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The Impact of Age and Executive Function On Susceptibility to Misinformation

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THE IMPACT OF AGE AND EXECUTIVE FUNCTION ON SUSCEPTIBILITY TO
MISINFORMATION

by

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ABSTRACT

The current study examined the impact of age and executive function on susceptibility to misinformation. A total of 41 healthy young (19-31) and older (59-77) adults were presented with visual misinformation in a paradigm originally used by Okado and Stark (2005). Participants then completed a recognition memory task while undergoing a functional magnetic resonance imaging (fMRI) scan. Participants also completed a series of cognitive measures used to assess executive function. Results showed that age and executive function were both significant predictors of recognition memory accuracy. Activity in brain regions associated with conflict processing was greater for accurate versus false memory retrieval in both older and young adults. In older adults, activity in the anterior cingulate cortex was positively correlated with accuracy. The results of the current work demonstrate that conflict resolution is a critical part of overcoming the effects of misinformation and individual difference variables predict susceptibility in young adults as well as older adults.

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CHAPTER 1 INTRODUCTION

The purpose of this project is to examine the roles that age and executive function play in susceptibility to misinformation. Past research has shown that older adults are more susceptible to the interfering effects of misinformation and typically experience more false memories than young adults. One theory for why older adults are more susceptible to misinformation is because they have difficulty with source monitoring, an episodic memory process (Mitchell & Johnson, 2009). Older adults typically perform worse than young adults on tasks that require attribution of source at retrieval and neuroimaging studies show consistent age-related differences in the prefrontal cortex during source retrieval. However, the few neuroimaging studies that have looked explicitly at false memories fail to support a strictly source monitoring account of increased susceptibility. Thus, the first goal of this work is to observe the neural correlates of accurate and false memory retrieval during a misinformation task and assess age-related as well as individual differences in these correlates. Additionally, recent behavioral studies suggest individual differences in tests of executive function may predict susceptibility to misinformation in both older and young adults. The second goal of this work is to determine the contributions of both age and executive function to retrieval accuracy during a misinformation task.

CHAPTER 2 AGING AND MEMORY

Decline in memory for events or episodic memory is perhaps one of the most prominent and researched topics in the field of cognitive aging. A robust finding in the literature is a decline in episodic memory across the lifespan (for a review see Zacks, Hasher, & Li, 2000). In addition to exhibiting general deficits in episodic memory, older adults are much more vulnerable to false memories than young adults (Zacks, Hasher, & Li, 2000). False memories most often occur when conflicting information is present in the long-term memory store and the incorrect information is mistakenly retrieved, but false memories can and do occur without the presentation or suggestion of conflicting information.

In laboratory studies, older adults are more likely than young adults to report actually witnessing events that are only suggested to them during “Misinformation Paradigms”. Misinformation is a manipulation in an experiment during which information is intentionally presented or only suggested which conflicts with previous to-be-remembered information (Loftus, 1979). For example, an early study by Schacter, Koustaal, Johnson, Gross, and Angell (1997) demonstrated that after reviewing photos of events that had not been shown earlier in a video, older adults were more likely to report that those events had been shown in the video.

Older adults are also more likely to misattribute events even when explicitly asked about their origin. Mitchell, Johnson, and Mather (2003) showed younger and older

adults a short video depicting a crime. After seeing the video, all participants answered questions about the events which contained misleading post event information. For example, while the thief was depicted without a gun at his waist during the video, a later question might imply that he did have a gun at his waist. After these initial questions, all participants were given a surprise source memory test which asked them to indicate where certain items originated. Older adults were more likely to attribute items suggested in the questions to the actual video.

One theory for why older adults are more susceptible to misinformation and thus experience more false memories is because they have more problems than young adults with something called source monitoring (Mitchell & Johnson, 2009). In 1993, Johnson, Hastroudi, & Lindsay (1993) outlined the source monitoring framework as a way to describe the attribution of source to memory traces. Similar updated descriptions of this framework can also be found in Johnson (2006) and Mitchell & Johnson (2009). According to Johnson and colleagues, the central tenet of the source monitoring framework (SMF) is that complex event memories (e.g. “Last Wednesday, when I went to the bank...”) are made up of features. These features can include perceptual information (e.g. her shirt was red), spatial details (e.g. the desk was on the right side of the room), temporal details (e.g. it was the afternoon), emotional information (e.g. the woman was angry) and so on. Binding these features together during the encoding stage helps us to distinguish one event from another, creating “episodes”. When brought to mind later during retrieval, these details or features provide evidence about the source of a mental experience.

Johnson and colleagues (1993) used the term differentiation to refer to the idea that as you pull information from memory, it coheres, giving rise to specific characteristics of memories such as the perceptual, temporal, or emotional details. Information is relatively undifferentiated at weak levels of cohesion or if only a single feature is activated. In other words, differentiation is greater when two or more features together form the basis for separating one event from another. Relatively undifferentiated information can result in nonspecific source attributions (e.g. “I’ve seen this word in the experiment.”) Other source attributions are based on more differentiated information (“I remember the word couch was written in blue ink.”).

Another key feature of the SMF is that during decision processes at retrieval, features are flexibly weighted according to current context or goals. This can determine what information is searched for and accessed and how it is combined and evaluated during the source attribution process. For example, in a study where people look at some actions taking place and also perform some actions themselves, later asking a participant “Did you perform this action?” would lead to an emphasis on internal thought processes and cognitive operations, whereas asking him/her “Did you see this action take place?” would lead to an emphasis on perceptual information when making the source attribution. This feature of the SMF suggests that in addition to encoding, processes at retrieval are important and necessary for a successful source attribution.

Past research shows that older adults have particular difficulties with source monitoring in comparison with younger adults (for reviews see Mitchell & Johnson, 2009; Spencer & Raz, 1995). Early studies demonstrated that older adults have more difficulty than younger adults in distinguishing whether they heard or saw something

(Norman & Schacter, 1997) or determining who said what (Naveh-Benjamin & Craik, 1996). Mitchell, Johnson, Raye, Mather, and D'Esposito (2000), using a working memory paradigm, found that older adults were fine at recognizing individual items but were impaired in ability to recognize an item in context (e.g. an object and its location). These studies, and other like them, provide behavioral evidence that older adults are more susceptible to the interfering effects of the misinformation because they have difficulty recollecting and monitoring the sources of their memories.

CHAPTER 3 NEUROIMAGING OF AGING AND SOURCE MEMORY

Much of the work on the neural bases of source monitoring has focused on the roles of the medial temporal lobes (MTL) and prefrontal cortex (PFC). The MTL has a strong role in both encoding and retrieval of sources (Davachi, Mitchell, & Wagner, 2003; Mitchell & Johnson, 2009). The hippocampus is involved in binding together features into complex episodic memories and in specific remembering of item plus context information at retrieval (often called “recollection”), whereas the perirhinal cortex, another division of the MTL, supports simple item memory and less-differentiated remembering (often called “familiarity”) (Ranganath, et al., 2004). The role of the MTL in source monitoring is important but the main focus of the current work is the role of the frontal lobes. I chose to focus mostly on the frontal lobes given recent evidence, discussed further below, that differences in tests of executive function may predict individual differences in susceptibility to misinformation (Butler, McDaniel, McCabe, & Dornburg, 2010; Chan & McDermott, 2007; Roediger & Geraci, 2007). Butler, et al. (2010) also administered tests of MTL functioning but found that they did not predict susceptibility to false memories.

Previous neuropsychological work has found that damage to the PFC disrupts revival and systematic evaluation of source information at retrieval (Mitchell & Johnson, 2009). Mitchell, Johnson, Raye & Greene (2004) found that the left lateral PFC (Brodmann areas (BAs) 9 and 46) was involved in the systematic monitoring of specific,

well-differentiated information during a source task in which participants tried to remember the format or location an item appeared in whereas the same areas in right lateral PFC were involved in the evaluation of less-differentiated information during a simple old/new recognition task. The areas involved in source evaluation in Mitchell, et al. (2004) tended to be more dorsal than ventral consistent with a proposal by Petrides (2002) that the ventrolateral PFC is involved in controlled retrieval and selection of relevant information whereas the left dorsolateral PFC is more involved in evaluation of active information (e.g. Is this information characteristic of Source X?). In a later study, Mitchell, Raye, Johnson, & Greene (2006) also found that the left dorsolateral PFC was more active during source judgments than during simple old-new judgments.

Neuroimaging studies show consistent age-related differences in PFC activity during source retrieval (Mitchell & Johnson, 2009). The frontal lobes show considerable age-related declines in volume which may lead to changes in processing (Dennis & Cabeza, 2008). For example, Mitchell, et al. (2006), within the same experiment discussed in the previous paragraph, found age-related decreases in left dorsolateral PFC activity during source judgments at the retrieval period. Given the proposal that left lateral PFC may be responsible for systematic monitoring of well-differentiated information during source retrieval (Petrides, 2002), evaluating specific information at retrieval may become more difficult as one ages.

Age-related reductions in right PFC have also been found and older adults show larger age-related deficits as retrieval task difficulty increases (Daselaar, Dennis, & Cabeza, 2007; Dennis & Cabeza, 2008). Cabeza, Anderson, Houle, Mangels, & Nyberg (2000) found age-related reductions in right PFC activity during retrieval of temporal

context information, a task similar to that of source monitoring, but no differences during simple retrieval of items, a less difficult task. It is interesting that while Cabeza, et al. (2000) found decreased right PFC activity during context retrieval, Mitchell, et al. (2006) found decreases in left PFC during source retrieval. It is possible that this is task-related. Mitchell and colleagues probed memory for location (left or right) and format (word or picture) of items. Cabeza and colleagues probed memory for temporal order (i.e. When did this item appear in a list?). It is possible that location or format decisions rely more on systematic evaluation of information (e.g. is the information I retrieved about this item characteristic of format A or B?") than do temporal order decisions.

Frequently, age-related reductions in activity in the PFC during episodic memory are accompanied by increased activity in other regions, especially contralateral PFC regions (for review see Daselaar, et al., 2007; Dennis & Cabeza, 2008; Mitchell & Johnson, 2009). Studies show initial reduction in activity may occur in either the left or right hemisphere, depending on the task. Figure 3.1 shows an example. The pattern is typically found only among high-performing older adults or is greatest among the highest-performing participants and has been found previously during source memory (Morcom, Li, & Rugg, 2007). Importantly, Morcom, Li, and Rugg (2007) investigated differences between older and young adults when task performance was matched. They found no age-related decreases in activity, only age-related increases.

This pattern of findings is thought to reflect compensatory activity and led to the development of the hemispheric asymmetry reduction in older adults (HAROLD) model (Cabeza, 2002). It has still been unclear whether the additional activity represents the recruitment of additional areas to do the same processing, or the recruitment of additional

processes to perform the same task (Mitchell & Johnson, 2009). A very recent study by Spaniol and Grady (2012) sheds light on this issue. Spaniol and Grady were able to show that during source memory, older adults disproportionately engaged frontally-mediated control processes in a way very similar to young adults when they were asked to complete a difficult memory task. While both groups showed greater activity in left medial anterior PFC (BA 10) for source memory, older adults also engaged the right inferior (BA 45), middle (BA 8), and superior frontal gyri (BA 8) during source retrieval. These results suggest that both young and older adults may engage in functional reorganization as a strategy to complete particularly laborious memory tasks. Given that the HAROLD pattern is typically seen in high-performing older adults, reorganization during retrieval may be a way for older adults to optimize their performance. When responding to questions about an event after exposure to misinformation, older adults (matched on performance to young adults) should also disproportionately engage these contralateral PFC regions. We would also expect to see more engagement of these regions as task performance improves.

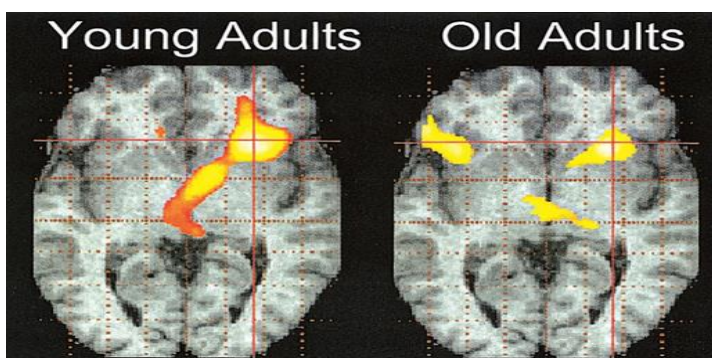


Figure 3.1 An example of the HAROLD pattern. Activity in the young adults is mainly restricted to the right hemisphere. Activity in the older adults is bilateral. Taken from Cabeza (2002).

In addition to PFC, activity in parietal cortex differs depending on the specificity of information being evaluated at retrieval (Mitchell & Johnson, 2009). Vilberg and Rugg (2007) found that left lateral inferior parietal cortex (BA 39) seemed to be associated with amount of specific information recollected, with more activity for more specific information recollected. Monitoring of source information at retrieval, then, seems to require coordinated activity between the prefrontal and parietal cortices. Mitchell, et al (2008) found, in a short-term source memory task, more activity in both left dorsolateral PFC and lateral parietal cortex (BAs 7/39/40) for source judgments.

Coordination between activity in PFC and parietal areas has also been found in misinformation studies. Okado and Stark (2003) found that both accurate and false memories following exposure to misinformation elicited activity in left dorsolateral PFC (BA 9) and left lateral parietal regions (BAs 7/39/40) . They concluded this activity may be related to the attempt to retrieve source information versus retrieval success specifically. Recently collected data from our lab (Meek, 2012) reflect a similar pattern, in that accurate memories after exposure to misinformation elicited greater activity in left dorsolateral frontal and lateral parietal regions than did memories not associated with misinformation.

While not specifically focused on source monitoring, a preponderance of studies show decreased activity in posterior regions in older adults during memory and attention tasks (for a review see Dennis & Cabeza, 2008). These reductions are often accompanied by the increases in PFC activity mentioned earlier. This pattern has been termed the posterior–anterior shift in aging (PASA; Cabeza, et al., 2004; Dennis, Hayes, et al., 2008) and may also be related to functional reorganization

CHAPTER 4 NEUROIMAGING OF AGING AND FALSE MEMORIES

Neuroimaging studies of false memory formation in older adults are few and currently no study has examined brain activity in older adults in the context of a visual eyewitness memory paradigm. Despite evidence for the source monitoring hypothesis, the few studies that have looked explicitly at false memories fail to support a strictly source monitoring account of increased susceptibility. Dennis, Kim, and Cabeza (2007, 2008) investigated the neural correlates of false recognition of semantically related lures with the Deese-Roediger-McDermott (DRM) paradigm (Roediger & McDermott, 1995). Figure 4.1 below illustrates the DRM paradigm. Dennis, et al. (2007) showed that encoding-related activity for subsequent accurate memories (i.e. calling a target word “old”) in MTL and left ventrolateral PFC was reduced in older adults. Despite these decreases, older adults did show an increase in right ventrolateral PFC activity which may reflect the compensatory activity discussed earlier (HAROLD model; Cabeza, 2002). They also showed increases in the left superior temporal gyrus (STG) for accurate memories and false memories. During the retrieval period of the same experiment, Dennis, et al. (2008) found that behaviorally, older adults exhibited poorer memory performance than young adults. Specifically, they displayed an increase in high confidence false alarms to related lures (i.e. calling a related lure “old”). Similar to the encoding period, older adults showed greater activity in lateral temporal cortex during

false remembering of non-presented items. Dennis and colleagues believe these results are consistent with an increase in semantically-based gist responding (mediated by the lateral temporal cortex), which leads to errors in this paradigm.

Recently, using a picture-based paradigm, Duarte, Graham, and Henson (2010) proposed that older adults show enhanced false alarm rates not because of an increase in more familiarity-based gist responding, but because the neural signatures associated with true and false recognition are less distinguishable in older adults than they are in the young. In support of their hypothesis, they found that a difference between true and false recognition in the dorsomedial PFC (BAs 6/8/32), inferior frontal areas (BA 47), and posterior inferior temporal areas (BAs 37/19) observed in young adults was absent in older adults, implying a reduced capacity of frontal and temporal regions to distinguish studied from unstudied items. The authors go on to discuss that dorsomedial (including anterior cingulate cortex (ACC)) and inferior frontal regions have previously been linked to conflict monitoring and resolving response competition (see Botvinick, Cohen, & Carter, 2004 for a recent review), suggesting that these control processes subserved by the frontal lobes may be disturbed in some older adults. The older adults in Duarte, et al. (2010) were chosen because they had high levels of false alarms or were “low-performers”. Older adults who are “high-performers” may be better able to engage in response conflict resolution and demonstrate enhanced performance during the retrieval task.

Conflict processing is especially relevant to the current work in that to successfully navigate misinformation; participants have to choose among competing items in memory to pick the correct piece of information. A recent behavioral study also provides support for the importance of conflict resolution during a misinformation task.

Dodson and Kreuger (2006) found that when young and older adults were matched on their overall memory for experienced events, both groups showed comparable rates of source errors or times they claimed to have seen events that appeared exclusively in a post-event questionnaire. However, older adults were most likely to make source errors when they were most confident in their response versus young adults who were most likely to make these errors when they were uncertain about their response. Dodson and Krueger proposed the errors were a result of older adults' confidently misremembering past events. It could also be that the uncertainty more often experienced by the young adults was a result of conflict between the original item and the post-event questionnaire item. Successful resolution of response conflict may be critical to success in a misinformation task.

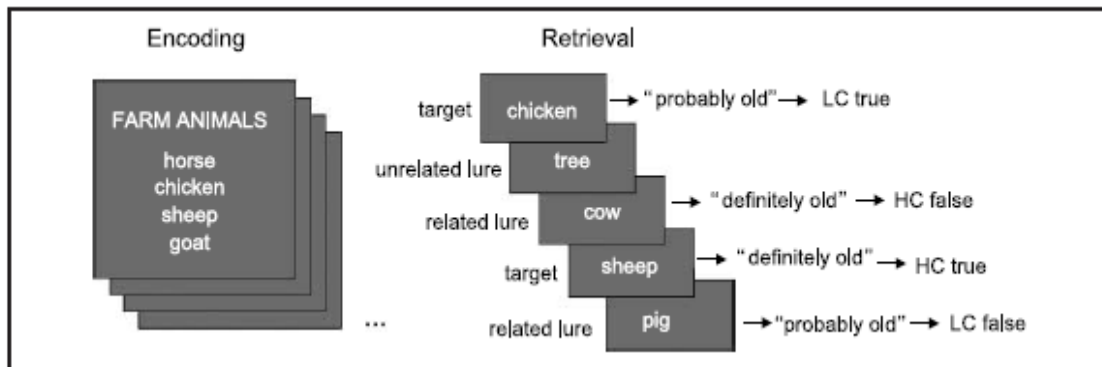


Figure 4.1 An example of the DRM paradigm (Roediger & McDermott, 1995). Targets are words that were presented previously. Unrelated lures are words that are unrelated to the semantic category “farm animals” and were not presented previously. Related lures are words that are related to the semantic category but were not presented previously. Responding with “old’ to a related lure is considered a false memory. Taken from Dennis, et al. (2008).

CHAPTER 5 INDIVIDUAL DIFFERENCES

Recent behavioral studies suggest that executive function may be important in determining individual differences in susceptibility to misinformation and formation of false memories. Such an investigation was that done by Roediger and Geraci (2007), who used a visual misinformation paradigm which presented participants first with a slide show of an event followed by a written account of the event that contained information not consistent with the slides (misinformation). They found that the older adults most susceptible to false memories in this misinformation paradigm had lower scores on measures of executive function.

A recent study by Butler, McDaniel, McCabe and Dornburg (2010) investigated whether older adults could use a strategy previously used with young adults to decrease false memories in the DRM paradigm. This strategy involves generating item-specific characteristics for each studied word at encoding. This information is then used as an additional type of cue at retrieval. Surprisingly, they found that under item-specific encoding instructions, false recall rose, especially for those with lower executive function. Butler and colleagues proposed that the extra information generated at encoding became a hindrance for the older adults as they now had more information to sift through and evaluate during retrieval. This was worse for those with lower executive function providing further evidence for the critical role of the frontal lobes in deliberate and controlled retrieval processes.

Both of the studies discussed above only measured executive function in the older adults and implicitly assumed that young adults' executive function was homogenous. This assumption was tested in a study by Chan and McDermott (2007). Chan and McDermott measured executive function in both young and older adults and looked at the contributions of both age and executive function to misinformation susceptibility in a paradigm similar to that used in Roediger and McDermott (2007). Using regression analyses, they found that both age and executive function were significant predictors of retrieval accuracy. These results suggest that executive function may be a general predictor of individual differences in susceptibility to misinformation, rather than age-specific. Before moving on, below is a summary table of the main findings discussed above.

Table 5.1 Summary of main findings.

Topic	Major Findings
Aging and Memory	Older adults are more susceptible to the interfering effects of misinformation than young adults.
Neuroimaging of Aging and Source Memory	Older adults have more difficulty than younger adults in distinguishing whether they heard or saw something, determining who said what, or recognizing an item in context.
Source Memory: General	Left dorsolateral PFC more active during source judgments than during simple old-new judgments.
	Left lateral inferior parietal cortex associated with amount of specific information recollected.
	More activity in both left dorsolateral PFC and lateral parietal cortex for source judgments.
	Both accurate and false memories following exposure to misinformation elicit activity in left dorsolateral PFC and left lateral parietal regions.
	Accurate and false memories may be distinguished by activity in dorsomedial PFC and posterior inferior temporal regions.
Source Memory: Age-Related	Age-related decreases in left and right PFC activity during source judgments at the retrieval period.
	Age-related reductions in activity in the PFC during episodic memory/source memory often accompanied by increased activity in other regions, especially contralateral PFC regions.
	Decreased activity in posterior regions in older adults during memory and attention tasks.
Neuroimaging of Aging and False Memories	In word-based false memory paradigms, older adults show more activity in lateral temporal regions related to familiarity-based gist processing.
	In a picture-based paradigm, older adults may show enhanced false alarms because the neural signatures associated with true and false recognition are less distinguishable.
Individual Differences	Lower executive function is related to enhanced susceptibility to misinformation in both older and young adults.

CHAPTER 6 CURRENT WORK

The current work examined age-related similarities and differences in the neural correlates of accurate and false memory retrieval using a misinformation paradigm originally developed by Loftus (1979) and recently updated by Okado and Stark (2005). Compared to the DRM paradigm and other word-based tasks, this paradigm more closely mimics real-world eyewitness memory scenarios and is very similar to the paradigm previously used by Roediger and Geraci (2007). Currently, only one of the three studies to specifically look at age-related differences in neural correlates of accurate and false memory retrieval did so with a picture-based paradigm and as such the current project fills a gap in the cognitive aging literature.

The current work also examined individual differences in susceptibility to misinformation in both young and older adults. We measured the ability of age and executive function to predict task accuracy in order to replicate the findings of Chan and McDermott (2007). Additionally, relationships between blood-oxygen-level-dependent (BOLD) signal change in specific regions-of-interest (ROIs), executive function, and task performance were explored.

The current work addresses the following four research questions:

1. How is behavioral performance (i.e. retrieval accuracy) on a misinformation task related to both age and executive function?

2. What are the neural correlates of accurate and false memory retrieval during a misinformation task?
3. How do those neural correlates differ between older and younger adults when performance is matched?
4. Are those neural correlates modulated by individual differences in retrieval accuracy and executive function?

Hypotheses¹

Specific hypotheses for each research question are listed below.

1. A regression analysis will show that executive function and age each account for variability in retrieval accuracy for critical items.
 - 2a. During accurate and false memory retrieval following exposure to misinformation, participants will attempt to resolve the conflict between the two salient items in memory. As a result, both accurate critical items and false critical items will elicit more relative activity in medial PFC, left lateral PFC, and ACC compared with accurate consistent items.
 - 2b. The increase in the amount of specific information recollected (as one attempts to resolve conflict) will also result in more activity in lateral parietal areas.
 - 2c. Accurate memory retrieval following exposure to misinformation will be distinguished from false memory retrieval following exposure to misinformation by greater relative activity for accurate memory in medial PFC and ACC as well as posterior

¹Accurate: endorse original item, False: endorse misinformation item, Inaccurate: endorse foil item.

inferior temporal regions previously associated with *successful* resolution of response competition.

3a. During accurate and false critical items, compared with young adults, older adults may show more activity than young adults in PFC regions, especially those contralateral to the PFC areas present in a conjunction analysis combining the two groups (consistent with HAROLD pattern).

3b. In older adults, accurate memory retrieval following exposure to misinformation *may* not be distinguished from false memory retrieval following exposure to misinformation by greater relative activity for accurate memory in medial PFC and ACC and posterior inferior temporal regions. As such, older adults *may* show less activity than young adults in these areas for this contrast.

4a. Executive function and task performance will be positively correlated with neural activity in ACC during accurate memory retrieval following exposure to misinformation in all participants. This will be measured by examining the correlation of composite executive function score and retrieval accuracy with mean BOLD percent signal change in ACC/medial PFC during accurate critical trials compared with false critical trials.

4b. *Older adults only:* Executive function and task performance will be positively correlated with neural activity in PFC areas contralateral to the PFC areas present in a conjunction analysis combining the two groups (consistent with HAROLD pattern) during accurate memory retrieval following exposure to misinformation. This will be measured by examining the correlation of composite executive function score and

retrieval accuracy with mean BOLD percent signal change in contralateral PFC during accurate critical trials compared with accurate consistent trials.

CHAPTER 7 METHODS

Participants

Twenty young adults (13 females) and 23 older adults (15 females) participated in this study. The young adults were 19-31 years of age ($M = 21.35$; $SD = 2.54$). The older adults were 59-77 years of age ($M = 66.39$; $SD = 4.73$). Mean level of education for young adults was 14.85 years ($SD = .88$). Mean level of education for older adults was 16.39 years ($SD = 2.29$). Older adults' mean level of education was significantly higher than that of the young adults ($t(41) = 2.83$, $p < .01$). This difference was mostly due to the fact that many of the young adult participants were still attending college at the time of data collection, and as such their maximum attained level of education was lower. Mean Mini Mental Status Exam (MMSE; Folstein, Folstein, & McHugh, 1975) score for older adults was a 29.2 out of 30 and no one scored lower than 28. Mean raw score for older adults on the Wechsler Adult Intelligence Scale (WAIS-IV) Vocabulary Subtest (Wechsler, 2008) was 42.73/52 ($SD = 5.46$). Raw score translates into a scaled score that is roughly .67, or 2/3rds of a standard deviation above the average scaled score. Older adults were also screened for the presence of significant neurological or cardiovascular issues (e.g. stroke, Parkinson's disease, Alzheimer's disease, uncontrolled hypertension, heart surgery, etc.). Two of the 23 older adults were excluded from the study, one because of excess fatigue during the experimental task and the other because of the presence of neurological

abnormalities on the MRI scan.² Informed consent was obtained from all participants in accordance with the guidelines of the University of South Carolina Institutional Review Board.

Neuropsychological Tests

A series of fully computerized, neuropsychological tests was given to all participants, with the exception of five young adults, to assess general cognitive ability as well as to derive a composite executive function score. Six tests were used from the CANTAB[®] computerized cognitive assessment battery (Cambridge Cognition, 2012). The CANTAB tests are designed to test a myriad of cognitive functions, including verbal ability, attention, memory, and executive functioning. They are predominantly non-linguistic and culturally neutral. The six tests used were: Reaction Time (RTI), Rapid Visual Information Processing (RVP), Stockings of Cambridge (SOC), Spatial Span (SSP), Spatial Working Memory (SWM), and Intra-Extra Dimensional Set Shift (IED). All CANTAB tests have satisfactory levels of test-retest reliability (Cambridge Cognition, 2012). Any participant scoring more than two standard deviations below age-matched normative data on more than two of the neuropsychological subtests would have been excluded post hoc. No participant was excluded on this basis.

Five measures total from three of the tests were used to derive a composite executive function z-score: mean thinking time and number of problems solved in minimum moves from the SOC, a spatial planning test which gives a measure of frontal lobe function; spatial span from the SSP, which assesses working memory capacity, and is a visuospatial analogue of the Digit Span test; and number of errors and strategy score

² Three of the remaining 21 older adults completed the misinformation task outside the scanner. Imaging data for one young adult was corrupt and had to be discarded.

from the SWM, which is a sensitive measure of frontal lobe and ‘executive’ dysfunction. The measures from these three tests were chosen based on a factor analysis of CANTAB tests done by Robbins, et al. (1998). Robbins and colleagues found that performance on these tests was not simply related to a measure of fluid intelligence and performance had a factor loading structure distinct from that for tests of visual memory and learning more dependent on the temporal lobes. Each measure was computed as an age-adjusted z-score by the CANTAB software. Age-adjusted scores control for age, such that a z-score of 1 means the same thing for a 65-year-old or a 20-year-old (one standard deviation above mean for appropriate age). The five age-adjusted z-scores were averaged to create one “composite” z-score.

Materials

The stimuli used in this study were taken, with permission, from previous fMRI studies of misinformation (Okado & Stark, 2005; Stark, Okado, & Loftus, 2010). These stimuli consisted of 8 vignettes, each of which contains 50 color slides that detail an event taking place. 12 of these 50 slides were marked as critical slides, and contain information that changes between the original event and misinformation trials. For example, in the first presentation the participant viewed an image of a man opening a car door using a credit card. In the second presentation, he committed the exact same action holding a wire hanger instead. Each set of 50 slides contained two different sets of critical items (62 slides in total). Slides were uniformly sized at 300 x 300 pixels.

The recognition test consisted of detailed questions regarding what was presented in the Original Event phase. For all eight vignettes, there was a total of 18 questions, 12 critical questions (pertaining to critical, changed slides), and six control questions

(pertaining to consistent slides). An example of a critical question was “Where was the man hiding after he stole the girl’s wallet and crossed the street?” Each critical question had three answer options: (1) the detail presented in the Original Event phase (Behind a Door), (2) the detail presented in the Misinformation phase (Behind a Tree), and (3) a foil option (Behind a Car). Control questions were similar in detail to critical questions. An example of a control question was “What kind of store was to the left of the video store?” Each control question also had three responses options: (1) the detail presented in both phases (Hair Salon), (2) a foil option (Music Store), and (3) a foil option (Clothing Store). There was a separate recognition test for all eight vignettes.

Procedure

Participants came to the 3T scanner suite located at Palmetto Richland Medical Center, Columbia, SC for two sessions. In Session 1, informed consent was obtained from all participants. Once consent was obtained, older adults filled out a health history questionnaire that included all health-related exclusion criteria. All participants filled out the MRI Participant Screening Document. Questions on these forms were used to determine final eligibility for the study. Eligible participants then underwent the series of neuropsychological tests³.

The first part of Session 2 occurred outside the MRI scanner and was conducted on a laboratory computer in the scanner suite. The original event and misleading post-event information was presented using power point software. A total of eight vignettes were presented twice, each consisting of 50 slides. Each slide was presented for four seconds, for a total of 200 seconds per vignette. There was a short (30 second) delay

³ Older adults also completed the MMSE and WAIS-IV Vocabulary Subtest at this time.

between vignette presentations. During the misleading post-event information slides, 12 of the initially presented critical slides were replaced by their misinformation counterparts. This resulted in a total of 96 misinformation items presented across the second presentation of the vignettes. There were three null trials per vignette (24 total). Null trials were white screens with a blue letter “X” randomly placed on the screen. Participants were asked to press the “X” button on the keyboard when they saw the “X” screen. Null trials were also presented for four seconds. All of the null trials were randomly intermixed within each event.

Participants were instructed to watch all eight vignettes, each containing different events, and were told that they would answer questions concerning what they witnessed later. Participants were initially presented with 50 slides depicting an event. After a short delay, they were then presented with the next vignette. This portion of the experiment served as the original event phase. After a delay, during which the experimenter went over the MRI screening document again with participants, a second presentation of the eight vignettes was given. However, in this second presentation 12 of the slides in each vignette contained different details from the original event slides. In these slides the scene itself remained almost identical, with just one major detail altered (i.e. a hat falling off a head, the main actor holding a wire hanger instead of a credit card, the denomination of bills, etc.).

The second part of session 2 occurred inside the MRI scanner approximately 20 minutes following viewing of the vignettes. Before participants went into the scanner they completed a short practice session outside the scanner to familiarize themselves with the nature of the task. The second part tested participants’ memory for the events they

remembered seeing in the *original* set of events they viewed. An event-related design was used to present 144 test items to each participant. Each trial consisted of a fixation screen, a test item screen (3.5s), and a response screen (4.5s). Participants were cued for a particular vignette before a new set of questions began. Within each set of questions they were presented with 12 critical questions related to items that changed between the vignettes. Another six questions were presented for items that were consistent for both the original and misleading information presentations. This resulted in a total of 18 questions per vignette, for a total of 144 questions (96 critical, 48 consistent; see Appendix A for a copy of all questions). A jittered inter-stimulus interval (ISI) was added between trials. The ISI between trials were one of four times: 400, 800, 1200, or 1600 milliseconds. The order of these times was randomly generated but balanced so as to have an equal number of each type. The order was randomly generated once and then kept the same for all participants.

At this stage of the study participants underwent both a functional and a structural MRI scan. The structural scan was first. The recognition test items were presented during the following functional scan, and participants were asked to respond using button press via a device strapped onto their hands. Trials consisted of a fixation screen followed by a question screen and then a response screen. At the response screen, participants were prompted to choose between three potential answer choices, pressing 1 with their index finger for the top answer option, 2 with their middle finger for the middle answer option, or 3 with their ring finger for the bottom answer option.

Image Acquisition

Scanning was performed on a 3T Siemens Trio scanner (Munich, Germany) equipped with a 12-element head coil.

Structural scans. A 3D sagittal T1-weighted MPRAGE scan (192 slices; 1mm thick) was employed the following parameters: TR = 2250 ms, T1 = 925 ms, TE = 4.15 ms, flip angle = 9°, matrix = 1 x 1 x 1 mm³, 256 X 256 FOV.

Functional scans. A total of 668 echo-planar imaging (EPI) volumes (36 axial slices; 3.0 mm thick, with a 0.6 mm gap between slices) was acquired during the fMRI session. The sequence employed the following parameters: TR = 2130 ms; TE = 35 ms; matrix = 64 X 64 voxels; flip angle = 90°, 208 X 208 mm FOV.

Data Analysis

Behavioral data. The general linear model (within SAS GLM) was used to analyze behavioral data (Research Question 1). A total of 36 subjects were included in this analysis (21 older adults, 15 young adults). The dependent variable was accuracy defined as rate of endorsement of original event item on a critical question. Composite executive function z-score and age group (categorical) were used as predictor variables.

Functional brain data. Data preprocessing and statistical analyses were performed using FEAT (fMRI Expert Analysis Tool) Version 5.98, part of FSL (FMRIB's Software Library, www.fmrib.ox.ac.uk/fsl). Preprocessing consisted of motion correction using MCFLIRT (Jenkinson, Bannister, Brady, & Smith, 2002). MCFLIRT uses linear image registration to attempt to correct for participant head motion during scanning. This was followed by slice-timing correction using Fourier-space time-series phase-shifting, which corrects for the fact that every slice was not acquired at exactly the middle of the TR. This process adjusts the actual middle time of acquisition of each slice

so that it matches the midpoint of the TR. Next, the brain was extracted from the whole head functional image using BET (brain extraction tool; Smith, 2002). Spatial smoothing using a Gaussian kernel of FWHM 5.0mm was then done to increase signal-to-noise ratio, followed by grand-mean intensity normalization of the entire 4D dataset by a single multiplicative factor. This final step accounted for potential spatial and temporal differences in MRI signal by forcing all volumes to have equal mean intensity values. Image registration involved a two-step procedure, whereby low-resolution functional data were first registered to the matched high-resolution structural data using a six-parameter affine transformation (Jenkinson, et al., 2002; Jenkinson & Smith, 2001) and then registered to standard Montreal Neurological Institute (MNI) space (FSL 4.5 MNI avg152 template) using a 12-parameter linear transformation (Jenkinson, et al., 2002; Jenkinson & Smith, 2001). Statistical analyses were performed in native space, with the statistical maps normalized to standard space prior to higher-level analysis.

Time-series statistical analysis used generalized least squares in FILM (FMRIB's Improved Linear Model) with local autocorrelation correction (Woolrich, Ripley, Brady, & Smith, 2001) after high pass temporal filtering (Gaussian-weighted least-squares straight line fitting, with $\sigma = 50.0s$). Voxel-wise analysis used flexible hemodynamic response function (HRF) modeling, allowing HRF to vary spatially and between subjects (Woolrich, Behrens, Beckmann, Jenkinson, & Smith, 2004). For each participant, activity related to each experimental condition of interest was modeled as a canonical HRF. A previous study looking at source memory modeled a second, delayed HRF (~ 1 TR) for older adults (Morcom, et al., 2007), however this second model did not account for any significant variance in older adults' activity, therefore only the canonical HRF was

modeled here. It should also be noted that reported differences in shape and timing of the HRF between older and younger groups has been small (Huettel, Singerman, & McCarthy, 2001). Trials were coded into three main conditions of interest: 1) correct responses to control, consistent items, 2) responding with the original event item to a critical question (accurate memory), and 3) responding with the second misinformation phase item to a critical question (false memory). Trials during which participants responded with the foil option or omitted a response were modeled as events of no interest.

A second-level analysis was then calculated by investigating the mean activation across a subset of 12 young adult participants and a subset of 12 older adult participants who were matched on retrieval accuracy for critical questions. Twelve participants is the typical number needed to have sufficient power in an fMRI experiment (Desmond & Glover, 2002). The range of endorsement rates of the original items for both groups ranged from roughly .45 - .65 with means that were not significantly different, $t(22) = -.99, p = .33$. The main effect for each group (Research Question 2) as well as the difference between groups (interaction) was calculated for each specified contrast (Research Question 3). This analysis utilized FLAME (FMRIB's Local Analysis of Mixed Effects; Woolrich, et al., 2004), a process that allows for estimation of mixed effects variance. A separate conjunction analysis (Nichols, Brett, Andersson, Wager, & Poline, 2005) was performed to look for activity in common between the two groups (Research Question 2). Z (Gaussianised T/F) statistic images were thresholded using clusters determined by $Z > 2.3$ and a corrected cluster significance threshold of $P = 0.05$ (Worsley, 2001).

Following the whole-brain analyses, functional ROI masks were created from the group results for two predetermined regions, ACC in all participants and contralateral PFC in older adults. The ACC mask was created separately for the older and young adult groups based on peak of activity in ACC for both groups from the accurate critical item > false critical item contrast (see Figure 7.1 for example of mask). The contralateral PFC mask was created for the older adult group based on peak of activity in contralateral PFC from the accurate critical item > accurate consistent item contrast (see Figure 7.1 for example of mask). These masks were overlaid on to each individual's T1 to ensure the mask only covered brain matter. Featquery, part of the FEAT analysis software package, was used to extract mean percent signal change values from the masks for each participant. The percent signal change values were entered into Pearson's correlations with composite executive function z-scores and accuracy scores (for the 33 participants with neuropsychological and functional imaging data) to understand the relationship between these variables and neural activity (Research Question 4).

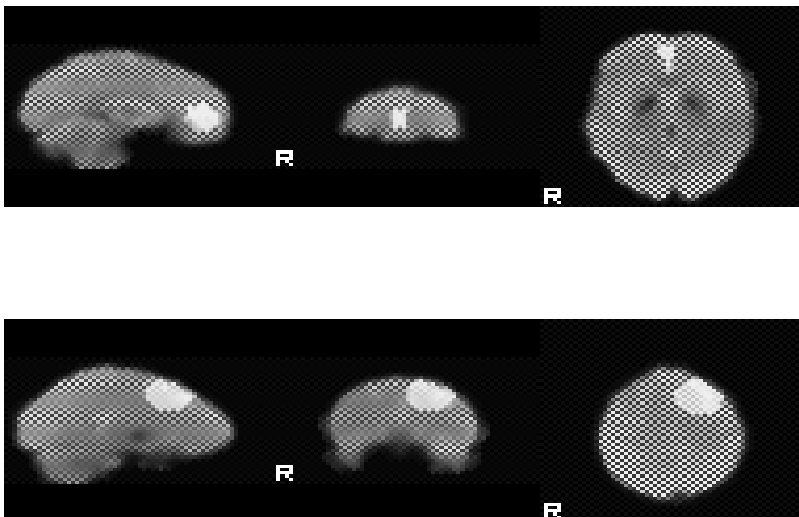


Figure 7.1 Functional region-of-interest (ROI) masks on one older adult participant. Top – ACC; Bottom – Contralateral PFC

CHAPTER 8 RESULTS

Behavioral Data

Overall, participants endorsed misleading post-event items more often than foil items ($t(40) = 16.041, p < .001$), confirming that the paradigm reliably created false memories (responding with items shown in the Misinformation phase when asked about the Original Event phase). As shown in Figure 8.1, young adults performed better on the recognition memory task than older adults. Both groups were more accurate on consistent items than critical items, in line with previous research (Okado & Stark, 2005). Table 8.1 displays raw scores and z-scores for both age groups on the five measures from three CANTAB tests used to create the composite executive function z-score. The raw scores for young adults demonstrated that they performed better than older adults on all measures, as would be expected given that many cognitive functions decline with age. The standard scores showed that overall, the older adults performed better than average for people their age. The young adults performed better than average for people their age except for the two SOC measures; where standard scores were slightly lower than average for their age. The average standard score (across all five measures) was not significantly different between the groups, $t(34) = .88, p > .05$ suggesting both groups performed similarly relative to people their own age.

The general linear model (within SAS GLM) was used to evaluate the ability of age group and composite executive function to predict accuracy on critical items. The overall

general linear model was significant, $F(3, 32) = 5.83, p < .01, R^2 = .35$. Both composite executive functioning z-score $F(1, 32) = 4.22, p < .05$ and age group $F(1, 32) = 10.08, p < .01$ predicted accuracy for critical items. There was no interaction between executive functioning and age group ($F < 1$). The relationship between executive function score and accuracy was the same within both age groups. Figure 8.2 shows a scatterplot of accuracy on critical items by composite executive score.

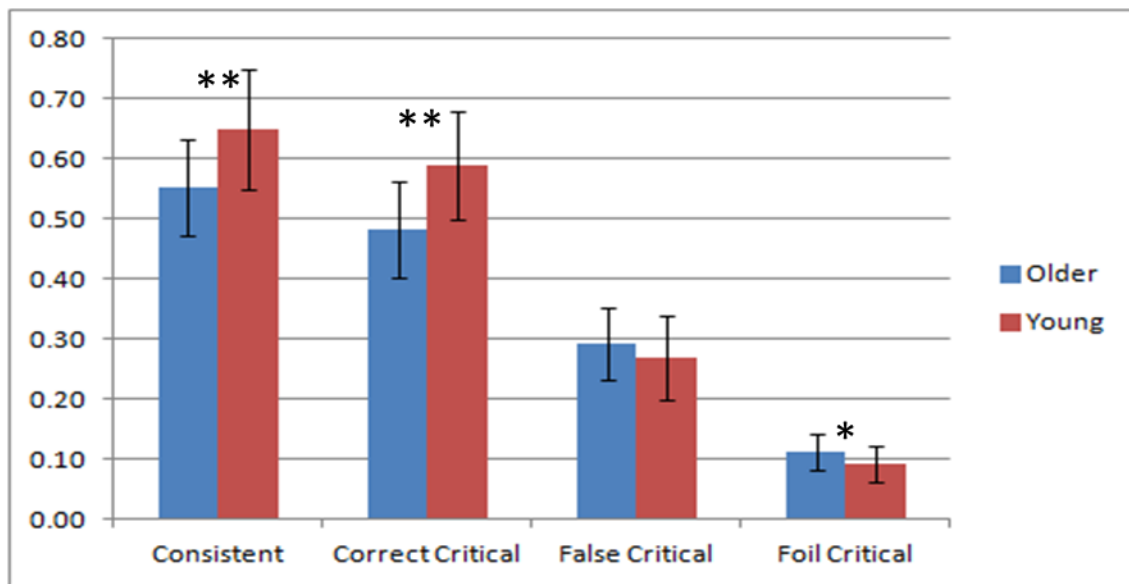


Figure 8.1 Accuracy on the recognition memory test. Consistent = proportion of time participants endorsed correct item. Original = proportion of time participants endorsed original event item on critical questions (accurate memory). Misinformation = proportion of time participants endorsed second, misinformation event item on critical questions (false memory). Foil = proportion of time participants endorsed foil item on critical questions. Error bars represent +/- 1 SE. * $p < .05$ ** $p < .01$

Functional Brain Data

Second-level group analyses were performed on a subset of 24 participants (12 per group) matched on accuracy for critical items, as discussed in the data analysis section. Results revealed, for both age groups, a significant relative signal increase on accurate critical trials compared against accurate consistent trials.

Table 8.1 Mean raw and standard scores for both age groups on the five measures used for the composite executive function z-score.

Test	Age group		Young	
	Older	Standard	Raw (SD)	Standard
SSP (Maximum 9)	5.24 (1.09)	0.21	7.47 (1.46)	0.67
SWM Errors (lower = better)	21.95 (16.23)	1.05	7.20 (6.58)	0.67
SWM Strategy (lower = better)	31.86 (5.44)	0.66	26.53 (5.62)	0.83
SOC Thinking Time (ms; lower = better)	2515.88 (3640.93)	0.13	743.13 (829.79)	-0.33
SOC Problems solved in minimum moves (Maximum 12)	8.48 (1.63)	0.44	9.33 (2.13)	-0.31
Average standard score		0.50		0.30

Note: SSP = Spatial Span; SWM = Spatial Working Memory; SOC = Stockings of Cambridge

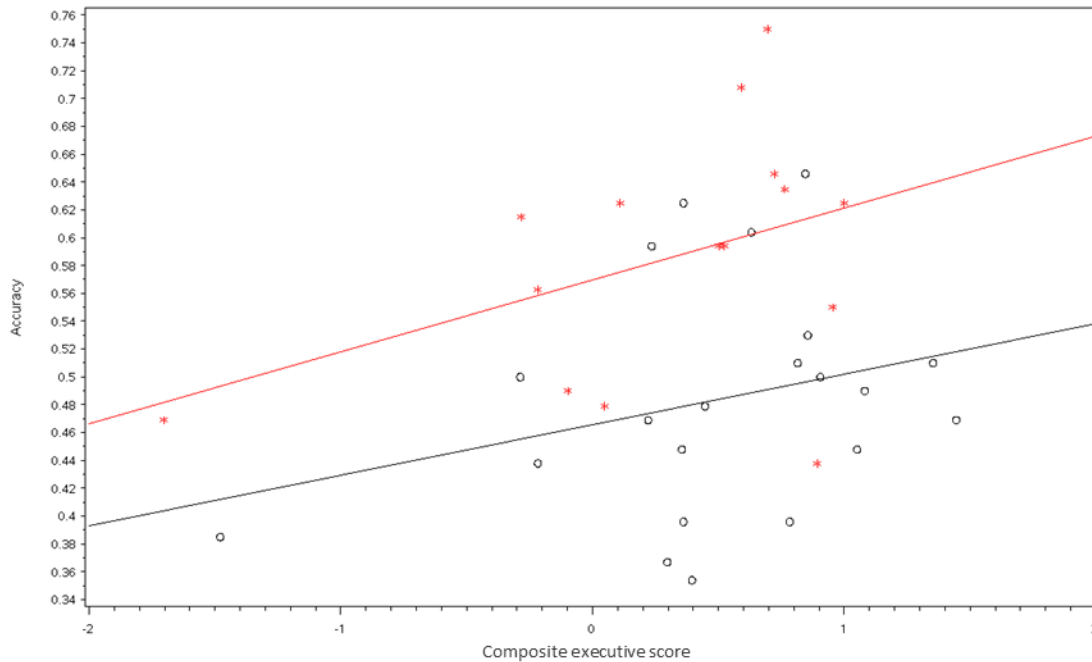


Figure 8.2 Scatterplot of accuracy on critical items by composite executive function score. Young adults' regression line and data points are shown in red, older adults in black.

For young adults, several clusters of activity emerged, most notably in right lateral parietal areas (BAs 39/40), right middle frontal gyrus (BA 9), right fusiform gyrus (BAs 37/19), and posterior cingulate (BA 23). For older adults, results were very similar with the exception of two clusters in left superior/middle (BAs 6,8,9) and inferior frontal cortex (BA 47). Table 8.2 reports cluster membership, MNI coordinates (x, y, z), region, and approximate Brodmann Area (BA) for each peak voxel within a cluster for the young and older groups separately. Figure 8.3 displays the results for both groups overlaid onto a brain representing the average of all 24 participants. The analysis revealed no significant relative signal increase on false critical trials compared against accurate consistent trials in either group. The analysis also revealed no significant relative signal increase on combined accurate and false critical trials compared against accurate consistent trials in either group.

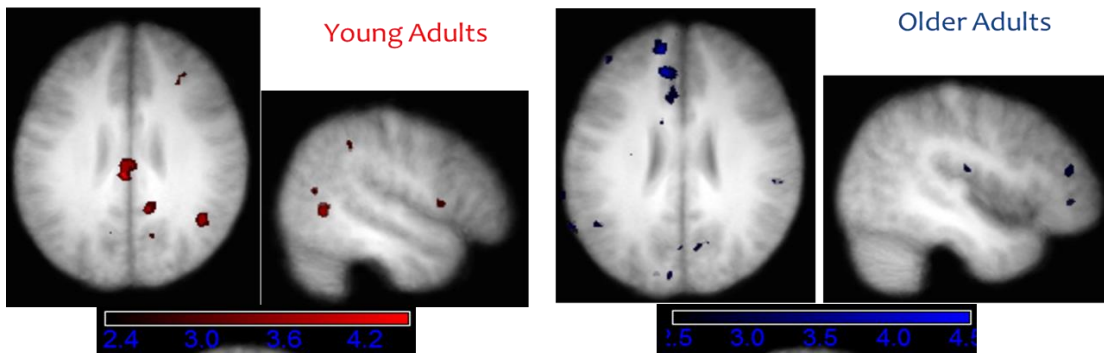


Figure 8.3 Areas showing a greater relative signal increase on accurate critical trials compared against accurate consistent trials. Thresholded at $Z > 2.3$, $p < .05$. Brain represents an average of all participants. Left – Young Adults; Right – Older Adults

Table 8.2 Results for accurate critical trials compared against accurate consistent trials.

Cluster	z-score	Coordinates (x,y,z)			Region	Approximate BA
Young Adults						
1	3.58	-2	-33	24	L/R posterior cingulate gyrus	23
2	3.73	11	-73	0	R lingual gyrus	18
3	3.64	54	-54	3	R fusiform gyrus	37/19
4	3.41	43	-54	29	R angular gyrus	39
5	2.99	58	-30	36	R inferior parietal lobule	40
6	3.03	28	29	28	R middle frontal gyrus	9
Older Adults						
1	3.91	-19	14	51	L superior/middle frontal gyrus	6/8/9
2	3.84	-64	-58	25	L fusiform gyrus	37/19
3	3.19	11	-71	34	L/R precuneus/angular gyrus	39/7
4	3.41	3	-94	22	L/R cuneus	18/19
5	3.49	-16	19	-25	L inferior frontal gyrus	47
6	3.07	44	41	18	R middle frontal gyrus	46
7	3.03	13	-98	-13	R lingual gyrus	17
8	3.35	-70	-32	23	L inferior parietal lobule	40
Older > Young						
1					L superior/middle frontal gyrus	6/8/9

A conjunction analysis combining both age groups for the accurate critical versus accurate consistent contrast revealed areas in right lateral parietal and right dorsal prefrontal cortex that were common to both the older and younger groups. These areas are highlighted in Figure 8.4. Examining the difference between groups for the accurate critical versus accurate consistent contrast (interaction), older adults had significantly more activity in a cluster in left superior/middle frontal gyrus (BAs 6, 8, 9; Figure 8.5; Table 8.2). This cluster in left PFC is contralateral to the right PFC areas present in the conjunction analysis (Figure 8.4). These left PFC areas were present in the main effect for the older adult group (as shown in Figure 8.3), but not in the main effect for the young

adult group. There were no areas where young adults had significantly more activity than older adults for this contrast.

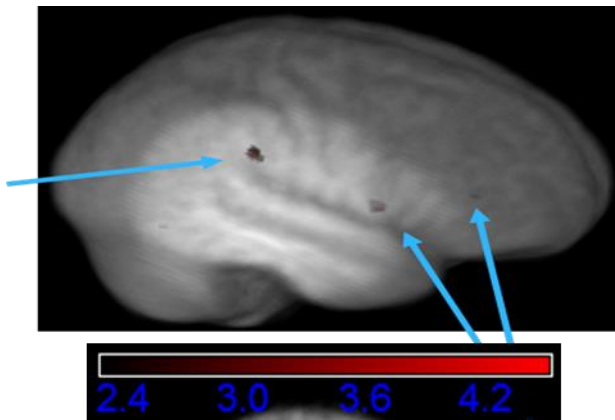


Figure 8.4 Results of conjunction analysis. Areas, in common to both groups, showing a greater relative signal increase for on accurate critical trials compared against accurate consistent trials. Thresholded at $Z > 2.3$, $p < .05$. Brain represents an average of all participants.

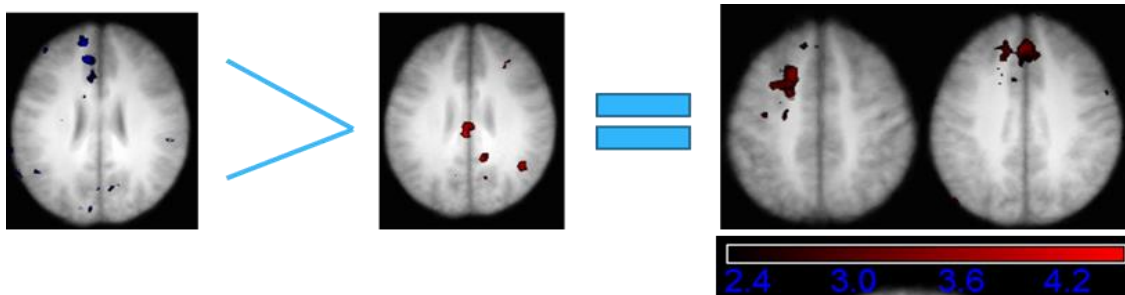


Figure 8.5 Areas showing a greater relative signal increase for older adults than young adults for accurate critical trials compared against accurate consistent trials. Left – Older adults' main effect; Middle – Young adults' main effect; Right – Significant difference between groups (interaction). Thresholded at $Z > 2.3$, $p < .05$. Brain represents an average of all participants.

Results also revealed a significant relative signal increase on accurate critical trials compared against false critical trials, in both age groups. For young adults, several clusters of activity emerged, bilateral posterior cingulate cortex (BAs 23, 31), bilateral anterior cingulate cortex/medial PFC (BAs 32/10), right inferior parietal areas (BA 40), and right middle occipital areas (BA 19). Results for older adults were similar. Older

adults did have a cluster of activity in left middle frontal gyrus (BA 10) not present in the young adults, but an analysis of the difference between groups for this contrast revealed no significant results. Table 8.3 reports cluster membership, MNI coordinates (x, y, z), region, and approximate Brodmann Area (BA) for each peak voxel within a cluster for both groups. Figure 8.6 displays the results for both groups overlaid onto a brain representing the average of all participants. A conjunction analysis combining both age groups for the accurate critical versus false critical contrast revealed areas in right lateral parietal and cingulate cortex that were common to both the older and younger groups. These areas are highlighted in Figure 8.7. There were no differences between groups for this contrast.

Table 8.3 Results for accurate critical trials compared against false critical trials.

Cluster	z-score	Coordinates (x,y,z)			Region	Approximate BA
Young Adults						
1	4.02	0	-30	28	L/R posterior cingulate cortex	23
2	3.65	25	-59	-14	R middle occipital gyrus	19
3	3.84	-32	-2	7	R insula	N/A
4	3.73	46	-29	16	R inferior parietal lobule	40
5	4.19	0	43	-6	L/R anterior cingulate cortex/medial prefrontal cortex	32/10
Older Adults						
1	4.46	1	-29	30	L/R posterior cingulate cortex	23/31
2	4.27	60	-24	14	R inferior parietal lobule	40
3	3.88	37	39	-4	L/R anterior cingulate cortex/medial prefrontal cortex	32/10
4	3.37	-43	46	12	L middle frontal gyrus	10

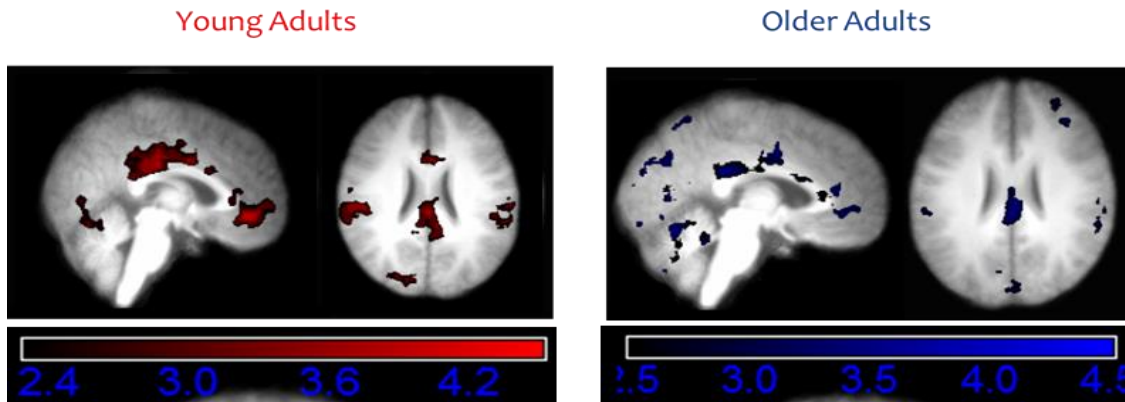


Figure 8.6 Areas showing a greater relative signal increase on accurate critical trials compared against false critical trials. Thresholded at $Z > 2.3$, $p < .05$. Brain represents an average of all participants. Left – Young Adults; Right – Older Adults

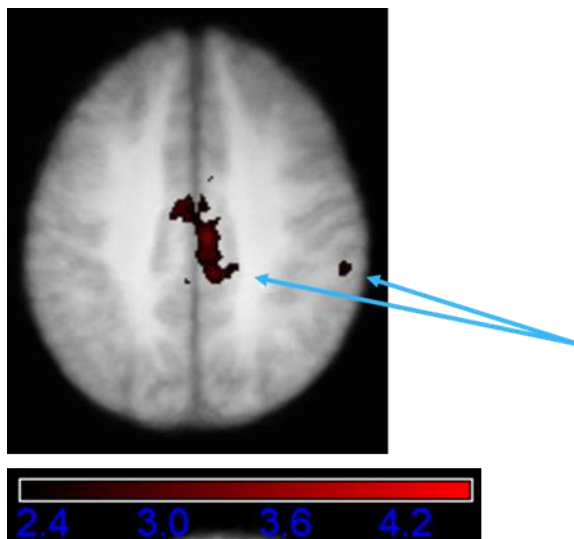


Figure 8.7 Results of conjunction analysis. Areas, in common to both groups, showing a greater relative signal increase for accurate critical trials compared against false critical trials. Thresholded at $Z > 2.3$, $p < .05$. Brain represents an average of all participants.

Functional ROI masks were created from the group results for predetermined regions. The anterior cingulate cortex (ACC) mask was created separately for the older and young adult groups based on peak of activity in ACC for both groups from the accurate critical item > false critical item contrast (see Figure 7.1 for example of mask).

The contralateral PFC mask was created for the older adult group based on peak of activity in contralateral PFC from the accurate critical item > accurate consistent item contrast (see Figure 7.1 for example of mask). Table 8.4 shows correlations between the percent signal change values, composite executive function z-scores, and accuracy for critical items. For ACC, collapsing across age groups produced extremely small correlations, thus correlations were looked at separately for the older and young groups. Due to the somewhat small sample sizes; only the correlation between accuracy on critical items and percent signal change in ACC for older adults was significant. Figure 8.8 shows a scatterplot of accuracy on critical items by percent signal change in ACC for older adults. Older adults did show a moderate positive correlation between accuracy on critical items and percent signal change in contralateral PFC. Figure 8.9 shows a scatterplot of accuracy on critical items by percent signal change in contralateral PFC for older adults. The correlations between accuracy on critical items, composite executive function, and percent signal change in ACC for young adults were both negative, explaining the very small values produced by collapsing across groups.

Table 8.4 Correlations between mean percent signal change, composite executive function score, and accuracy.

Region	Composite score	Accuracy (critical)
Anterior cingulate cortex (ACC)		
Older (n = 18)	.10	.56*
Young (n = 14)	-.21	-.19
Contralateral PFC		
Older	.08	.37

* $p < 0.05$

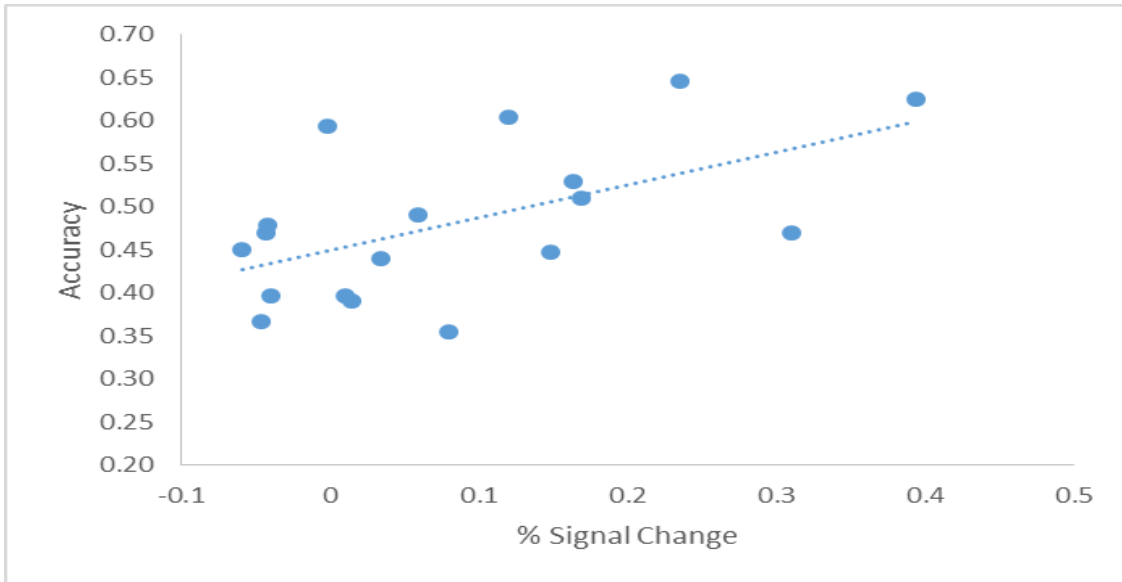


Figure 8.8 Scatterplot of accuracy on critical items by mean percent signal change in the ACC for older adults.

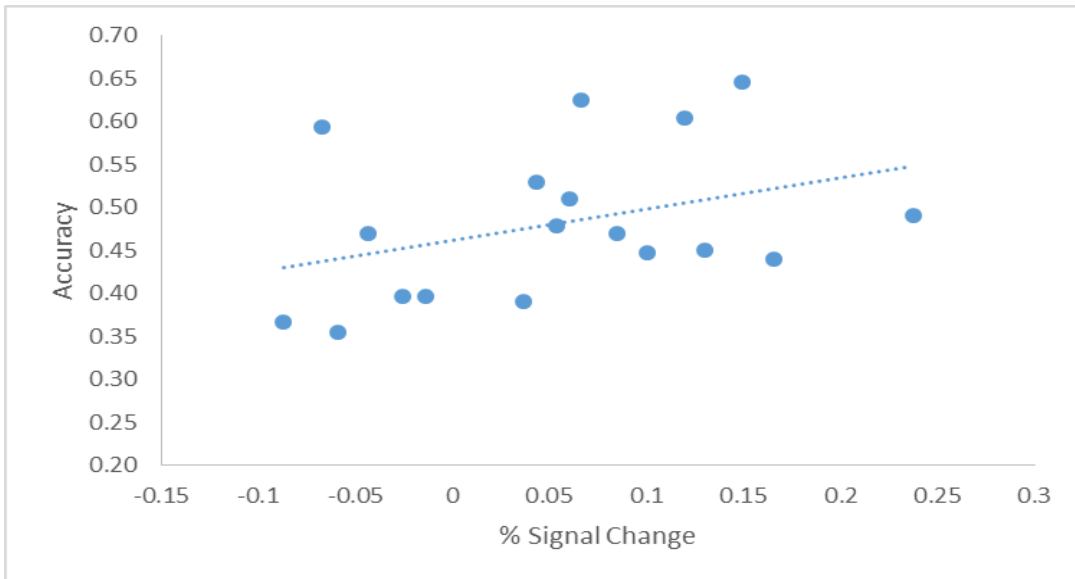


Figure 8.9 Scatterplot of accuracy on critical items by mean percent signal change in contralateral PFC for older adults.

Follow-Up Analyses

Previous literature (Robbins, et al., 1998) suggested that the five measures used to derive the composite executive function score loaded onto one factor. However, a post-

hoc factor analysis (within SPSS) of the five measures for the current dataset suggested that a three-factor solution fitted the data better than a one-factor (80% versus 34% of the variance explained, respectively). Table 8.5 displays the rotated (Varimax rotation) component matrix for the three-factor solution. Each component best represents the measures from each of the three CANTAB tests (SSP, SWM, SOC), suggesting they should not be combined into a composite score, as the literature originally suggested.

Table 8.5 Rotated component matrix for a three-factor solution of the five measures used to derive the composite executive function score.

Measure	Component		
	1	2	3
SWM Errors	.571	.501	.207
SWM Strategy	.058	.944	.108
SOC Thinking Time	.754	.310	.038
SOC Minimum Moves	.908	-.119	.010
SSP Span	.056	.131	.986

Note: SWM = Spatial Working Memory; SOC = Stockings of Cambridge; SSP = Spatial Span

We ran three additional separate regression analyses (within SPSS) using the age-adjusted z-score measures from each factor, along with age group, as predictor variables. Only the measures comprising SWM were significant and as such, only the results of that regression analysis are presented here. The overall model was significant, $F(3, 31) = 10.914, p < .001, R^2 = .51$. SWM errors z-score, $\beta = .51, t(32) = 3.44, p < .01$, SWM strategy z-score, $\beta = -.28, t(32) = -2.05, p < .05$, and age group, $\beta = .76, t(32) = 5.51, p < .001$ all significantly predicted accuracy for critical items. Figures 8.10 and 8.11 contain scatterplots of accuracy on critical items by SWM errors z-score and SWM strategy z-score. SWM errors z-scores and SWM strategy z-scores were fairly normally distributed with no large outliers. The general linear model (within SAS GLM) was used

to test for the interaction between age group and SWM errors z-score and between age group and SWM strategy z-score. There was no interaction between SWM errors and age ($F < 1$) or between SWM strategy and age ($F < 1$). The relationship between these variables and accuracy was the same within both age groups.

Given the results of the factor analysis and new regressions, additional Pearson's correlations were computed between mean percent signal change values and the two measures from the SWM. Table 8.6 shows these new correlations. Correlations between composite executive function scores and mean percent signal change values were small, especially for the older adults. Correlations between the two SWM measures and mean percent signal change values were much higher for the older adults. The correlation between percent signal change in the ACC and SWM errors was quite large and significant.

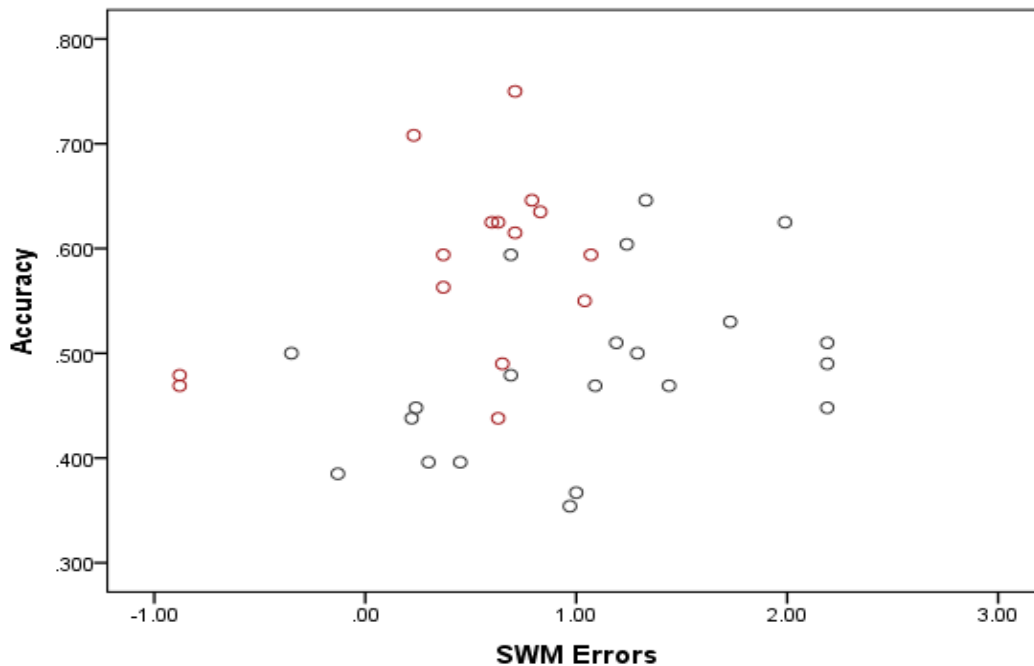


Figure 8.10 Scatterplot of accuracy on critical items by SWM errors z-score. Young adults' data points are shown in red, older adults in black.

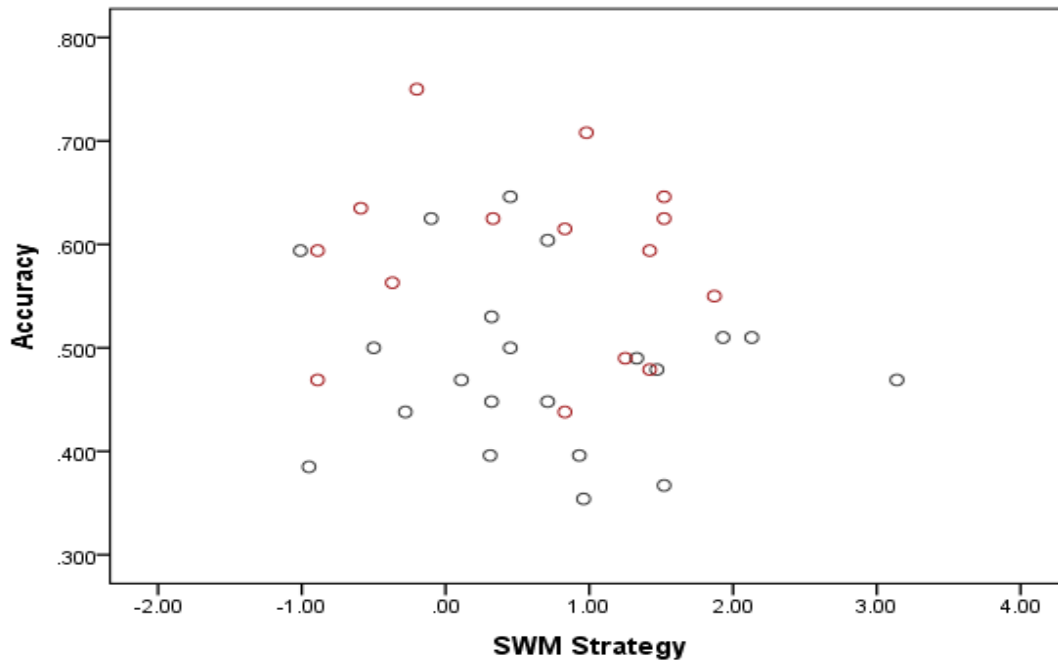


Figure 8.11 Scatterplot of accuracy on critical items by SWM strategy z-score. Young adults' data points are shown in red, older adults in black.

Table 8.6 Correlations between mean percent signal change, SWM errors z-score, and SWM strategy z-score.

Region	SWM Errors	SWM Strategy
Anterior cingulate cortex (ACC)		
Older (n = 18)	.56*	-.22
Young (n = 14)	-.03	-.04
Contralateral PFC		
Older	.28	-.13

Note: Measures are age-adjusted z-scores; SWM = Spatial Working Memory

* $p < 0.05$

CHAPTER 9 DISCUSSION

Behavioral Findings – Research Question 1

Accuracy results supported the main behavioral hypothesis (Hypothesis 1), as age and executive function were both predictors of endorsement of the original event items on critical questions. There was no interaction between age and executive function, suggesting that the relationship between executive function and accuracy was not different for older and young adults. Although the intent of the current work was to use a composite executive function score, a post-hoc factor analysis suggested the measures used for the composite were best explained by three factors, each representing a separate CANTAB test. Thus, it may be best to look at the contributions of these tests separately rather than as a composite. Separate post-hoc regression analyses revealed that only the two measures from the Spatial Working Memory subtest were significant predictors of accuracy on critical questions. This is not entirely surprising given that the Spatial Working Memory subtest requires one to continuously monitor and update stored information, similar to what is required during the misinformation task. There was again no interaction between age and these measures. These results support those of Chan & McDermott (2007) and provide support for executive function as a general predictor of susceptibility to misinformation and not an age-specific mechanism. Individual differences in scores on measures of executive function cannot explain all of the variability in older adults' increased susceptibility to misinformation.

Across both age groups, the pattern of accuracy results was similar to previous work with this paradigm. Figure 9.1 shows the results from Okado and Stark (2005) side by side with the current results. Overall, the ratios of responses for young adults in the current study closely matched those for the participants (all young adults) in Okado and Stark. In addition to performing better on critical questions, young adults also performed better than older adults on control, consistent questions. In the original design of this paradigm by Okado and Stark, consistent information items were balanced for effort of recall by involving details that were less salient to the overall theme of the vignette (i.e. obscure details). This manipulation maintained effortful processing for both consistent and critical items, since critical items would theoretically create much larger demands on both long-term and working memory than consistent items. As such, it is not totally surprising that young adults would perform better on these items.

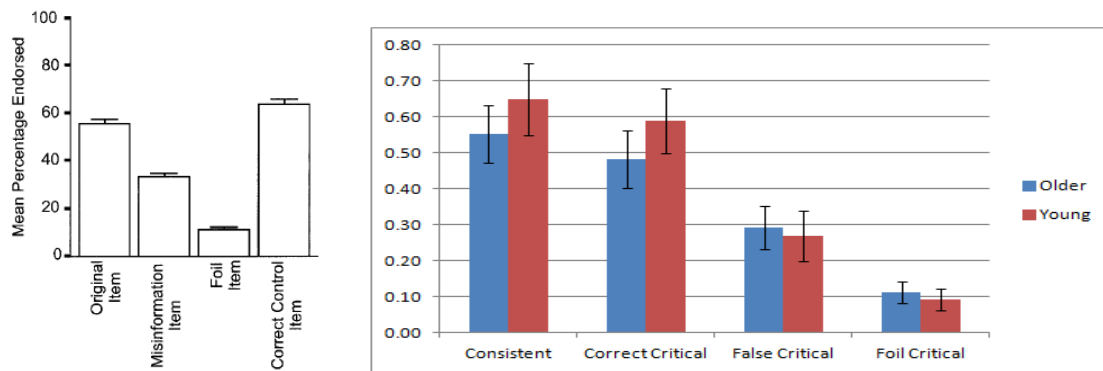


Figure 9.1 Endorsement rates for original, misinformation and foil items for critical items, as well as correct endorsement rate for control, consistent items. Left – taken from Okado and Stark (2005).

Functional Data Findings

Research question 2. Hypothesis 2a predicted that both accurate and false critical items would elicit more relative activity in medial PFC, left lateral PFC, and ACC compared with accurate consistent items, as participants attempted to resolve the conflict

between the two salient items in memory. Results provided some support for this hypothesis. A conjunction analysis combining the results for both age groups showed that activity in right lateral PFC was consistently greater for accurate critical items compared with accurate consistent items. Previous imaging studies of source memory and misinformation (Mitchell, et al., 2004; Mitchell, et al., 2006; Mitchell, et al., 2008; Okado & Stark, 2003) found the left PFC to be more active. However, Cabeza and colleagues (2000) found greater involvement of right PFC for a temporal order task. Responding to critical items in the current paradigm, in contrast to other paradigms, can be thought of as a temporal order task (i.e. which item did I see first?). Greater relative right lateral PFC activity for critical items over consistent items may reflect the temporal nature of the task. Neither age group showed greater relative activity in medial PFC/ACC for accurate critical versus accurate consistent items, contrary to what was predicted. The pattern of activity in both groups was more consistent with previous source/context memory studies (Cabeza, et al., 2000; Mitchell, et al., 2004; Mitchell, et al., 2006; Mitchell, et al., 2008; Okado & Stark, 2003; Petrides, 2002) and highlights the increase in retrieval difficulty for critical versus consistent items.

Hypothesis 2b predicted that the increase in the amount of specific information recollected during critical items would also result in more activity in lateral parietal areas. Results also provided support for this hypothesis. A conjunction analysis combining the results for both age groups showed that activity in right lateral parietal areas was consistently greater for accurate critical items compared with accurate consistent items. Greater involvement of lateral parietal areas reflects the fact that in determining temporal order, more specific information needs to be recollected, versus just determining whether

you saw an item at all. Although more frequently found on the left side, this finding is in line with previous studies (Mitchell, et al., 2008; Okado & Stark, 2003; Vilberg & Rugg, 2007). Both groups independently showed greater activity in fusiform gyrus for accurate critical items versus accurate consistent items. Hypothesis 2c predicted greater relative activity in this area for accurate critical items versus false critical items, indicative of *successful* resolution of response competition (Duarte, et al., 2010). It appears this area may be generally important for decisions involving competing items in visual memory.

Results supported Hypothesis 2c, in that for both age groups, accurate critical items elicited greater relative activity in ACC and medial PFC regions than did false critical items. These findings match closely with those of Duarte, et al. (2010) and suggest that participants were involved in resolution of response competition as they tried to decide between the original event item and the misinformation event item. Successful resolution of this conflict resulted in greater relative activity of these areas. Young adults also showed greater relative activity in extrastriate visual areas adjacent to the posterior inferior temporal areas found by Duarte and colleagues (2010). Recruitment of visual processing areas may contribute to successful resolution of competition between two visual items in memory. Both young and older adults showed greater activity in posterior cingulate cortex (Brodmann Areas 23/31) for accurate critical items compared to both accurate consistent and false critical items. Many previous neuroimaging studies have found that the posterior cingulate cortex is active during episodic memory retrieval (see Nielsen, Balslev, & Hansen, 2005 for a recent review), thus activity in this area is not completely surprising.

Research question 3. Hypothesis 3a predicted that older adults would show more activity than young adults in PFC regions, especially regions contralateral to PFC areas present in the conjunction analysis, for accurate and false critical items compared with accurate consistent items. Results provided support for this hypothesis. Older adults had significantly more activity in left superior and inferior PFC (contralateral to right PFC areas present in main effect for each group and conjunction analysis between groups) for accurate critical items versus accurate consistent items. There is much debate regarding the HAROLD pattern in older adults and what it means. The current results support a comprehensive model of the original HAROLD pattern recently proposed by Cabeza and Dennis (2012). Their model assumes that aging reduces available neural resources, which leads to a reduction in resources available for task performance and cognitive processing. Older adults try to reduce the mismatch between available processing resources and task demands by recruiting additional neural resources. Some older adults succeed and this recruitment enhances cognitive performance. In the current study, older adults faced high task demands during critical items. Those that succeeded in recruiting additional neural resources performed similarly to their young adult counterparts.

Hypothesis 3b predicted that for the accurate critical versus false critical contrast, older adults might show less activity than young adults in medial PFC, ACC, and posterior inferior temporal regions. Results did not support this hypothesis. There were no significant differences between groups for the accurate critical versus false critical contrast. The pattern of brain activity for the two age groups was very similar. This result is not completely surprising as the older adults who showed this pattern in Duarte, et al.

(2010) were chosen because they were “low-performers”. Matched on performance, older adults showed the same increase in activity in ACC/medial PFC for accurate critical items. These older adults experienced conflict between original event item and misinformation event item, similar to their young adults counterparts, and were able to successfully resolve it. Findings related to Research Question 3 fit closely with those of Morcom, et al. (2007). When matched on performance, older adults only show neural activity increases compared with young adults, and no neural activity decreases. While “low-performing older adults” may not show activity in conflict-related regions for accurate memory retrieval in false memory paradigms, this does not seem to be generally true of all older adults.

Research question 4. Hypothesis 4a predicted that task performance would be positively correlated with neural activity in ACC during accurate critical items (compared with false critical items) in all participants. Results provided some support for this hypothesis. Neural activity in ACC was significantly positively correlated with accuracy on critical items in older adults. The result in older adults suggests that the ability to successfully resolve the conflict between the original event item and misinformation event item was critical to task performance in this group. The lack of successful conflict resolution in the “low-performers” of Duarte, et al. (2010) most likely contributed to their low performance. Difficulty engaging in conflict resolution may have more to do with older adults’ increased susceptibility to misinformation than problems with source monitoring.

Surprisingly, neural activity in ACC was negatively correlated with accuracy on critical items in young adults (although not significantly so). This result was contrary to

what was predicted but makes sense in the context of the broader literature on episodic memory retrieval. An early finding in event-related fMRI studies of episodic memory retrieval was more activity in frontal regions during low-confidence accurate memory retrieval and less during high-confidence (Fleck, Daselaar, Dobbins, & Cabeza, 2006; Henson, Rugg, Shallice, & Dolan, 2000). In the same vein, young adults who found the retrieval task easier may have recruited fewer neural resources during completion of the items.

Hypothesis 4b predicted that task performance would be positively correlated with neural activity in contralateral PFC during accurate critical items (compared with accurate consistent items) in older adults. Results again provided support for this hypothesis. Neural activity in contralateral PFC was moderately positively correlated with accuracy on critical items in older adults. This result supports the frontal compensation model recently proposed by Cabeza and Dennis (2012). Older adults who succeeded in recruiting additional neural resources tended to perform better on the task and more recruitment led to better performance. Positive correlations between PFC activity and performance during episodic retrieval have been found before in the literature (Davis, Dennis, Daselaar, Fleck, & Cabeza, 2008).

Both Hypotheses 4a and 4b predicted that executive function score would be positively correlated with neural activity in both age groups. Correlations between neural activity and the composite executive function score were quite small in older adults; however correlations between neural activity and measures from the Spatial Working Memory subtest were much higher, providing further evidence that the measures used here should be examined separately. These results can best be understood in the context

of the frontal compensation model (Cabeza and Dennis, 2012), pictured in Figure 9.2. Those older adults who succeeded in recruiting additional neural resources demonstrated higher task performance as well as enhanced performance on cognitive measures. The relationship between cognitive measures and susceptibility to misinformation is most likely moderated by available neural resources.

The current work is one of the first to go beyond behavioral data and demonstrate a relationship between cognitive measures and task-specific neural activity in older adults. Recent studies have found correlations between cognitive measures and resting state functional connectivity in normal older adults and those with Parkinson's disease (Chou, Chen, & Madden, 2013; Olde Dubbelink, et al., 2013), and between measures of memory, verbal fluency, and naming and resting state glucose metabolism in temporal and prefrontal areas in those with Alzheimer's disease (Teipel, et al., 2006). The current work supports and extends these findings.

In young adults, neural activity in the ACC showed almost no correlation with the two measures from the Spatial Working Memory subtest. This subtest requires one to encode information and to retrieve, monitor, and update encoded information. It is possible that individual differences in young adults' abilities at *retrieval* are not as important in determining susceptibility to misinformation. Previous research has shown that young adults show an advantage over older adults in binding features together at encoding (Dennis & Cabeza, 2008; Grady, McIntosh, Horwitz, & Maisog, 1995; Mitchell, Johnson, Raye, & D'Esposito, 2000). If young adults have done a better job binding together item and context (i.e. original event item – original event; misinformation event item – misinformation event), conflict monitoring during retrieval

becomes less critical for task performance and as such activity in areas underlying conflict monitoring is not related to the cognitive measure.

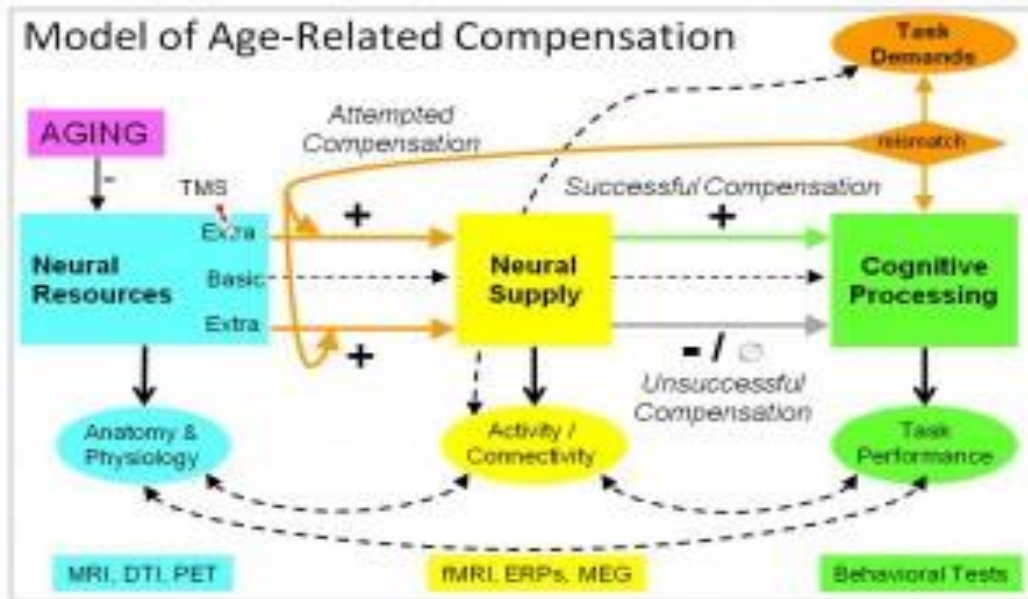


Figure 9.2 Pictorial representation of the frontal compensation model. Taken from Cabeza and Dennis (2012).

CHAPTER 10 CONCLUSIONS

The results of the current work have several theoretical and practical implications. From a theoretical perspective, this research may change how study investigators think about individual differences in susceptibility to misinformation. Studies have tended to look only at individual differences in older adults to understand susceptibility. The current work, in combination with Chan and McDermott (2007), urges future studies to look at these differences in all participants. These findings also highlight the need for longitudinal work. Do young adults with lower scores on measures of executive function continue to have lower scores as they age?

The current study was one of the first to investigate age-related similarities and differences in the neural correlates of accurate and false memory retrieval in a misinformation paradigm. The results of this work highlight conflict resolution as an important part of successful memory retrieval when presented with misinformation. Difficulties with conflict resolution may be a more critical part of older adults' increased susceptibility than general problems with source monitoring. The results of this work also underscore the importance of examining age-related differences in neural activity when performance is matched between older and young groups. Using matched performance ensures that any differences found relate to recruitment of neural resources for task completion, rather than simply task difficulty. Matched performance also made it

possible to then investigate meaningful correlations between neural activity and task performance.

Future work of this nature will involve extending the resting state findings discussed above. Along with the structural and functional MR scans acquired during the current study (described in the methods section), a resting state functional scan was also acquired on many of the participants. These participants also completed four subtests from an online working memory measure (WOMBAT) developed by Julia Englund and Dr. Scott Decker (Englund, 2013) at the University of South Carolina. A future goal is to look at relationships between all of these measures and resting state functional connectivity.

Practically, this research will help us to understand why some people, but not others, may be unreliable eyewitnesses in real-world situations. A small body of research has investigated how we can improve older adults' source monitoring abilities (Glisky, Rubin, & Davidson, 2001; Koutstaal, 2003; Luo & Craik, 2009; Naveh-Benjamin, Brav, & Levy, 2007; Thomas & Bulevich, 2006). These studies could be extended to investigate improvements in older adults' (and other age groups) conflict resolution abilities. Future work could also investigate changes in neural activity following paradigm manipulations designed to improve eyewitness memory accuracy.

Finally, previous studies using the same paradigm as the current work (Okado & Stark, 2005; Meek, 2012) used much longer delays (24 & 48 hours) between viewing of the event slides and the recognition memory task. A goal of future work is to investigate age-related differences with longer delay periods. A longer delay does increase task difficulty which may impact age-related differences. Additionally, Okado and Stark

(2005) investigate neural activity during the encoding period. Future directions should also include examining age-related differences during this period.

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APPENDIX A – TEST QUESTIONS USED IN THE STUDY

Vignette 1

What type of jewelry did the man find in the trunk?

Which shoe(s) did the man bend down to tie?

Approximately how far was the car parked from the tree in front of it?

What did the young man find in the purse that was inside the car?

What type of bills did the young man find in the change compartment?

After the young man opened the trunk, he thought he heard a noise and looked across the street. What did he find?

On which hand(s) did the young man accidentally slam the trunk on?

How did the man open the trunk?

What was in the bag that the young man found in the trunk?

What did the man take from the glove compartment?

What did the young man use to break into the car?

What did the man, in frustration, do to the car after he slammed the trunk on his hand(s)?

What university sticker was on the rear window?

When the man exited the car from the driver-side to head towards the trunk, what did he do to the door?

As the man ran away, what happened to his hat?

What did the man find underneath the sunshade?

What coins were in the change compartment?

What type of car was parked behind the car the young man broke into?

Vignette 2

What kind of soup did Rachel choose?

What color was the candle Rachel picked up and almost bought?

What did Rachel find in her shopping basket at the grocery store?

What store does Rachel shop at?

What kind of pasta did Rachel buy?

How much was the sandwich Rachel had made at the deli?

What color was the tissue box Rachel picked up?

On which shelf in her kitchen cabinet did Rachel find food?

Where does Rachel put her shopping bags in the kitchen?

How many eggs does Rachel buy?

In the fruit section, how many bananas did Rachel pick up?

What other fruit did Rachel select?

Which floor did Rachel take the elevator to?

What did Rachel pick up at the dairy section for her coffee?

In the vegetable section, what was the man next to Rachel holding?

When she first checked her refrigerator, what did she not have in it?

What was the aisle number Rachel chose to ring up her groceries?

When Rachel grabbed a number at the deli, what brand of chips are on the shelf nearby?

Vignette 3

Where did Jenny punch Dirk?

What type of phone did Jenny use to call for help?

Who accused whom of cheating?

What color were the chips that Dirk stole while Jenny was getting drinks in the kitchen?

When Jenny began to assault Dirk, what did Dirk do in response?

When Dirk saw that he had a flush, he bet five of what color chips?

When Dirk stood up as Jenny began to assault Dirk, what happened to Dirk's chair?

Who lost the first round?

After Jenny stopped kicking Dirk, she seemed:

Where did Jenny kick Dirk?

What did Jenny grab first before she left?

How much did Dirk and Jenny drink of their bottle after many hours into the game?

As Jenny walked down the stairs, what did she do with her hood?

Who dealt the cards in the first round?

When Jenny took the glasses to the kitchen, what did she do with them?

What did the poster by the sink say?

When Jenny checked on Dirk right before she left, what was Dirk's condition?

Dirk got a flush (cards all of the same suit) at one point. What suit was the flush?

Vignette 4

What color was the piano?

What shoulder(s) did Sam, the building monitor, carry his bookbag on as he walked across the courtyard?

How did R.J. (blue shirt) encourage Andy (plaid flannel shirt) to lie to Sam, the building monitor?

How did Sam get into the building?

What was the musician's reaction when Sam took him to the first room without a piano?

How did Andy express his nervousness after R.J. unplugged the copier?

When R.J. and Andy first arrived at the student group's cubicle, what did Andy do?

Was the girl friend who waved to Sam as she was entering another room wearing glasses?

Did Sam lock up his bike in the bike rack?

How much Pepsi was left when Sam took it out of his bookbag?

Which sign did Sam put up first when he left his desk to check out the copier?

What was Sam reading at the desk?

How does R.J. signal to Andy that it was safe to steal the monitor?

What did Sam do immediately after the witness told him what just happened?

What did Andy do when he passed by the witness to the theft?

Who signed the musician into the sign-in book?

How does Sam hold the phone when he's reporting the theft to security?

What was Sam's first approach to fixing the copier?

Vignette 5

Where was the repairman's number listed?

When the repairman arrived, which hand did he use to wave hello?

Which hand did the repairman use to turn off the monitor?

What did the repairman blatantly take out of the drawer?

What was in the hallway to the left of the lab after the repairman left?

When the repairman looked through the RA's wallet, what did he decide to take?

What time was the repairman supposed to arrive?

How did the repairman start working with the computer?

What was the first tool he used to work on the back of the CPU?

What did the repairman use to wipe his forehead?

While she waited for the repairman, what journal did the RA read?

Did the RA write in the journal?

Did the RA have the magazine she was studying with her after she greeted the repairman?

What was the color of the handle on the screwdriver?

What did the repairman specifically put into his toolbag?

When the RA returned to the lab, what was she carrying?

Where did the repairman put the item(s) he stole from the wallet?

Did the repairman say goodbye to the RA on the way out of the lab?

Vignette 6

Was Seth happy to see Christina when he first greeted her?

When Christina goes to the bathroom to freshen up, what does she do?

Was Seth's watch on his right or left wrist?

What advertisement was on the TV the first time Christina walks by it?

How did Christina greet Seth at the door?

When Christina goes to Seth's closet to get a sweater, is his closet door already opened or closed?

How does Seth react to the TV being turned off?

What does Christina do to the TV to get Seth's attention?

How does Seth help Christina at the door after he greets her?

When Christina is in Seth's room getting a sweater, what else does she do?

What painting was hanging above the desk in the hallway as Seth goes to open the door to greet Christina?

As Seth and Christina argue, and Seth begins to shout, what is Christina's reaction?

When Christina returns from Seth's room after getting a sweater, what does she find Seth doing?

Was the light on in the bathroom before Christina enters it?

After their argument, Christina is upset and decides to leave. What does she grab before leaving the apartment?

What is Seth's reaction when Christina indicates that she is cold?

After their argument, Christina is upset and decides to leave. How does she leave?

What was to the left of the fireplace?

Vignette 7

Which hand did the man use to steal the girl's wallet?

Where did the man put the wallet after he stole it from the girl's pocketbook?

What kind of store was to the left of the video store?

How did the girl say goodbye to her friend in front of the video store?

What movie did the girl purchase in the video store?

The man bumped the girl in front of a café. What did the café sign say?

From what direction did the man bump into the girl?

What kind of design was on her plastic video shopping bag?

As the man looked to cross the street, what was going on with the black car in front of him?

What did the girl's friend think of her movie choice?

What was wrong with the man's shoes as he bent down to help the girl?

What kind of beer truck drove through the lighted intersection?

What did the man place back into the girl's bag?

How did the girl realize that her wallet was missing?

When the girl first passed by the woman on the cell phone, what did she have to avoid walking on?

How did the girl thank the man for helping her pick up her things?

After the man bumped into her, what part of the girl's body was hurt?

Where was the man hiding after he stole the girl's wallet and crossed the street?

Vignette 8

How does Nicholas leave the classroom?

What was the color of the notebook Nicholas used to check the exam day for his friend, Frank?

What day was the exam going to be?

What kind of shirt was Nicholas' friend, Henry (curly hair) showing off?

From what direction did Henry come to say hello to Nicholas?

When Nicholas told his friend, Frank (buzzed hair) about when the exam day was, what was the Frank's reaction?

In what manner does Stephanie, Nicholas' girlfriend, react to Nicholas' question?

What section of the newspaper was Nicholas reading when he first got to the bench?

How was Nicholas sitting when he was writing his notes in the classroom?

What kind of shoes was Nicholas' girlfriend, Stephanie, wearing?

How did Nicholas react to seeing Stephanie?

While Nicholas and Stephanie were talking, who had to answer a call on their cell phone?

What was the study guide Nicholas was reading when his girlfriend, Stephanie, walked by?

What was Nicholas' t-shirt like?

Was there a water fountain in the building Nicholas was sitting in?

What class did Nicholas cross out in his daily planner?

What time was Nicholas' next Math class going to be?

What color was the post-it note Nicholas used to mark his place in the textbook?