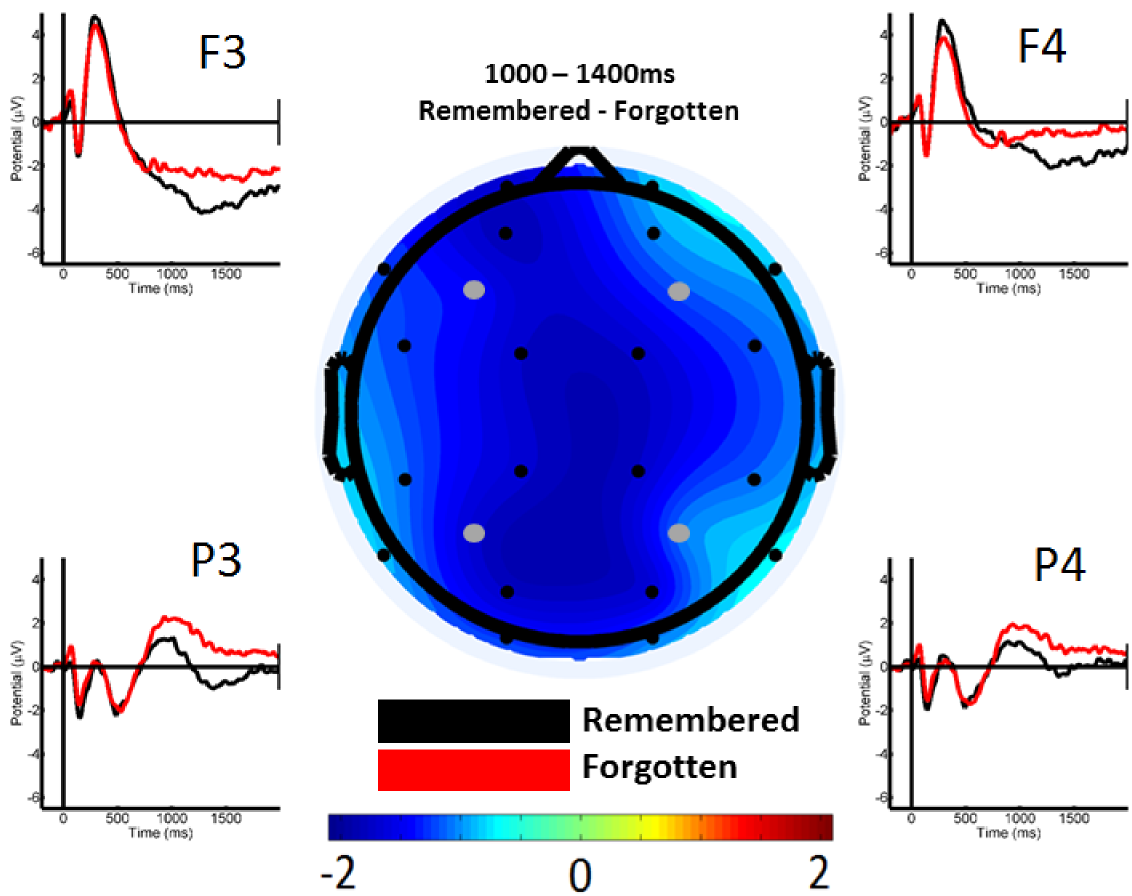

Figure 11: Older adult audio stimulus (Dm)

*Electrodes in gray are represented as wave forms. Word onset at 0ms. Amplitude in microvolts.

3.2.3 Audio Items: Group Differences

The younger and older adult preSME was reliable in different time windows, and the Dms were in opposite directions. Thus, were are unable to compare them.

3.2.3.1 Summary

Taken all together this suggests that for the audio items younger adults have an earlier starting posterior preSME than older adults, but these differences subside in the later time windows as an older adult preSME is revealed in the 600 to 1200ms time window. Both younger and older adults show reliable Dm effects starting the in 1000 to

1400ms time window, although young adults show a positive effect while older adults show a negative effect.

Table 10: EEG Omnibus ANOVAs – Audio Items

Omnibus		200 to 600		600 to 1200		1200 to 1750			
YA Audio Cue	**df**	**F**	**p**	**F**	**p**	**F**	**p**		
A	(1,17)	-	-	-	-	-	-		
A x C	(1,17)	6.621	0.02	-	-	-	-		
A x H	(1,17)	-	-	-	-	-	-		
A x L	(5,85)	-	-	-	-	-	-		
A x C x H	(1,17)	-	-	-	-	-	-		
A x C x L	(4.71,84.15)	3.483	0.008	-	-	-	-		
A x H x L	(5,85)	-	-	2.131	0.069	-	-		
A x C x H x L	(5,85)	-	-	-	-	-	-		
OA Audio Cue									
A	(1,17)	-	-	8.465	0.009	-	-		
A x C	(1,17)	-	-	-	-	-	-		
A x H	(1,17)	-	-	-	-	-	-		
A x L	(5,85)	-	-	1.976	0.09	-	-		
A x C x H	(1,17)	-	-	-	-	4.274	0.053		
A x C x L	(5,85)	-	-	-	-	-	-		
A x H x L	(5,85)	-	-	2.061	0.078	-	-		
A x C x H x L	(5,85)	-	-	-	-	-	-		
Omnibus		**200 to 600**		**600 to 1000**		**1000 to 1400**		**1400 to 2000**	
YA Audio Stim	**df**	**F**	**p**	**F**	**p**	**F**	**p**	**F**	**p**
A	(1,17)	-	-	-	-	3.423	0.082	-	-
A x C	(1,17)	-	-	-	-	-	-	-	-
A x H	(1,17)	-	-	-	-	-	-	-	-
A x L	(5,85)	-	-	-	-	-	-	-	-
A x C x H	(1,17)	-	-	-	-	-	-	-	-
A x C x L	(5,85)	-	-	-	-	-	-	-	-
A x H x L	(5,85)	-	-	-	-	-	-	-	-
A x C x H x L	(5,85)	2.412	0.043	-	-	-	-	-	-
OA Audio Stim									
A	(1,17)	-	-	-	-	4.926	0.04	-	-
A x C	(1,17)	-	-	-	-	-	-	-	-
A x H	(1,17)	-	-	-	-	-	-	-	-
A x L	(3.87,69.66)	-	-	-	-	-	-	2.528	0.05
A x C x H	(1,17)	-	-	-	-	-	-	-	-
A x C x L	(5,85)	-	-	-	-	-	-	-	-
A x H x L	(5,85)	-	-	-	-	-	-	-	-
A x C x H x L	(5,85)	-	-	-	-	-	-	-	-

*A = Accuracy (Hit, Miss); C = Chain (Anterior, Posterior); H = Hemisphere (Right, Left); L = Location; Only p < 0.1 reported.

3.2.4 EEG Correlations

Correlations between memory performance, AX-CPT performance, preSME and Dm was ran separately for visual and audio items and both young and old adults separately. In young adults we found the proactive index (based on accuracy) correlated with the later visual Dm (1400 – 2000 ms) [R (18) = 0.510, p = 0.031]. The older adults showed a similar correlation for visual items (proactive index by Dm (200 – 600 ms) [R (19) = 0.459, p = 0.048], proactive index by Dm (600 – 1000 ms) [R (19) = 0.529, p = 0.019]). For audio trials older adults showed a correlation between Pr and Dm (1000 – 1400 ms) [R (19) = -0.604, p = 0.006]. No measures of memory performance, proactive control, or Dm correlated with the preSME.

CHAPTER 4

DISCUSSION

To our knowledge this is the first study to investigate preparatory control in episodic memory in aging. We found both younger and older adults are capable of recruiting preparatory strategies that predict subsequent memory performance. We did not find significant age differences in memory performance. But, in both younger and older adults, we found worse memory performance for audio items compared to visual items. Neither group showed a preSME for visual trials, but both elicited a positive Dm. For audio trials both groups showed reliable preSME and Dm effects. Interestingly, for audio trials, the younger adult Dm was positive while the older adult Dm was negative. If the Dm reflects effortful encoding strategies that benefit later memory performance, this would suggest that younger and older adults encoded the audio items in a qualitatively different manner to achieve later memory accuracy. For the AX-CPT task we found older adults made less errors than the younger adults, but both groups showed more proactive errors than reactive errors. This suggests both younger and older adults used proactive strategies in the AX-CPT.

4.1 Memory Encoding

The lack of age differences in memory performance is not surprising for two reasons. First the current study only tested for item memory, and previous research suggests older adults have relatively intact item memory, but are impaired for contextual information (Spencer & Raz, 1995). Second, younger adults were more likely to be excluded for high accuracy, than older adults, and the most participants were rejected for having a low number of miss trials. Thus, we may have inadvertently skewed our sample of younger adults. Interestingly, we found memory for audio items were reduced compared to visual items in both groups. Anecdotally, older participants made more comments about the difficulty of the audio items, while younger adults did not. One possibility for this difficulty, is that the audio stimuli were recorded in a female voice and aging is associated with loss of hearing for higher frequencies (Ferrand, 2002). If the audio stimuli had been recorded in a male voice, with a deeper voice, we may have seen better memory performance. Numerically, older adults had a bigger difference between audio and visual items than younger adults. But, we did not find Modality by Group interaction, and younger adults also showed reduced memory performance for the audio items. Another possibility for the modality difference may be due to the creation of the internal representation. Creating an internal representation may have been more difficult for audio trials. Since we did not predict a modality difference, additional research is warranted.

4.1.1 PreSME

Although we had predicted preSME effects for both visual and audio trials, preSME effects were only reliable for audio trials and not visual trials, in both age groups. This fits in well with the behavioral results, since memory was worse for the audio items and there was some feedback about them being more difficult, the participants may have recruited a proactive strategy to prepare for the audio stimulus in response to the audio cue. The visual items, which were likely perceived as easier, did not recruit a proactive encoding strategy. Inspection of the visual waveform suggest both age groups perceived the visual cue in both remembered and forgotten conditions.

The differences in memory performance and preSME effects suggest task difficulty biases how and when proactive control is recruited. Very little research has looked explicitly at proactive strategies and task difficulty, but there is evidence that task difficulty shifts the cognitive strategy people use. For example, in Speer et al. (2003), working memory load was manipulated between one and eleven items, and after list presentation the participants received a target work where they indicated if it was in the list or not. Preceding each list was a cue to indicate if it was a short or long list. Lists of six items could have been preceded by either a short (easy) or long (hard) cue. On a subsequent memory test for all items across all lists, they found items from the six item lists were remembered better when preceded by a long cue, compared to a short cue. The take home is that longer list items recruited a memory based strategy while short list items recruited a maintenance based strategy, and the memory based strategy led to better encoding. Alternatively, in the current study, the difficulty between the tasks may have caused the participants to pay attention to the audio cue more than the visual cue. In other words, the audio cue may have shifted the importance of each cue and thus the visual cue was given less of a priority than the audio cue.

Previous research has reported no differences between the audio and visual preSME (Otten et al., 2010), but other research has found a preSME for visual and not audio trials (Otten et al., 2006). Interestingly these studies also report different preSME time courses' ranging from immediately preceding the stimulus (Otten et al., 2006) to mid cue-stimulus interval (Gruber & Otten, 2010; Otten et al., 2010; Padovani et al., 2011). The topography of the preSME also varied across studies. In studies with semantic orientation tasks (Otten et al., 2006; Otten et al., 2010) a focal negative going preSME was found over a frontal electrode, in an emotional task a positive going central preSME was found (Padovani et al., 2011), and another study reported a positive wide spread preSME (Gruber & Otten, 2010). Our results are inline the variable nature of the preSME. Younger adults show an early negative preSME over posterior electrodes that may represent a shift in attention to orient to the upcoming audio item. The older adult preSME is also negative going but occurs mid-stimulus interval and is distributed over frontal electrodes, this may represent a shift in attention to interpreting the upcoming stimuli, or possibly the inhibition of internal or external distractors (e.g. computer hum, hallway noise, review of a mental shopping list, etc.). Further research, possibly using various levels of degraded stimuli, would help resolve if stimulus difficulty contributed to these findings.

4.1.2 Dm Effects

We found Dm effects in for both modalities and age groups. Previous research, suggests a wide spread positive Dm (Paller & Wagner, 2002). Both younger and older adults show a widespread positive Dm for visual trials that shifts to frontal electrode sites, similar to previous research (Otten et al., 2010; Paller et al., 1987). The Dm for audio items is especially interesting, younger and older adults showed opposite widespread polarity in the same time window. These results suggest that they used qualitatively different encoding processes once the item was presented. One possibility is that younger adults recruited semantic processes related to the orienting task (comparing size), while older adults may have used a different semantic strategy, such as continuing to build a representation. Little is published about the audio Dm and some studies fail to one (Otten et al., 2006; Otten et al., 2010). The negative Dm in older adults may represent the sustained activation of the item's representation (Mangels, Picton, & Craik, 2001), or an increase in resource allocation on items that would be subsequently forgotten (Jordan, Kotchoubey, Grozinger, & Westphal, 1995). It is likely that younger adults used the same encoding process in audio and visual items, but older adults used different strategies based on modality.

In summary, these results definitively show that pre- and post-stimulus processes have qualitatively separable neural underpinnings in both young and old adults, which corroborates previous research (Otten et al., 2006; Otten et al., 2010). Indeed, we did not find correlations between the preSME and Dm. Additional research is warranted to investigate if (or how much) proactive strategies influence memory encoding.

There are a number of limitations worth mentioning. Relying on confidence judgments in the memory task was highly variable with some participants utilizing the full spectrum of responses while others rarely used any low confidence responses. Due to this subjective variation in the confidence judgments it is hard to know the exact criterion each participant was using. Performance was higher than anticipated, resulting in a low number of misses and low confidence hits for many participants. In order to increase the signal to noise ratio those conditions we combined them to create a ‘forgotten’ condition. While this has been done previously in younger adults (Otten et al., 2010; Padovani et al., 2011), some evidence suggests that older adults have similar ERPs for hit items regardless of assessed memory strength, and using a ‘forgotten’ condition may have attenuated some effects (Friedman & Trott, 2000). Most participants had too few low confident hits to reliably analyze separately, but visual inspection of the waveforms suggests low confident hits were different from the high confident hits in both young and older adults. Since a reliable preSME was not found for visual items, stay and switch ERPs were not assessed.

4.2 AX-CPT

The results from our AX-CPT task were surprising but not unprecedented. Both young and old adults had more ‘A-Y’ errors and longer reaction times than ‘B-X’ errors and reaction times. Thus, both groups showed proactive patterns of behavior. We had expected older adults to behave with reactive or less proactive strategies.

A similar AX-CPT design assessed young adults, young-old adults (66-75), and old-old adults (76-92) for the use of proactive and reactive strategies (Braver et al., 2005). They also found that young-old adults had overall fewer errors compared to young adults. Although, they found young adults made more proactive errors than young-old adults, while we found both young and older adults performed with the similar pattern of more proactive errors. Accuracy and reaction time patterns showed differences between the age groups in the Braver et al. (2005) sample, while our sample shows similar accuracy and reaction time patterns between younger and older adults. We further investigated the relationship between proactive and reactive errors and unlike Braver et al. (2005) we did not find any interaction with age when assessed together or separately. Although, we did find a negative relationship between AY and BX reaction times after the Z-score transformation. This suggests a similar underlying pattern exists in our data, but our older adults where utilizing more proactive strategies. These discrepancies may be due to a couple of reasons: (1) We are under powered at 37 participants to detect reliable age related correlations in the AX-CPT. (2) Our older adults would be considered high functioning, young (mean age: 66), and mostly consisted of those with at least a bachelor's degree.

Additionally, all participants went through an experimenter led walk through and practice in which they had to correctly respond to 70% of all trial types or they repeated the practice until they passed the threshold. Only a few older adults needed additional practice, but this type of instruction may have inadvertently trained them to use a proactive strategy. Such training has been shown to increase the use of proactive strategies by the old (Braver et al., 2009). If the instructions altered how older adults performed the AX-CPT task, it could account for the lack of a correlation between the AX-CPT and memory performance in the elderly. The younger adults may have already been utilizing a proactive strategy, and thus the cross task behavioral correlation may represent the use of an underlying cognitive control strategy. Unfortunately, this study did not explicitly set out to investigate training strategies so additional research is needed to further tease apart exactly what constitutes training and the generalizability of cognitive strategy between tasks.

4.3 Conclusion

The current study adds to the literature that older adults are capable of recruiting proactive processes that reflect subsequent memory, and that these processes are separable from post stimulus processes involved in effortful encoding. Furthermore, these processes can be flexible engaged at will in both younger and older adults. It remains tenable that pre-stimulus processes are not required for subsequent memory, but they may help support it. Further research is needed that directly manipulates when and how task processes are brought online to better control for variability in the recruited cognitive strategy.

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