AGE-RELATED DIFFERENCES IN THE RETRIEVAL AND

DEFINITION OF EVENTS FROM MEMORY

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ABSTRACT

Older adults often struggle to recall events from a specific time and specific place when presented with a cue word (Piolino et al., 2010). When they are able to successfully retrieve an event, they tend to recall fewer specific details, focusing instead on contextual and factual information (Levine, Svoboda, Hay, Winocur, & Moscovitch, 2002). These age differences are not relegated to the retrieval scenario alone; at encoding older adults also show differences in the way they segment ongoing information into discrete events (Zacks, Speer, Vettel, & Jacoby, 2006). The present work investigated age differences in the retrieval and definition of events from memory. First we delineated the age differences in neural activity during autobiographical recall. Second, we established how age alters event definitions during retrieval. Finally, we explored whether a more global change in event understanding could account for age differences in event memory. Our results highlight key differences in brain activity during autobiographical memory retrieval in the prefrontal cortex and anterior cingulate, and in the functional connectivity between these regions and the hippocampus. Further, our results demonstrate age differences in event definitions during perception and retrieval. We conclude by highlighting how these findings relate to the processes of memory retrieval and event segmentation.

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INTRODUCTION

My wife and I used to treasure our time with Grandpa during the last few years of his life, especially when he would tell stories from his childhood. As a chef, he could recall specific meals from various international journeys, along with a few classic stories, like the time he paid for his best friend's honeymoon (and then tagged along), or the time my wife drove past his exit and had to continue on the highway for an extra 20 miles to get him home. These specific episodes were important to his personal identity. In fact, specific events like these provide the basis from which we all determine who we are, and how we view the world around us. Yet specific episodes were not the norm for grandpa, and as he grew older, his stories seemed to focus on fewer and fewer specific events. While we could always cue the classics, his memories tended to focus on repeated events or entire life periods. He would tell of his time as a chef in France, or how he used to love to ski in Switzerland, both in rather broad terms.

Grandpa's reminiscing style was not abnormal for his age. Indeed, older adults show differences from younger adults in the way they perceive and retrieve specific events (Kurby & Zacks, 2010; Levine et al., 2002; Piolino et al., 2010). As we grow older, it becomes more and more difficult to retrieve specific events, and the specific events that are retrieved contain fewer details about that episode. Given the pivotal role event memory plays in understanding the world – from the identity we build based on our memories, to the relationships we define through common memories – the differences in event memory during normal aging may help inform clinical interventions in a wide variety of cognitive and behavior impairments in older adulthood.

Throughout the field of autobiographical memory research, individual characteristics that are related to poor memory performance have been of primary interest, particularly individual differences that influence event retrieval. Event memory deficits are observed in brain damaged patients (Hebben, Corkin, Eichenbaum, & Shedlack, 1985; Rosenbaum et al., 2008; Steinvorth, Levine, & Corkin, 2005), in patients with dissociative disorders (Kikuchi et al., 2010; MacDonald & MacDonald, 2009; Ross, 2009), in patients with depression (Sumner, Griffith, & Mineka, 2010), in patients with dementia (Gilboa et al., 2005; Meulenbroek, Rijpkema, Kessels, Rikkert, & Fernandez, 2010; Moses, Culpin, Lowe, & McWilliam, 2004), and as noted already, in healthy older adults (Gidron & Alon, 2007; Piolino et al., 2010; Ros, Latorre, & Serrano, 2010). In each of these populations there is a complicated interaction of biological changes, life changes, and identity changes that confound the central cause of poor event memory. Further, in each of these populations memory impairment is present even for events that were encoded prior to the onset of the memory deficit, highlighting the critical role of retrieval in proper event memory.

However, retrieval deficits cannot fully explain deficits in event memory. For example, in the earliest years of autobiographical memory research, age at encoding was investigated because it had been noted that adults struggled to recall memories from the earliest years of life (Crook, 1925). Since that time, childhood amnesia has been studied extensively, with many concluding that specific events prior to about three or four years of age cannot be recalled properly by adults, although the exact age boundary is still debated (Davis, Gross, & Hayne, 2008). Interestingly, this finding depends on more than the age at encoding. Recent work has shown that the propensity to recall early memories, and the age of earliest memory, also depends on the age of the subject at retrieval (Tustin & Hayne, 2010). That is, it appears adults have more difficulty retrieving early memories than children and teenagers, and children are able to remember events from an earlier age than adults. This finding highlights the complex interaction between variables at encoding and variables during retrieval, and also provides an example of the way age can influence the accessibility of memories through a variety of mechanisms. Aging can limit the accessibility of certain events at retrieval, and also limit an individual's access to details within a retrieved event. However, prior to exploring age differences in event memory in particular, it is helpful to put event memory in the context of a global framework of autobiographical memory.

A Framework of Autobiographical Memory

Although the extremes in event recall are quite interesting, a comprehensive theory of autobiographical memory must also account for the mundane events that make up our everyday lives. Within daily experience, there is a complex interaction between the way people perceive themselves, the way they *want* to perceive themselves, and the way they recall events from their lives. One model of autobiographical memory which attempts to account for these factors is the Self Memory System (SMS; Conway & Plydell-Pearce, 2000). Within this framework, as shown in **Figure 1**, Autobiographical Memory is understood to be a hierarchical system in which a person's self-perceptions and long term recall interact. At the top of this hierarchy is an individual's life story that is made up of specific lifetime periods, and those periods are composed of general events. These top components form the "conceptual self" (Conway, 2005, 597). The conceptual self constrains the way specific episodes are encoded and retrieved, while specific episodic memories and knowledge from life experiences constrain the way the self can be viewed. The self-images that flow out of this complex interaction are combined with an individual's personal goals and socially constructed schemas to define the self. The self then provides a framework by which people are able to understand who they are and how they relate to the world around them. At any given moment, a particular set of goals within the conceptual self will be active and influence the way the world is perceived and understood. This active self-image is termed the working self (Conway, 2005). It is thought that memories and ambitions play a crucial role in defining one's identity and that the working self influences the way memories are encoded and retrieved. Specifically, during retrieval the working self can constrain access to events, and can shift attention to those aspects of an event that are most relevant to personal goals. Thus memories, self-knowledge, and personal goals interact in working memory to maintain a coherent self that corresponds to the real world (Conway, 2005).

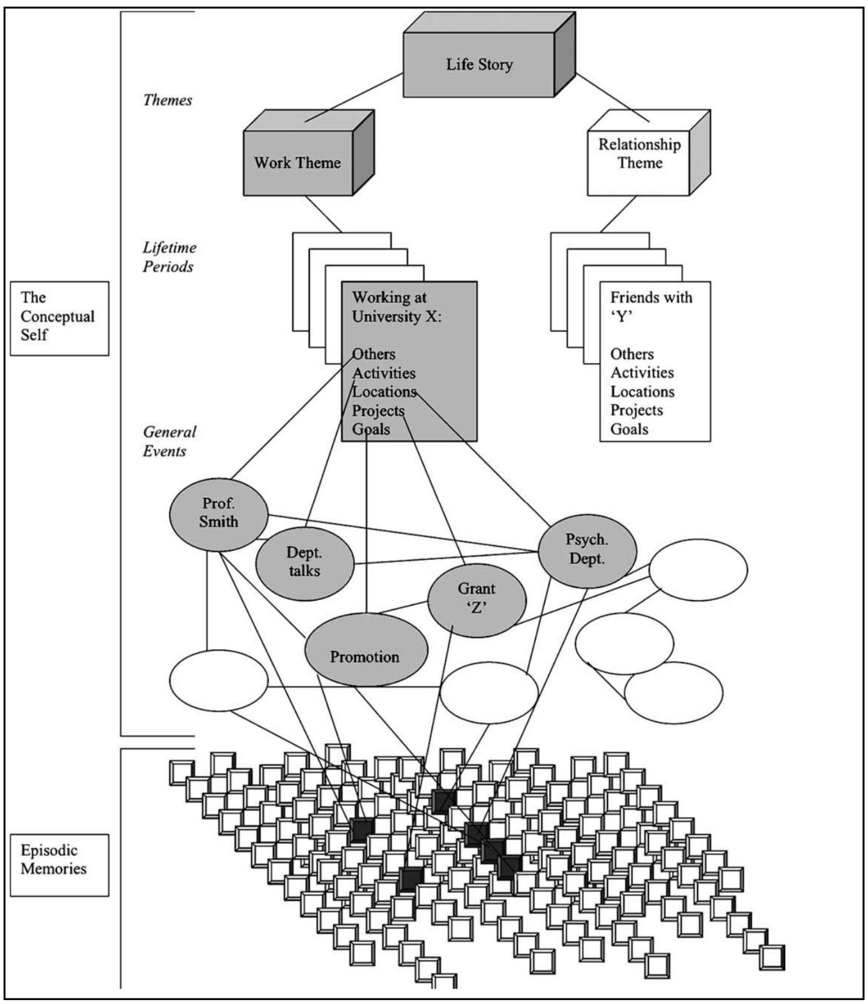

Figure 1: Conway, M. 2005. Knowledge Structures in Autobiographical Memory.

Age-related Differences in Autobiographical Memory and Overgeneral Recall

One of the most notable differences in the autobiographical memory system of older adults compared to younger adults relates to Conway's basic theory of event retrieval. He has proposed that when recalling episodic events, participants work their way down the SMS hierarchy eventually landing on a specific episode (2005). Interestingly, when compared to younger adults, older adults show impaired retrieval of specific episodes in response to cue words (Piolino et al., 2010; Ros et al., 2010). Older adults tend to report events that are non-specific, or “overgeneral”, rather than reporting specific episodes. It has been suggested that older adults work their way down the SMS hierarchy, but fail to move past the level of the general event (Williams et al., 2007).

In this dissertation, we concentrate on three possible explanations that may account for the differences in event memory during normal aging: a neural deficit that influences retrieval, a change in the strategic approach to event definitions during retrieval in older adults, or a schematic shift in the way events are perceived and understood in general. In order to investigate the first possibility, we aimed to delineate the neural differences in older adults that may be related to some of the observed differences in event recall. To address the second, we aimed to establish how these observed differences might be related to event definitions during retrieval. Finally, to investigate the third, we aimed to explore whether differences in event definitions are specific to event definitions in memory, or whether a more global change in event understanding could account for age differences in event memory.

Neural Differences in Older Adults and Autobiographical Recall

Normal aging brings about predictable and measureable neural differences that influence memory retrieval in general. For instance, healthy older adults show impaired frontal function and working memory that may also be the basis of overgeneral recall (Ros, Latorre, & Serrano, 2010). Dalgleish et al. (2007) argue that such higher-order cognitive decline, specifically deficits in executive control, lead to a deficit in the initiation of retrieval strategies during autobiographical recall. The term executive control will be used in this dissertation to highlight those aspects of executive function that relate to the initiation and maintenance of appropriate retrieval strategies, and the inhibition of interfering cognitive processes. In support of this hypothesis, healthy older adults show deficits in prefrontal function (Baena, Allen, Kaut, & Hall, 2010), and show gray matter loss in similar areas of higher-order function (Resnick, Pham, Kraut, Zonderman, & Davatzikos, 2003). The biological underpinnings of autobiographical memory have been investigated using a variety of methods (Cabeza & St. Jacques, 2007), and commonly activation in the prefrontal cortex and anterior cingulate are commonly observed, especially during event retrieval (Botzung et al., 2008).

In the present study, Experiment 1 investigated whether overgeneral memory is tied to neural differences between older and younger adults by looking at both brain activation and functional connectivity during autobiographical recall. If older adults are compensating for differences in executive control as a result of neural deterioration, there should be age differences in those regions that are shown to be involved in both executive control and autobiographical memory, specifically prefrontal and cingulate regions. In terms of the activation patterns, we expected to see reduced activation of these regions in older adults, and we expected to see decreased connectivity during autobiographical memory task performance between these regions and the hippocampus.

Changing Event Definitions

Conway has argued that the “short time slices of experience” that make up the base of his autobiographical memory hierarchy are defined at encoding based on the process of event segmentation (2009, p. 2306). This is based on the work of Reynolds, Zacks, and Braver (2007), who have suggested that cognitive models are used when perceiving ongoing activity and that, based on these models, people are able to make predictions about what is likely to occur next in a normal situation. As long as the predictions made are consistent with the ongoing activity, the entire sequence will be viewed as a single event. When something happens which the model does not predict, the action is segmented and a new event is encoded (2007). Other studies have demonstrated that this segmentation process is automatic and consistent from person to person (Zacks, Swallow, Vettel, & McAvoy, 2006), that poor segmentation leads to poor recall (Zacks, Speer, Vettel, & Jacoby, 2006), and that the segmentation process leads to better recall for details located at event boundaries (Swallow, Zacks, & Abrams, 2009). Thus, it appears that there is a way people perceive an event that is "normal" and that the segmentation process has an effect on long-term recall. In the same manner, Conway's (2009) framework posits that event definition takes place at encoding based on the elements present and a frame of understanding, which guides the process by which episodic memories are embedded within the autobiographical memory system.

Conway's framework does not leave room for changes in event definitions during retrieval. A host of work has shown how episodic memories (Tulving, Donaldson, & Bower, 1972) can change long after encoding is complete. The misinformation effect has shown that episodic memories can be altered at recall (e.g., Loftus, 1979a, 1979b), memory for pictures and stories become more schematized with repeated recall (e.g., Bartlett, 1932), and reconstruction has been identified as one of the basic principles that guide human memory (Surprenant & Neath, 2009). Recent work has also shown that stored memories are vulnerable to change at recall in a manner which influences all future recollections of that episodic memory (Hupbach, Gomez, Hardt, & Nadel, 2007). Conway, perhaps borrowing from Multiple Trace Theory and reconsolidation theory, which posit that memory traces can be altered during the retrieval process

(Moscovitch et al., 2005; Nadel & Moscovitch, 1997), explains these types of findings in relation to the activation of memory traces present during episodic retrieval. When an episodic memory is accessed the activation pattern present can be altered, but with time the activation/inhibition pattern becomes more difficult to alter, and thus the long term result is similar to that reported by the reconstruction literature (Racsmany & Conway, 2006). That is, events are originally defined at encoding and that definition is accessed and redefined at retrieval. Ultimately even this account relies on the initial encoding scenario as the baseline activation pattern that must be accessed, and thus maintains that there is some sort of event definition at encoding that dictates the size of an event in memory.

In daily life, it is rare that all episodic elements within an event are accessible at recall. Conway's participants, for example, lost the vast majority of detail and all ability to order events that took place on the walk from their dorm to the experiment after one week (Conway, 2005). Given the amount of change that can take place at recall, and the details that can be lost within even a week of episodic encoding, one must question how stable the original structure of an episodic memory is with time. When prodding college students for episodic memories from 8 different life periods stemming from one hour prior to recall to 15+ years prior to recall, it was found that the definition of an event was less stable as one moved further from the event (Hohman & Peynircioğlu, 2009). When there were accessible details outside of the originally perceived event, participants often would alter the placement of event boundaries for events that were a month or a year from encoding. Yet when more recent events were recollected, participants would rarely move the boundaries. What is interesting about this account is that the events that should have more stable event boundaries based on the activation/inhibition account above (those from more distant memories which have been schematized) in fact had less stable boundaries. This suggests that perhaps the recall of an "event" does not merely involve pulling out a predefined experience and recalling it, but rather piecing together available episodic elements and autobiographical knowledge as best as possible. Only subsequent to this process is an episodic memory defined.

Event Definitions during Retrieval

In the present study, Experiment 2 investigated whether the overgeneral tendency of older adults is also related to the way events are defined during retrieval. If event definitions rely on information available at recall, one would expect the boundaries of an episode to be the same at encoding and retrieval when the original boundary information is present at recall. When boundary information is not present (those specific perceptual details are not recalled) the boundaries at recall should be flexible because the event would need to be redefined in terms of available information. In such a scenario, the frames suggested by Conway (2009) merely provide a conceptual basis for reconstruction, rather than a storage site for multiple episodic elements.

Given the tendency of older adults to recall less specific episodes and fewer specific details, it would not be surprising to find they adopt a strategy in which events are defined in a vague manner, with boundaries that are more flexible during retrieval. The emphasis on details external to an event – rather than information specific to that event, as demonstrated by Levine et al. (2002) – should increase the odds that episodic boundary information will be absent at recall, thus forcing older adults to redefine events in a more arbitrary fashion. Consequently, in Experiment 2 we predicted that older adults would show more flexible event boundaries than younger adults regardless of time period.

A Schematic Shift in Event Definitions in Older Adults

Event definitions likely rely on event schemas at encoding and retrieval, as well as the use of retrieval strategies that emphasize the particular strengths of an individual. If overgeneral memory is related to a strategic shift in old age, age differences should not be observed on tasks that would force participants to use a more specific strategy. That is, older adults should be able to change their strategy when it is appropriate to do so.

Levine et al. (2002) found that when older adults were able to retrieve a specific episode, they were more likely than younger adults to give details that are external to that event. That is, their description of the event contained a good deal of factual information about people who were a part of the event, general facts about the location, contextual information, but much less detail about the specific happenings. It appears that older adults were unable to change their retrieval strategy and were in fact still recalling events at a higher level of the hierarchy. Conversely it may suggest that their concept of an event was in fact much different from that of younger adults. If this external focus is simply a reflection of a change in recall strategies, the bias should influence the way older adults understand events in memory, but it should not influence events at perception or initial encoding. A schematic shift on the other hand should influence events at both encoding and retrieval. Some recent work on event perception found that older adults actually perceived events in a way that was fundamentally distinct from that of younger adults, and had a long-term effect on memory (Kurby & Zacks, 2010).

In the present study, Experiment 3 investigated such possible differences in event schemas in order to clarify the role episodic elements play in event reconstruction, and identify any global differences in event definitions during normal aging. Sensecam technology was used to record an event at encoding and then to later test event definitions from both a subject's memory and from the Sensecam images. One prediction in the case of older adults, and in light of the expected age differences in Experiment 2, was that they should also be able to make use of Sensecam images in a manner similar to younger adults. Thus, if flexibility of event boundaries is due primarily to a deficit in recalling episodic details, then age differences should evaporate when Sensecam images are presented during retrieval. If, however, age differences in event definitions at retrieval are due to a more general schematic shift, then age differences should be present even when Sensecam images are presented during retrieval.

To summarize, this work investigated the process of retrieving and defining events from memory. We investigated age differences at the neural level by comparing the activation patterns of older adults during autobiographical recall with the patterns in younger adults, and also established differences in functional connectivity during retrieval. We also investigated age differences in event definitions during retrieval, and the manner in which boundary cues act to curtail the observed differences.

CHAPTER 2

EXPERIMENT 1: AGE-RELATED DIFFERENCES IN BRAIN FUNCTION DURING AUTOBIOGRAPHICAL RECALL

Older adults often have difficulty retrieving autobiographical episodes from a specific time and a specific place when using cue words (Piolino et al., 2010). Additionally, when older adults do recall an event, it is more general in nature rather than focusing on one specific episode. The working hypothesis of event retrieval put forth by Conway (2005), suggests that an individual will work his way down the Autobiographical Memory hierarchy and eventually arrive at a specific event. Some have suggested that in the case of older adults, they follow the same retrieval strategy as younger adults, but are unable to reach the level of a specific episode (Williams et al., 2007 253).

Some have also suggested that this tendency to recall generalized events, termed “overgeneral” memory, may be due to differences in executive control that accompany normal aging (Ros et al., 2010). Executive dysfunction in older adults has been associated with differences in prefrontal function (Baena et al., 2010), and differences in episodic memory (Troyer, Graves, & Cullum, 1994). Further, the prefrontal cortex and anterior cingulate regions of the brain increase activity during autobiographical memory retrieval (Cabeza & St Jacques, 2007). Together these findings suggest that prefrontal and anterior cingulate function may be related to the retrieval outcomes observed in older adults.

In addition to the role of the frontal cortex during memory retrieval, Multiple Trace Theory suggests that the hippocampus is involved in both the encoding and retrieval of episodic memories regardless of their remoteness (Moscovitch et al., 2005). Indeed, during an autobiographical retrieval task, adults show hippocampal activation when recalling both recent and remote autobiographical events (Piolino et al., 2004) arguing in opposition to findings in the amnesic literature suggesting that the hippocampus is only involved in the storage of recent episodic memories (Squire & Alvarez, 1995). In addition, hippocampal activation during autobiographical retrieval appears to be part of a network of co-activation that involves both the prefrontal cortex and the hippocampus (Greenberg et al., 2005; Viard et al., 2007). This suggests that any change in prefrontal function may have downstream effects on hippocampal activation, and may best be detected by investigating the connectivity between these regions. Indeed, recent work has suggested that it is the connectivity between these regions that may begin to degrade during normal aging (St. Jacques, Rubin, & Cabeza, 2010).

The current experiment tested whether there are observable differences in brain activation patterns and functional connectivity between brain regions during autobiographical recall in younger and older adults. Differences in the brain activation patterns between younger and older adults were examined by contrasting autobiographical memory recall to a baseline resting state and to a semantic memory control task. Functional connectivity between the hippocampus and other brain regions were also assessed and compared between groups given the vital role the hippocampus plays in memory processing.

Based on differences in autobiographical recall with age, we hypothesized that older adults would have decreased regional brain activation and decreased functional connectivity between memory regions in the medial temporal lobe and the higher order regions involved in executive control. In particular, we hypothesized that older adults would show decreased activation in the anterior cingulate and prefrontal regions of the brain given the role these regions play in both executive control and autobiographical memory, and would also show decreased connectivity to the hippocampus.

Method

Participants

Participants were recruited from the community around Harbor Hospital in Baltimore, MD and from the American University campus community. Recruitment included 8 older adults (Mean Age = 66.62, Standard Deviation = 8.39) and 8 younger adults (M = 25.5, SD = 1.92). All participants provided informed consent, were screened for MRI safety and health, and were compensated at rate of $25/hour for their participation. Participants were excluded if they had any neurological disorders or dementia (self-reported). The local Institutional Review Board approved the research protocol for this study and informed consent was obtained for all participants.

Image Acquisition

13 subjects underwent scanning on a Philips 3.0 T MRI and 3 subjects (2 old, 1 young) were scanned on a Siemens 3.0T MRI. During the session, two structural scans were acquired. First, a three-dimensional T1-weighted image using a magnetization-prepared rapid gradient echo sequence (MPRAGE) with a voxel dimension of 1 x 1 x 1 mm^3, a repetition time (TR) of 6.8 milliseconds (ms) and a echo time (TE) of 3.2 ms. Second, a T2-weighted image along the anterior commissure/posterior commissure plane using a pulse-sequence with a voxel dimension of 1 x 1 x 1 mm^3, a TR of 3000 ms and a TE of 80 ms. Both the T1 and T2 images were used for segmentation and normalization procedures during image processing. The structural scans took approximately 20 minutes.

During functional scans subjects took part in a modified version of the Autobiographical Memory Test (AMT; Williams & Broadbent, 1986). A block design was used where two blocks of the autobiographical memory task and two blocks of the semantic control task were randomly

alternated with 5 blocks of a fixation resting condition. These 9 blocks would constitute a single run (**Figure 2)**. Each subject was given 5 runs of the task; each run was approximately 5 minutes in duration. Functional data was acquired using an echo planar BOLD sequence (3x3x3 voxel size, TR of 2000 ms, TE of 30 ms,
75^o flip angle).

Subjects were trained prior to scanning. For the autobiographical memory blocks, participants were given two cue words from the AMT, such as “happy” or “angry”, with instructions to recall a specific event from their past. An explanation of a specific event was given during the training session prior to scanning. Each cue word was presented for 30 seconds and subjects were asked to press a button when they had retrieved an event from memory. Once retrieved, participants were asked to think through the event from beginning to end performing a button press at the beginning and at the end to mark the boundaries of the event. Participants were asked to think over the same event a second time if the 30 seconds had not elapsed (the word was still on the screen) and to move on if the time elapsed prior to thinking all the way through the event (the word disappeared while thinking about the event). Following each AMT block, subjects were asked to rate how clearly they were able to visualize the event. Between each run, participants were asked to give a brief description of the events recalled during that run and asked to provide an approximate date for each event. This oral description was recorded manually to score whether or not the event was a specific episodic memory.

For the semantic control task, participants were presented with an object word (e.g., pencil) and were asked to think of generic descriptors of that type of object. Participants were asked to press a button for each descriptor that came to mind. There was one trial per block in both the semantic and autobiographical memory conditions.

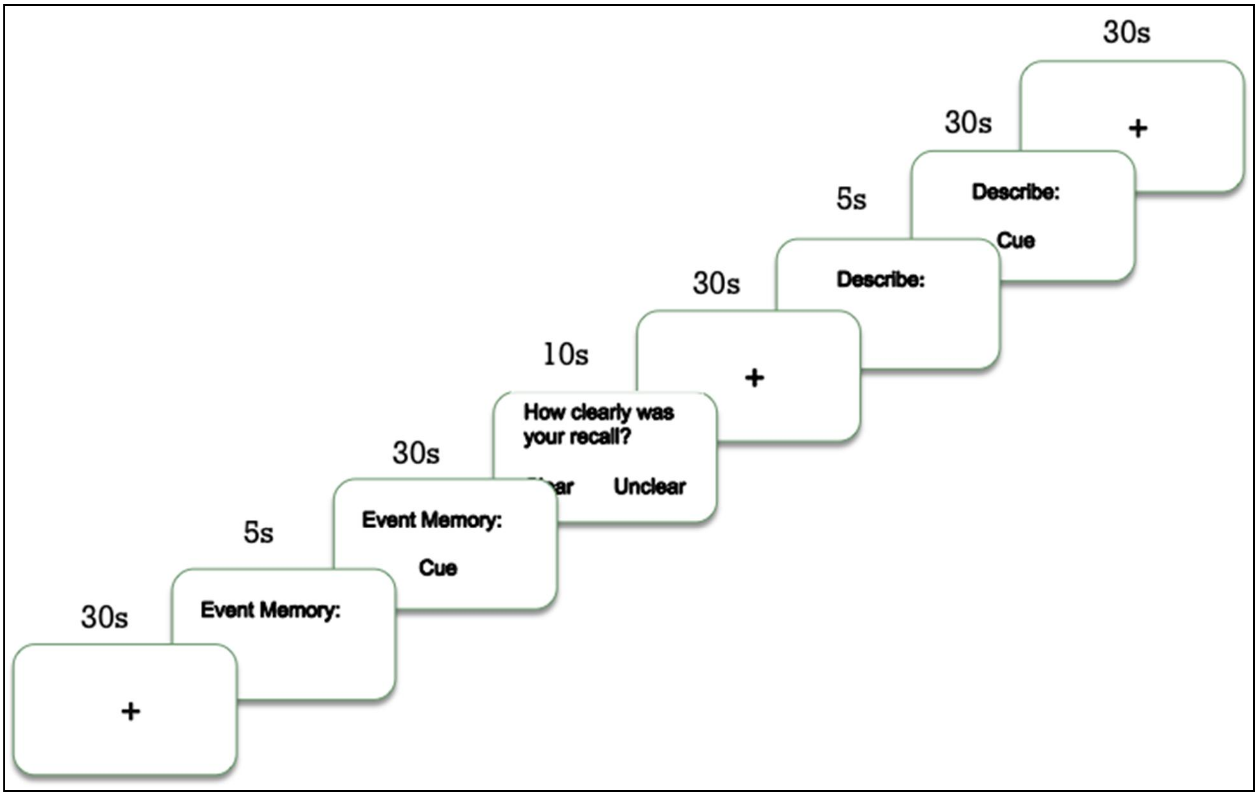

Figure 2: Stimulus Presentation Example Illustrating the AMT ('Event Memory') and Semantic Control ('Describe') Portions of the fMRI run

Image Processing

Images were preprocessed using SPM8 software (Wellcome Department of Cognitive Neurology, London, UK). Images were coregistered, spatially transformed into standard MNI space, temporally corrected for slice acquisition, and smoothed with an 8-mm Gaussian filter. Normalized images were used for first level (single subject contrast images) and second level (group contrast images) analyses.

For first-level analyses of brain activation, for each subject contrast images were generated that represented brain activation during the autobiographical memory task relative to rest, and brain activation during the semantic control task relative to rest for each subject. These contrast images were then brought up to second-level analyses for group comparisons. Second-level analyses utilized a full factorial model. The model included a group factor (young v. old), a condition factor (AMT v. Semantic), and a group by task interaction. We examined within group comparisons of autobiographical memory activation relative to rest, as well as autobiographical memory relative to the semantic control task. Finally, we examined the group x task interaction to identify differences in brain activation between younger and older adults for the autobiographical task relative to the semantic control task. All contrasts were generated using a statistical magnitude threshold of $p < 0.005$ and an extent threshold of $k > 50$ voxels.

For the functional connectivity analysis a seed analysis was performed using the Conn functional connectivity toolbox (http://web.mit.edu/swg/software.htm). For first level analyses, seeds were placed in the hippocampus bilaterally based on Regions of Interest (ROI) defined in WFU PickAtlas version 2.5 (Maldjian, Laurienti, Kraft, & Burdette, 2003) using the Talairach Daemon atlas (Lancaster, Summerln, Rainey, Feitas, & Fox, 1997) and r-values were calculated at each voxel in relation to hippocampal activity within each individual subject. These correlations were done based on raw activation maps prior to any contrasts. Based on these correlations, r-maps were calculated for each individual during autobiographical memory task blocks within each run; no contrasts were used for individual subject r-maps. The r-maps were then taken up to the second level to investigate differences in the functional connectivity of the hippocampus during autobiographical memory performance for younger adults compared to older adults. As in previous group comparisons, T-maps were corrected for statistical significance with a magnitude threshold of $p < 0.005$ and an extent threshold of $k > 50$ voxels.

Results

Behavioral Results

Reaction times and dates of events were not recorded for one older adult and one younger adult. As expected older adults reported a significantly greater number of overgeneral events than younger adults during scanning, $t(13) = 2.81$, $p = 0.008$, however for the imaging comparison, only runs with specific episodic memories were included in analyses. For the older adults, an average of 1.3 runs (out of 5) were thrown out for overgeneral memories or motion, while for younger adults an average of 1 run was thrown out for overgeneral recall or motion. On average, older adults also recalled events from the more distant past (older adults recalled events from on average 19 years prior to scanning while younger adults recalled events from on average 5 years prior to scanning, $p = 0.028$). Finally, older adults showed slightly faster retrieval time than younger adults when looking at those runs without overgeneral recall, $t(12) = 3.46$, $p = 0.004$, however this difference disappeared when including all memories in the reaction time comparison (on average younger adults recalled an event in approximately 25 seconds, while older adults recalled an event in approximately 23 seconds).

Autobiographical Activation Relative to Rest

To investigate activation related to autographical memory we first looked at the autobiographical memory task relative to rest within each group **(Table 1)**. In older adults, autobiographical memory retrieval was associated with a bilateral activation pattern including the dorsolateral prefrontal cortex, dorsomedial prefrontal cortex extending to the cingulate gyrus, the occipital gyrus, and lateralized activation in the right cerebellum and left midbrain. In younger adults autobiographical memory retrieval was associated with a similar bilateral pattern of activation in the anterior regions of the brain including the dorsomedial and dorsolateral prefrontal cortex and a more right lateralized pattern in the posterior regions of the brain.

When comparing autobiographical activation between younger and older adults (**Table 1)**, older adults showed more activation in the dorsomedial prefrontal cortex bilaterally, and in the left occipital gyrus, left superior temporal gyrus, and right inferior parietal cortex. Younger

Table 1 – Brain Activation During the Autobiographical Memory Task Relative to Rest

Region (BA)	Coordinate					p-value	Size (# of voxels)
	Side	X	Y	Z	t-value		
Older Adults							
Middle Frontal Gyrus (6)	L	-42	6	44	8.92	< .001	6113*
Middle Frontal Gyrus (6)	R	4	12	60	8.73	< .001	6113*
Middle Frontal Gyrus (6)	R	6	18	44	8.39	< .001	6113*
Superior Frontal Gyrus (10)	L	-34	50	20	4.87	< .001	305
Superior Frontal Gyrus (10)	R	28	40	26	5.43	<.001	217
Insula	R	38	18	8	5.66	<.001	211
Cerebellum	R	36	-68	-26	7.22	<.001	1112
Midbrain	L	-6	-24	-18	5.81	<.001	278^
Putamen	R	14	-2	0	4.36	<.001	278^
Inferior Occipital Gyrus	L	-26	-92	-2	9.54	<.001	1285
Inferior Parietal Gyrus	L	-48	-32	48	4.13	<.001	96
Younger Adults							
Middle Frontal Gyrus (10)	L	-34	52	14	6.56	< .001	493
Middle Frontal Gyrus (10)	R	30	48	20	5.25	< .001	154
Superior Frontal Gyrus (6)	R	4	12	62	9.57	<.001	3691
Inferior Frontal Gyrus (47)	L	-46	16	0	5.30	<.001	292
Inferior Frontal Gyrus (45)	R	30	26	4	6.33	<.001	63
Putamen	L	-24	24	2	4.75	<.001	59
Putamen	R	20	-2	-2	6.45	<.001	816+
Thalamus	R	16	-4	12	6.20	<.001	816+
Caudate	R	20	6	16	4.90	<.001	816+
Caudate	L	-16	0	18	6.09	<.001	738#
Thalamus	L	-16	-6	12	5.83	<.001	738#
Insula	R	44	14	2	4.17	<.001	96
Cuneus	R	16	-74	10	4.48	<.001	119
Cerebellum	R	32	-58	-28	7.99	< .001	664
Brainstem	L	-4	-24	-12	6.37	<.001	481
Old > Young							
Precentral Gyrus (4)	R	22	-18	50	5.71	<.001	260
Inferior Occipital Gyrus (18)	L	-28	-92	-2	4.71	<.001	389
Medial Frontal Gyrus (6)	R	14	-2	70	3.97	<.001	83
Medial Frontal Gyrus (6)	L	-10	2	56	3.59	.001	120
Superior Temporal Gyrus (42)	L	-64	-18	12	3.74	<.001	129
Inferior Parietal Gyrus (40)	R	38	-34	42	3.67	.001	54
Precentral Gyrus (4)	L	-40	-6	22	3.61	.001	59
Young > Old							
Cuneus	R	14	-74	10	4.61	<.001	971~
Lingual Gyrus	L	-20	-64	-4	3.82	<.001	971~
Caudate	R	18	14	14	4.23	<.001	195
Caudate	L	-12	10	12	3.49	.001	74

* ^ # + ~ Regions contained within the same cluster

adults showed more activation than older adults in the caudate bilaterally, the right cuneus and the left lingual gyrus.

Autobiographical Activation Relative to Semantic Activation

To investigate the activation related to autobiographical memory processes specifically, we contrasted the AMT activity to the semantic activity **(Table 2)**. Older adults showed increased activation during autobiographical memory performance in the left lingual gyrus and inferior occipital gyrus, the posterior cingulate bilaterally, and the right precentral gyrus. In line with activation reported in past studies (Svoboda, McKinnon, & Levine, 2006), younger adults showed increased bilateral activation in the inferior parietal lobe, the precuneus, the posterior cingulate, the midbrain, the anterior cingulate, and the middle frontal gyrus. When comparing the

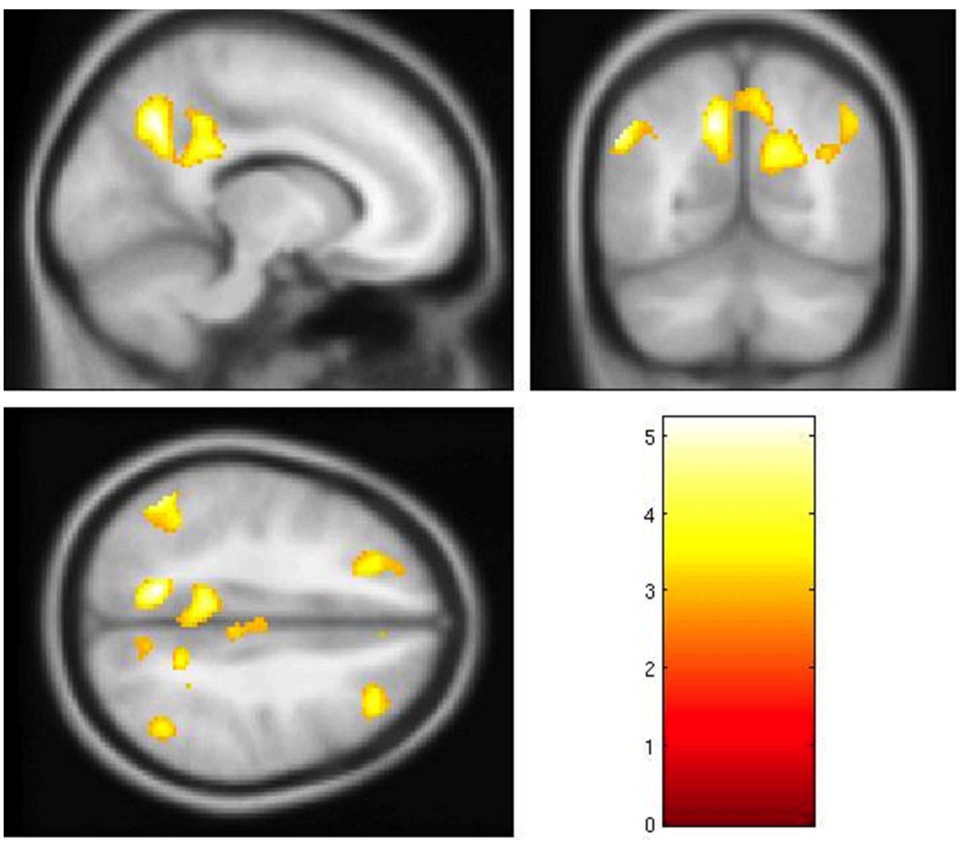

Figure 3: Age Effects during Autobiographical Memory Performance**.** Illustration of areas of greater activation in younger adults compared to older adults when contrasting autobiographical memory related activity to semantic control related activity. Colors represent T-value at that location. Slice coordinates (x, y, z): -10, -60, 35

activation pattern in older adults with the pattern in younger adults, younger adults showed more activation during the autobiographical task relative to the semantic control task in the normal autobiographical memory network including the posterior cingulate stretching to inferior parietal cortex, and the anterior cingulate stretching to the prefrontal cortex **(Figure 3)**. There were no areas of increased activation in older compared to younger adults.

Table 2 – Brain Activation During the Autobiographical Memory Task Relative to the Semantic Memory Task

Region (BA)	Coordinate					p-value	Size (# of voxels)
	Side	X	Y	Z	t-value		
Older Adults							
Lingual Gyrus (18)	L	-14	-84	-10	5.57	< .001	976
Posterior Cingulate (31)	L	-6	-58	28	4.53	< .001	718*
Posterior Cingulate (31)	R	10	-58	28	3.00	.003	718*
Precentral Gyrus	R	22	-18	50	4.12	< .001	66
Younger Adults							
Middle Frontal Gyrus (8)	L	-22	24	40	5.40	< .001	768
Middle Frontal Gyrus (8)	R	26	24	50	5.10	< .001	776
Inferior Frontal Gyrus (47)	R	32	20	-6	3.92	<.001	142
Inferior Frontal Gyrus (45)	R	20	56	12	3.91	<.001	1803#
Anterior Cingulate Cortex (32)	R	14	38	16	3.69	<.001	1803#
Superior Frontal Gyrus (8)	R	6	34	48	3.30	.001	70^
Superior Frontal Gyrus (8)	L	-4	28	50	2.95	.003	70^
Precuneus	L	-12	-60	34	9.17	<.001	9160+
Precuneus	R	12	-58	26	7.89	<.001	9160+
Supramarginal Gyrus	L	-50	-58	32	7.08	<.001	1617
Brainstem	R	2	-28	-16	4.10	<.001	342
Young > Old							
Middle Frontal Gyrus (8)	L	-24	32	38	3.73	<.001	145
Middle Frontal Gyrus (8)	R	36	32	38	3.87	<.001	329
Superior Frontal Gyrus (10)	R	22	60	22	3.42	.001	139
Anterior Cingulate	R	14	34	10	4.19	<.001	585~
Medial Frontal Gyrus (9)	L	-2	48	24	3.41	.001	585~
Medial Frontal Gyrus (8)	R	6	32	46	3.64	.001	131
Precuneus (7)	L	-12	-62	40	5.20	<.001	2555
Supramarginal Gyrus (40)	L	-52	-60	34	4.95	<.001	390
Angular Gyrus (39)	R	36	-66	28	3.59	.001	304
Caudate	R	12	-10	18	3.61	.001	
Old > Young							
No significant voxels							

* # ^ + ~ Regions contained within the same cluster

Functional Connectivity During Autobiographical Recall

Overall, across age groups the hippocampus was functionally connected to bordering regions within the medial temporal lobes, and to posterior regions of the brain including the posterior cingulate, cuneus, and cerebellum in both younger and older adults. Younger adults also showed regional connectivity with the frontal cortex that did not appear in older adults. Group comparisons confirmed that younger adults showed increased connectivity between the hippocampus and the prefrontal cortex compared to older adults **(Figure 4)**. There were higher levels of connectivity between the hippocampus and the anterior cingulate bilaterally, the middle frontal gyrus bilaterally, and the left superior frontal gyrus **(Table 3)**. There were no significant areas of increased connectivity in older adults compared to younger adults.

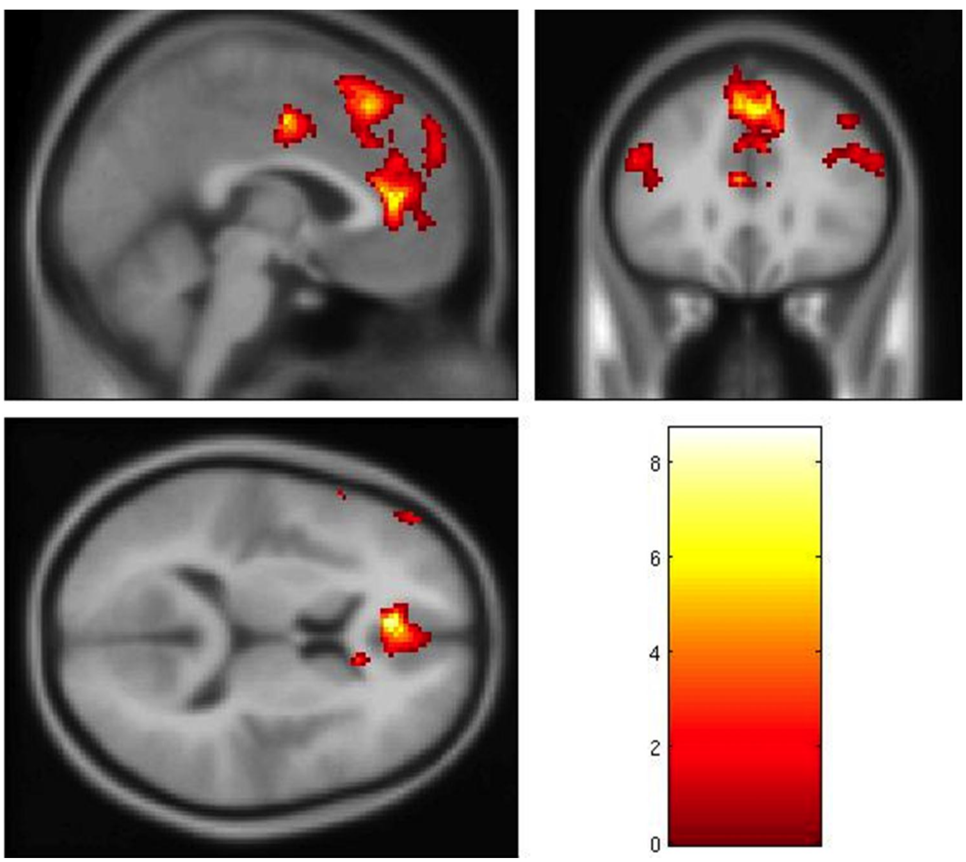

Figure 4: Age Differences in Functional Connectivity. Clusters represent areas which show increased connectivity to the hippocampus in younger adults compared to older adults during the autobiographical memory task. Colors represent T-value at that location. Slice coordinates (x, y, z): 0, 30, 16.

Table 3 – Hippocampal Connectivity during Autobiographical Memory Performance

Region (BA)	Coordinate				t-value	p-value	Size (# of voxels)
	Side	X	Y	Z			
Young > Old							
Anterior Cingulate (32)	L	-4	36	12	7.33	< .001	3765
Anterior Cingulate (24)	R	4	-10	38	8.64	< .001	372
Middle Frontal Gyrus (8)	L	-32	36	44	3.29	<.001	92
Middle Frontal Gyrus (8)	R	38	10	46	7.38	< .001	991
Middle Frontal Gyrus (8)	L	-32	10	50	3.14	<.001	92
Middle Frontal Gyrus (46)	L	-48	48	16	3.84	<.001	351
Superior Frontal Gyrus (8)	L	-24	46	40	1.41	.001	81
Old > Young							
No significant voxels							

* # ^ + ~ Regions contained within the same cluster

Discussion

As expected, older adults showed major differences in both the brain activation pattern during autobiographical recall and in the connectivity between regions within this memory network. Although both older adults and younger adults activated similar brain regions during autobiographical memory processes, differences in the magnitude of activation were observed between groups. The decreased activation in frontal regions and the decreased connectivity between the hippocampus and frontal regions of this network may contribute to the often-reported age differences in autobiographical memory performance (Ros et al., 2010).

Autobiographical Memory Activation Relative to Rest

We first investigated differences in brain activation during autobiographical memory task performance by examining task activation relative to rest within each age group. Contrary to our expectations, older adults showed increased activation in a variety of anterior regions including the dorsolateral prefrontal cortex. These areas included the medial frontal and precentral cortex, as well as posterior regions of the brain including the inferior occipital gyrus, inferior parietal gyrus, and the superior temporal gyrus. The older adults also exhibited a more bilateral pattern of activation during the autobiographical memory task in general. Some have suggested that this common finding of increased task activation in older adults may reflect compensatory changes at the neuronal level (Cabeza, 2001). Indeed, older adults tend to show a more bilateral pattern of activation than younger adults, and may also show a shift from posterior to anterior activation during cognitive task performance (Cabeza, 2002; Davis, Dennis, Daselaar, Fleck, & Cabeza, 2008). These findings suggest that older adults may rely less on the brain structures used for various tasks by younger adults and instead recruit additional regions outside the younger adult networks. This tendency may reflect compensatory brain changes, but almost certainly relates to a more general age-related degradation in the efficiency of normal neural networks (Dennis & Cabeza, 2010).

The activation increases in older adults compared to younger adults appear to be in areas that are active across memory tasks in other studies (e.g., St-Laurent et al., 2011) including the superior temporal, supplementary motor areas, and medial frontal regions, suggesting that these differences may be related to more general memory processing that is present in both the autobiographical task and control task in our sample. Further, and in line with Cabeza's observations, the pattern in the current sample is more bilateral than the typically left lateralized pattern reported in other studies across memory conditions. In particular the supplementary motor, precentral, occipital, and superior temporal activation may be related to the sensory processing within a range of memory task and may further suggest a generic difference in the neural activity related to the more basic aspects of memory. It is interesting that none of the regions of increase in older adults during the autobiographical condition relative to rest are in fact specific to the autobiographical memory task in either group (when performing task –

control contrasts discussed below). That is, although older adults are showing increased activation, it seems to be in brain regions that are not critical for the autobiographical memory task compared to other memory tasks.

The data from the autobiographical task relative to rest appear to reflect a more general increase in brain activity during memory performance. A similar pattern of activation increases during the semantic task suggests that older adults may have a more diffuse pattern of activation across both tasks. We further investigated this issue by directly contrasting the autobiographical and semantic tasks in the next section.

Autobiographical Memory Activation Relative to Semantic Control Task

We investigated the activation pattern specific to autobiographical memory by contrasting this condition with the activity during the semantic control task. In this case, younger adults showed an activation pattern that included the posterior cingulate, inferior parietal lobe, anterior cingulate, and prefrontal cortex, consistent with previous autobiographical memory experiments (Cabeza & St. Jacques, 2007). Interestingly, younger adults also showed greater autobiographical-specific activation in all of these areas relative to older adults, suggesting that younger adults selectively activate these regions during the autobiographical memory task relative to the semantic control task. Older adults, in contrast, showed very few regions that were uniquely involved in the autobiographical memory task alone. These results show that older adults exhibit a similar increase in brain activation during both cognitive tasks, and suggest that older adults have a more generalized as opposed to modality-specific pattern of memory related brain activation.

Our finding of reduced differentiation during memory processes in older adults is supported by recent work showing that the actual regional activation is preserved in older adults during episodic and semantic memory performance (with a similar trend toward increased activation in older adults), but that there are significant age differences in the relative differences between the various types of memory performance (St-Laurent, Abdi, Burianov, & Grady, 2011). This parallels our finding that age differences are most prevalent in the contrast between autobiographical memory and the semantic control task. Although older adults are able to activate the same brain regions, and often activate more regions, they are unable to selectively activate in a manner that may be critical for proper task performance, especially as retrieval difficulty increases, suggesting such differences may be more apparent when comparing overgeneral trials to successful trials. Future work will further investigate such a possibility.

Functional Connectivity during Autobiographical Recall

The age differences in task specific activation, especially in light of the executive deficits in older adults previously discussed, suggest that there may be subtle differences in role of the prefrontal cortex within the general network of autobiographical memory activation. Work by Greenberg et al. (2005) suggests that frontal and medial temporal activation show a functional relationship during normal autobiographical memory performance, and recent imaging studies of autobiographical memory suggest that there may be subtle age-related differences in functional connectivity between the prefrontal cortex and the hippocampus that relate to the performance differences observed between younger and older adults (St. Jacques et al., 2010). Indeed, work by Maguire and Firth (2003) has suggested that it is the engagement of the hippocampus within this autobiographical memory network that changes with age.

In order to further investigate the age differences in our sample and clarify the role of the prefrontal cortex within each age group, we looked at the functional connectivity between the hippocampus and all voxels in the brain during the autobiographical memory task. As expected, younger adults showed higher levels of functional connectivity between the hippocampus and the prefrontal cortex and anterior cingulate regions relative to older adults. This suggests that although older adults are able to activate frontal regions during the autobiographical memory task, this activation has a weaker relationship to activity within the hippocampus. This decrease in coupling between the medial temporal lobe and prefrontal cortex with age could be related to the dedifferentiation of frontal lobe activation across different memory tasks, or may also be related to structural changes in white matter tracts observed during normal aging.

Default Mode Network

Activation differences seen in the medial prefrontal cortex, medial temporal regions, and medial and lateral parietal regions in this study are considered to be components of the default mode network (Buckner & Carroll, 2007). This network has been described as a more general self-projection system that makes use of information in memory to imagine one's self in the past, present, and future. Indeed, these core regions have significant functional overlap with those seen in studies on navigation, theory of mind, imagining the future, and remembering the past (e.g., Spreng, Mar, & Kim, 2008).

The activation differences we are seeing in the current study may reflect a more general age-related difference in the ability or tendency to project the self within these various domains. In support of this possibility, the largest age-related differences in the current study are seen when contrasting the autobiographical task to the semantic memory task, suggesting the large "self" component unique to the autobiographical task may drive these differences. These findings are consistent with cross-sectional imaging studies which have observed lower levels of activation within the default mode network in older compared to younger adults (Damoiseaux et al., 2008). Therefore, it may be that our age-related differences reflect a change in the engagement of the default mode network during normal aging.

The connectivity differences we observe are also localized in the default mode network and further support the possibility of age-related differences in the engagement of this critical brain network. Indeed, older adults show lower levels of functional connectivity within the default mode network when compared to younger adults (Grady et al., 2010). Further, decreased functional connectivity in the default mode network has been directly related to white matter changes measured by DTI within this network (Greicius, Supekar, Menon, & Dougherty, 2009). Importantly, the DTI results highlight clear structural connectivity between the posterior cingulate and prefrontal cortex, as well as the posterior cingulate and medial temporal regions; however, structural connectivity between the medial temporal lobe and prefrontal cortex was not observed. This suggests that the functional connectivity differences seen in the older adults compared to the younger adults in our sample may relate to an age-related difference in the indirect structural connection between the medial temporal lobe and the prefrontal cortex. Future work implementing DTI measures and functional connectivity within older and younger adults may help to confirm whether these functional differences relate to an age-related change in white matter integrity.

Overgeneral Memory and Depression

The current findings highlight the neural deficits in frontal function during autobiographical retrieval in older adults, suggesting these differences may indeed play a role in the observed overgeneral memory. Similar deficits in frontal and executive function are present in depressed adults (Rogers et al., 2004), and have been implicated in the observed overgeneral memory within this population (Dalgleish et al., 2007). One possibility is that in both older adults and depressed adults, there is a cognitive shift in the way events are selected from an individual's life narrative during retrieval.

Carstensen's (e.g., 1999) Socioemotional Selectivity theory suggests that the selection of goals (a process that Conway has argued influences the selection of events in memory) is directly related to the way time is perceived by that individual. During the process of normal aging, individuals begin to perceive time constraints to their lifespan and goal selection begins to favor emotional goals rather than knowledge-related goals. In older adults, this results in a reduction in novel relationship and an increased emotional closeness in significant relationships (Carstensen, 1992). In addition, this difference in goal-selection has been implicated in the age-related differences in autobiographical memory, specifically in terms of a positivity bias, but more broadly in selecting events from which the individual is able to derive more emotional meaning (Cartensen, Fung, & Charles, 2003). Similar biases to emotional, and particularly self-relevant emotional events, have been demonstrated in depressed adults during an autobiographical retrieval task (Pyszczynski, Hamilton, Herring, & Greenberg, 1989) and reinforced by findings of mood-congruent findings in a variety of cognitive domains (e.g., Koster, Daedt, Leyman, & Lissnyder, 2008). Together, these findings suggest that there may be a similar emotional selection bias taking place in both older adults and depressed adults that leads to the same overgeneral recall tendency.

In order to clarify the role of both emotional selectivity and the neural differences in depression and older age compared to healthy controls, it may be useful to further investigate the activation patterns in each of these populations. One possibility, and a simple explanation of the finding in both populations, is that overgeneral memory is due to a single neural mechanism relating to the observed executive deficits in relation to autiobiographical retrieval (e.g., Ros et al, 2010; Dalgleish et al., 2007). Another possibility is that a selection bias in each of these populations, based on difference cognitive and neural mechanisms, ultimately leads to a similar change in autobiographical retrieval. The current results suggest that older adults show activation differences congruent with the an executive deficit during autobiographical retrieval, leaving open the possibility of a single mechanism of overgeneral recall, and suggesting this may be a good initial hypothesis for future work.

Reaction Time and Accessibility

The reaction time data present an interesting conundrum, as older adults in fact retrieved events at a faster rate than younger adults. The implication of such a finding is discussed in greater detail in the final chapter, however one possible interpretation related particularly to the argument in the present discussion is that the activation differences are not in fact due to an age-related difference in event accessibility. Older adults are showing the observed differences in brain activation even though they are accessing events at a faster rate. This may suggest that the age-related differences are due to the executive role in accessing specific details with events, rather than the executive role in search process per se. Indeed, St. Jacques et al. (2010) found that largest age-related differences in a similar task of autobiographical recall were present in the elaboration phase rather than the search phase. Although we were not powered to look at the two phases individually, the vast majority of time in both groups was spent in the search phase rather than elaboration, suggesting that elaboration may not have been driving the effect. Further, given that the reaction time difference was only present in successful retrievals, it is possible that it was due primarily to a selection bias based on the time restriction during this difficult autobiographical task. Currently we can only conclude that there seems to be some age-related difference in the frontal role in autobiographical recall, and that such a difference is present even when older adults are able to retrieve an event more rapidly than younger adults.

Conclusions

The current experiment supports the hypothesis of Ros et al. (2010) that overgeneral memory in older adults may be due in part to differences in executive control. Although the prefrontal cortex continues to activate during autobiographical memory tasks in older adults, there may be a decrease in the efficiency of the memory network that results in a decreased coupling between the prefrontal and medial temporal regions of the brain during complex memory tasks. The impairment in executive control thus may not be due to reduced activity in higher-order brain regions, but rather be due to a reduction in the top-down interaction between the frontal cortex and medial temporal lobe.

These results do not prove whether these differences in frontal function and connectivity actually result in overgeneral recall. For example, previous work looking at hippocampal connectivity during the retrieval of specific events compared to the retrieval of general events found that there were no significant differences in areas of co-activation (Addis, McIntosh, Moscovitch, Crawley, & McAndrews, 2004), suggesting that the differences in hippocampal connectivity in the present study may not lead to general rather than specific retrieval. The current experiment was not powered to look at the difference between general and specific recall separately within older adults, but future work will attempt to clarify the role of the differences observed between older and younger adults in producing overgeneral recall. Currently we can conclude that the increased activation in older adults during autobiographical memory relative to rest, and the lower levels of memory-specific activation in older adults during the autobiographical task relative to the semantic control task support the theory of a less efficient memory network in aging.

CHAPTER 3

EXPERIMENT 2: THE EFFECTS OF AGE ON BOUNDARY STABILITY IN AUTOBIOGRAPHICAL MEMORY

Events during perception are defined in a consistent manner from one person to the next. People use event models to make predictions about ongoing activity, and when these predictions fail, a boundary is placed to mark the end of one event and the beginning of another event (Reynolds et al., 2007). Conway (2005) has theorized that this type of event perception has an impact on the way memories are encoded, with differences in goal processing ultimately leading to the encoding of a new event in the autobiographical memory system. These events make up the bottom of the SMS hierarchy.

One possibility in opposition to this viewpoint is that boundaries in memory are not encoded, but rather are imposed ad-hoc after an event has been reconstructed. In such a case, one would expect boundaries to be quite variable depending on the time that has elapsed from action to retrieval. Work in our lab has previously shown that events that are closest to retrieval had boundaries that were quite rigid, even though information outside of those boundaries could be freely recalled. At the same time, boundaries were more flexible about a month from recall as the amount of detail within and around the event began to wane (Hohman & Peynircioğlu, 2009). From the data, it appears that event boundaries are most likely to be flexible when surrounding events can be recalled, but much of the specific detail about the event has been lost. As it becomes more likely that the perceptual boundaries have been forgotten, it becomes more likely that imposed boundaries will be moved. Although Reynolds et al. (2007) have shown that information at event boundaries is remembered at an improved rate over non-boundary information, at some point even those details begin to fade, and as they do, people are more likely to redefine where an event begins and ends. As long as surrounding information is present, the loss of episodic details should be directly related to increased flexibility scores, that is, an increased likelihood that event boundaries will be moved at recall.

Our aim in this experiment was to establish the ways the age-related differences in autobiographical recall, which have been demonstrated in behavioral and neural measures of function, relate to differences in event definitions during retrieval. As previously mentioned, older adults' memories typically contain fewer internal details about the event itself, and more external details about the context. Further, Experiment 1 has shown that older adults show differences in prefrontal activation during autobiographical recall, and that this decreased activation is related to a decreased coupling between the prefrontal cortex and medial temporal regions. Given the cognitive and biological data suggesting older adults struggle to retrieve specific episodic memories, older adults should be more susceptible to forgetting the perceptual boundaries of specific events. Thus we expected older adults to have more flexible event boundaries than younger adults when controlling for distance from recall.

As a secondary aim, this experiment attempted to clarify the roles of age at encoding and age at recall in defining events during retrieval. Previous work in our lab found that events from childhood were likely to be recalled without any memory of surrounding events, and without any boundary movement. By testing older adults, we were able to tease apart whether this finding was due to the distance from recall or the age at encoding. It may be that young children have not formed the necessary hierarchy to encode sequential events in relation to one another (Nelson & Fivush, 2004), in which case we would expect age at encoding to be the consistent factor between the two age groups that predicts this pattern of isolation and rigidity. It is also possible that as one moves farther from an event, it becomes more difficult to remember surrounding information, and to place that event in a hierarchical structure, in which case we would expect age at retrieval to best predict the pattern of isolation and rigidity.

Method

Participants

A total of 36 participants were recruited from the American University community and included 12 Older Age adults (Mean Age = 75.92, Stand Deviation = 4.25), 12 Middle Age adults (M = 46.83, SD = 4.21), and 12 College Age adults (M = 20.92, SD = 1.83). Older and Middle Age adults were compensated at a rate of $10/hour, and College Age Adults received extra credit for their participation as in Experiment 1 or monetary compensation at the same rate as the Older and Middle Age Adults. The local Institutional Review Board approved the research protocol for this study and informed consent was obtained for all participants.

Materials, Design, and Procedure

Following the Autobiographical Interview procedures (Levine et al., 2002), participants took part in three interview phases: a Free Recall phase, a General Probe phase, and a Specific Probe phase. College age participants were asked to recall an event from eight time periods spanning their life: Early Childhood (0 – 5 years), Childhood (6 – 11 years), Teenage Years (12 – 18), One Year Ago, One Month Ago, One Week Ago, One Day Ago, and One Hour Ago. Middle Age adults received those cues, and in addition were asked for two memories from Early Adulthood (19-30 years old). Older Age Adults received the cues of College Age adults and in addition were asked for one event from Early Adulthood (19-30 years old) and one event from Middle Adulthood (30 -55 years old). Older Age adults and Middle Age adults were asked to give only one event from Childhood (0 – 11 years old).

All participants completed the Free Recall and General Probe phases for each time period prior to going over each event a second time in the Specific Probe phase. During Free Recall, participants described a memory without any guidance from the researcher. The General Probe phase was used to help the participants move to an episodic memory if they had not given one. Finally, the Specific Probe phase included questions about the duration of the reported event, certain qualitative characteristics on rating scales of 1-6 (where 1 was low and 6 was high), and questions about event boundaries. The order in which the specific probes were given was randomized for each participant.

During the Specific Probe phase, the event boundary query comprised questions about what the participant considered the event boundaries to be (that is, what detail marks the beginning of the event and what detail marks the end of the event). Following these questions, boundary flexibility was probed by asking participants if they were able to recall details prior to the first boundary and after the end boundary (do you remember what happened before [the first boundary], do you remember what happened after [the last boundary]), and whether they would consider these new details to be part of the initially reported event (do you consider that to be part of the originally reported event). In addition to questions about boundary flexibility beyond event boundaries, participants were asked whether there was a natural beginning point after the initial reported boundary as well as a natural end point prior to the initial reported boundary. This allowed us to measure boundary contraction in addition to the boundary expansion. Finally a self-report of hierarchical structure was obtained by asking participants if the reported event was part of a larger, encompassing event, and whether the reported event contained smaller events of its own. All interviews were recorded via a Dell Inspiron 1420 laptop recorder, and interviews were later transcribed to allow for detail scoring.

Results

Boundary Scoring

All scores reflect the answers of the participants during the Specific Probe phase. Expansion Flexibility, Contraction Flexibility, Extra-Event Information, and Hierarchy scores are thus self-report measures reflecting perceived boundary locations and inter-event relationships. Expansion Flexibility scores reflect how participants moved event boundaries and were scored on a 3-point scale. A score of zero indicated that the participant did not include any details recalled prior to the first boundary or after the last boundary as part of the originally reported event. A score of one indicated that the participant included information in one direction and a score of two indicated that the participant included information in both directions. Half of the reported events showed a flexibility score greater than zero. The Contraction Flexibility score was also on a 3-point scale and reflected whether or not participants were able to shrink the event by redefining the beginning or the end. A score of zero indicated the participant did not believe there was another meaningful beginning or end point within the event boundaries. A score of one indicated the participant was able to contract in only one direction. A score of two indicated the participant was able contract both boundaries, and thus define the event without the original boundaries.

Extra-Event Information scores refer to whether information just beyond event boundaries could be recalled at all. That is, this score reflects whether or not boundary movement was possible and is also on a 3-point scale. A score of zero indicated that no information on either side of the event could be recalled. A score of one indicated that information on only one side of the event could be recalled. A score of two indicated information on both sides of the event could be recalled. This factor was used primarily as a selection variable in that by looking at events based on the Extra-Event Information score, we were able exclude events in which it was impossible to move the boundary (a score of zero). The vast majority of events (83%) showed an Extra-Event Information score greater than zero.

Finally, Hierarchy scores refer to how participants viewed events in relation to other events (cf., Conway, 2005) and were also scored on a 3-point scale. A score of zero indicated there were no larger events that encompassed the reported event, nor were there smaller events that were contained within the reported event. A score of one indicated that there was either a larger event(s) or a smaller event(s) reported and a score of two indicated that both a larger and a smaller event(s) were present. All events showed a hierarchy score greater than zero.

There were also four self-reported measures of the subjective characteristics of memory that were scored on 6-point rating scales. There were significant differences in Visualization (Kruskal Wallis $\chi^2 = 10.95$, $p = 0.004$), and Importance during Retrieval (Kruskal Wallis $\chi^2 = 10.70$, $p = 0.005$) with Older Age adults reporting higher levels on each of these measures than Middle Age or College Age adults. There were no age differences in Emotionality or Importance during Encoding. Finally, duration was recorded in minutes based on a self-report of how many minutes of the event the participants believed they could recall. They were asked: "how long was the event in minutes, and how much of that do you have detailed recollection for in minutes?" Duration reflected the number of minutes of the event for which they had detailed recollection. There were no age-related differences in the reported duration of events.

Factors Related to Boundary Movement

To examine how our measures of interest related to event boundary movement, we applied a Generalized Estimating Equations (GEE) model with Time Period entered as the repeated index and included only those time periods that were used as cues in all three age groups (Childhood, Teenage Years, One Year Ago, One Month Ago, One Week Ago, One Day

Ago, One Hour Ago). The early childhood time period (0 – 5 years old), which was specific to College Age adults, was not used in analyses. We restricted the analysis to include only those events in which boundary movement was possible (Extra-Event Information score of 1 or 2). Flexibility scores were entered as the ordinal response variable, Age Group was entered as a between subject predictor, and Distance from Encoding was entered as a within subjects predictor. There was a main effect of Age Group (Wald χ^2= 10.68 p = 0.005), and a significant interaction between Distance from Encoding and Age Group (Wald χ^2 = 11.97, p = 0.003). As can be seen in **Figure 5**, in the case of Age Group, Older Age adults reported more flexible event boundaries than the other groups, with College Age adults reporting the least flexible event boundaries.

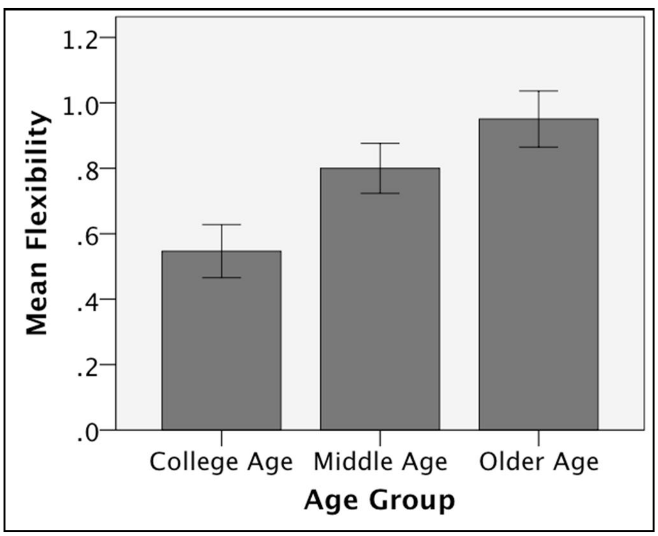

Figure 5: Boundary Flexibility as a Function of Age

Also, as shown in **Figure 6**, while both Middle Age and College Age adults showed increased flexibility with distance, Older Age adults' event boundaries did not become increasingly flexible with distance from encoding. Only when Older Age adults were removed from the analysis, was there a main effect of Distance from Encoding on boundary flexibility (p = 0.001).

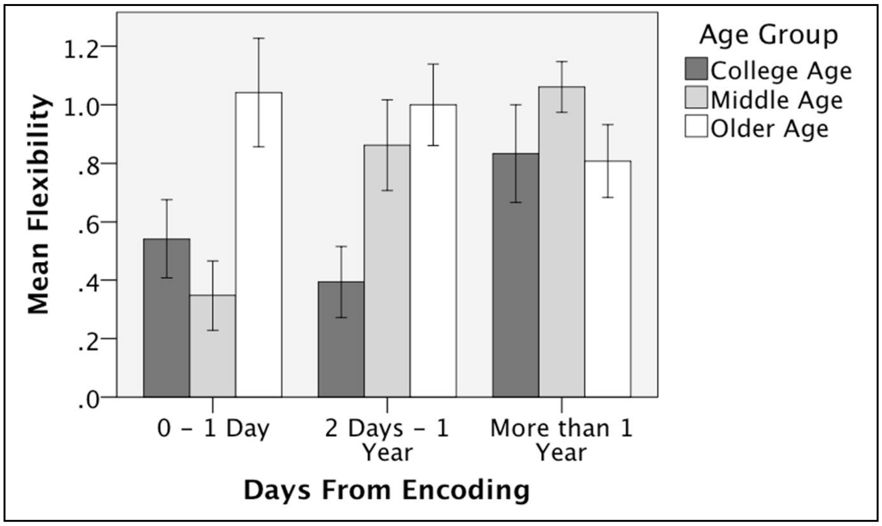

Figure 6: Boundary Flexibility as a Function of Distance From Encoding and Age

Dissociating the Effect of Time and Age at Encoding

In order to disentangle the effect of passage of time from that of age at encoding on the presence of extra-event information and on the isolation of the earliest events recalled, we looked at events from Childhood separately (for College Age adults we used the time period representing 6 – 11 years of age). If distance from encoding was the most critical factor in the observed differences for the most distant memories, then an age effect should be present. If the difference was primarily due to age at encoding, then the differences should be consistent from one age group to the next.

As illustrated in **Figure 7**, it appears that distance from encoding played a critical role in the observed differences. The effect of age on Extra-Event Information appeared to be graded from young adults to older adults, so a Jonckheere-Terpstra test was applied to test for an ordered effect of age group. Indeed, there appears to be an ordered effect of age group with College Age adults reporting more Extra-Event Information than Midde Age adults, and Middle Age adults reporting more Extra-Event Information than Older Adults, $JT = -2.06$, $p = 0.020$. An age difference was also present in the tendency to report events in the context of a hierarchical structure (Kruskal Wallis χ^2 (2) = 7.46, $p < 0.024$). Older Age adults reported significantly less Extra-Event Information than College Age and Middle Age adults, and they also reported fewer hierarchical relationships (Older adults (mean, *standard deviation*): 1.00, *0.57*, Middle Age Adults: 1.63, *0.50*, College Age Adults: 1.50, *0.52*). These finding suggests that age at encoding was not driving these differences in the young cohort from previous work in our lab (Hohman & Peynircioğlu, 2009). Instead, as time passes, it becomes increasingly difficult to remember information around an event and to relate an event to other events in memory.

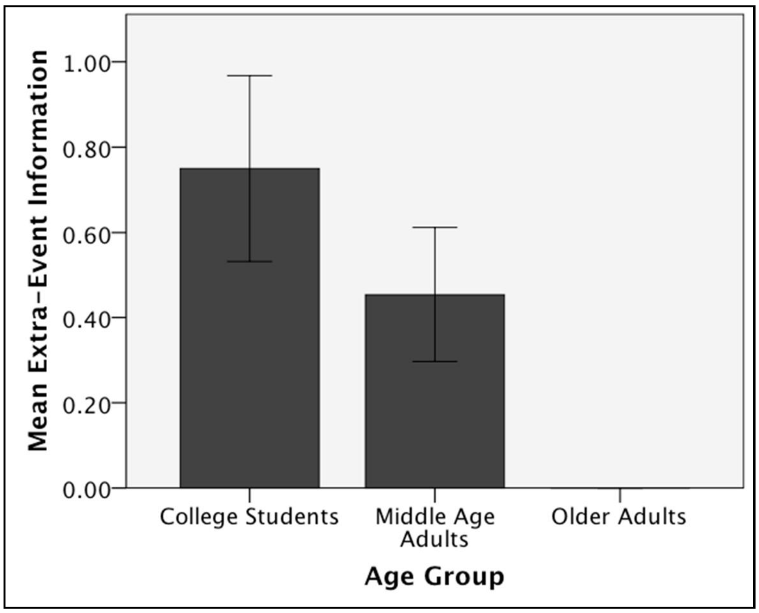

Figure 7: Age Differences in Observed Extra-Event Information for Events from Childhood

Time and Age on Extra-Event Information and Hierarchy

For the final analysis, we set Extra-Event Information as the ordinal response variable and inserted Distance from Encoding, Age Group, and an interaction term into the model. There was a main effect of Distance from Encoding (Wald χ^2 = 56.44, $p < 0.001$). There was also a significant interaction between Age Group and Distance from Encoding (Wald χ^2 = 16.78, $p < 0.001$), with College Age adults showing the steepest decline in extra-event information across Distance from Encoding and Older Age adults showing the most gradual decline. These differences make intuitive sense given the difference in range for Distance from Encoding between groups. In all cases, less Extra-Event Information was recalled for more distant events.

In the case of Hierarchical structure, Distance from Encoding and Age Group were entered as predictors along with the interaction term. There was a main effect of Distance from Encoding (Wald $\chi^2 = 8.83$, $p = 0.003$), with more distant events showing a less hierarchical structure, and Age Group (Wald $\chi^2 = 10.47$, $p = 0.001$), with older adults showing less hierarchical structure than younger adults. There was also a trend toward a significant interaction between Age Group and Distance from Encoding (Wald $\chi^2 = 5.61$, $p = 0.061$), with College Age adults showing a steeper decline in hierarchical structure across distance from encoding than the other two groups.

Discussion

The present experiment supported our original hypothesis that older adults would show more flexible event boundaries in memory due to the neural and cognitive differences during autobiographical retrieval. In addition, we replicated previous findings in our lab by showing that events in autobiographical memory display more flexible event boundaries as distance from encoding increases. For more distant events, participants were less likely to recall information beyond event boundaries, but were more likely to redefine events to include extra-event information when it was recalled. From these results, it is possible that boundary placement at recall is less reliant on factors at encoding and more akin to the processes involved in time estimation in memory. When estimating time across varying time scales, Friedman and Wilkins (1985) found that subjects were most accurate on fine time scales rather than coarse time scales, suggesting that instead of having time as an inherent attribute of a memory, participants inferred it based on the reconstructive process. In the same way, boundaries in memory may not be an inherent attribute of the memory trace, but rather may be imposed at recall based on the reconstructive process. Interestingly, in prior workings of his Self Memory System (SMS), Conway avoided predefined episodic events as memory units (Conway & Plydell-Pearce, 2000, p. 272). However, in the more recent versions of the SMS model, predefined episodic memories with clear boundaries based on the predominant goal lie at the foundation of the episodic hierarchy (Conway, 2005; 2009). Our data suggest that while processes at encoding play a crucial role in initial event definitions, memories may not be in a predefined form at recall.

Age and Distance from Encoding on Event Flexibility

Our data showed a significant effect of age on event flexibility. In general, Older Age adults were more likely than College Age adults and Middle Age adults to move event boundaries at recall and thus include extra-event information. Interestingly, Zacks, Speer, Vettel, and Jacoby (2006) reported differences in the initial segmentation of activity in Older Age adults when compared to College Age adults. The current data suggest that the same abilities that influence event segmentation at encoding may also influence event definitions at retrieval. Perhaps in both cases, an increased reliance on gist-based processes leads to less rigid event boundaries and less specific event definitions. This possibility will be further explored in Experiment 3.

Although Older Age adults showed more flexible event boundaries in general, they did not show increasingly flexible boundaries with distance from encoding. Whereas College Age adults and Middle Age adults showed increased flexibility with time, Older Age adults had high levels of flexibility for recent events and levels remained high for events throughout their lifespan. Indeed, the pattern shown by Older Age adults was very similar to the pattern in College Age adults for relatively unimportant events (Hohman & Peynircioğlu, 2009). One explanation for these findings is that both scenarios rely more heavily on gist-based reconstructive processes. In the case of Older Age adults, the decreased amount of event-specific detail at retrieval leads to gist-based reconstruction. In the same way, the less important events in College Age adults need only be recalled at the gist level and thus show a similar flexibility pattern to that of Older Age adults.

The higher levels of flexibility for recent events, and lower levels for distant events present in older adulthood is also consistent with the stereotyping that takes place with repeated reconstruction (Bartlett, 1932). For very recent events, gist-based reconstruction would decrease the likelihood of recalling the perceptual boundaries. Over long periods of time, however, a memory becomes increasing schematized, leading to a stabilized event recalled with consistent boundaries that do not rely on boundary information from the original encoding scenario.

Distance from Encoding on Extra-Event Information and Hierarchy

In line with previous results in our lab, we also observed a clear relationship between Extra-Event Information and Distance from Encoding. Participants were less likely to recall information beyond event boundaries for more distant events. Further, Hierarchy scores showed a similar relationship to Distance from Encoding. For the most distant events, participants were less likely to report a hierarchical structure. As previously noted, the differences in hierarchical structure and extra-event information may be due to the rather late development of autobiographical memory (Nelson & Fivush, 2004; Picard, Reffuveille, Eustache, & Piolino, 2009; Piolino, Desgranges, & Eustache, 2009). Children may not have the ability to encode sequential events into their autobiographical memory system in relation to one another, and for that reason each event may become isolated in memory. Conway (2009) suggests that in early childhood, episodic elements do not contain “frames” which would be the theoretical equivalent of the larger encompassing events in the current study. Perhaps, given the lack of full development of a “self” in children, the autobiographical hierarchy is not yet present at an early age, and thus events are not stored in any sort of context (Nelson & Fivush, 2004). Yet, when holding age of encoding constant, and examining the data across age groups, we found that Older Age adults reported significantly less extra-event information and less hierarchical relationships between events, suggesting that the differences in early childhood memories are due at least in part to the distance from encoding rather than age at encoding.

Similar to the differences in flexibility observed in Older Age adults, differences in extra-event information and hierarchy scores may be explained in terms of the increased stereotyping that occurs with time and age. Regardless of age group, the effect of time on stereotyping is present in the events reported from childhood, but in the oldest cohort an additional reliance on reconstructive processes may result in increasingly schematized representations. As time passes, less detail can be recalled and thus fewer surrounding details and events can be recalled, and events shrink to a size where there are no longer sub-events. Although age at encoding may contribute to some differences in extra-event information and hierarchy scores, it appears that distance from encoding is a major contributing factor. The difficulty in this interpretation is that there appears to be two competing processes, both related to the loss of specific detail: stereotyping leading to stable event definitions and redefinition leading to flexible events. In our data we see the flexibility scores increase when looking only at events in which such a move is possible, however when looking across events the general tendency is for detail outside of reported boundaries to be forgotten. That is, the reconstructive process plays a role in event definitions, but eventually those definitions appear to stabilize as schemas are relied upon to make up for extreme losses in detail. Future work following subjects across time may be helpful in better defining the dynamics of this interaction.

Conclusions

Experiment 2 confirmed that there are age differences in the manner in which events are defined during retrieval. Older adults are more likely than younger adults to move event boundaries to include information originally deemed to be external to that event. This highlights the ways in which age differences in autobiographical recall may have an influence not just on the specificity of episodic events, but also the way events in memory are understood and defined.

These results also have important implications about the nature of event retrieval in general. It appears that although episodic memories may be initially defined at encoding in line with Event Segmentation Theory (Reynolds et al., 2007), these definitions are not necessarily maintained in long-term memory. This finding is especially interesting given the recent suggestion that event definitions are maintained in episodic memory (Ezzyat & Davachi, 2011). Encoding plays a crucial role in how episodic memories are defined, but encoding alone cannot explain the current findings.

Finally, these results suggest that the mechanisms at work during perception, which differentiate the manner in which older adults segment events from the way in which younger adults segment events, may also have an influence at retrieval. In fact, older adults’ tendency toward more general event definitions may actually influence both the way they parse events during perception, which in turn should influence their initial encoding, and the way they remember events during retrieval.

CHAPTER 4

EXPERIMENT 3: AGE DIFFERENCES IN EVENT DEFINITIONS AT ENCODING AND RETRIEVAL

Experiment 2 highlighted the influence of age on event definitions in memory, and Experiment 3 will further investigate this difference to explore the possibility that a common mechanism is at work during encoding and retrieval. The process of event segmentation is the natural outcome of an automatic prediction system in which humans use event schemata to understand the constant flow of ongoing information (Zacks et al., 2007). Further, older adults seem to strategically apply cognitive schemas in a manner that is distinct from younger adults, and this strategic application can occasionally be altered to more closely resemble younger adults (Koutstaal, Schacter, Galluccio, & Stofer, 1999). Results from Experiment 2 indicate that older adults define events at retrieval differently than younger adults, in line with our hypothesis that events are strategically redefined in order to make use of available detail. However, it is also known that older adults define events in a different way than younger adults at encoding (Kurby & Zacks, 2010), which leaves open the possibility that these differences reflect a more general shift in event understanding. The present experiment will look to highlight the role of available detail during retrieval to clarify the meaning of the age differences in Experiment 2.

Sensecam technology (Microsoft Research Cambridge; http://research.microsoft.com/sensecam/) provides a particularly valuable tool for investigating the relationship between specific details present during the encoding scenario and the recall of those details during retrieval. Sensecams can be worn without disrupting normal activity and will take thousands of pictures automatically. Sensecam images also provide a cue at retrieval that is in a similar form to the mental “snapshots” often experienced in the act of remembering. Further, these images have been shown to be powerful cues for healthy adults and adults suffering from memory impairment (Berry et al., 2007; Hodges et al., 2006; St. Jacques, Conway, & Cabeza, 2010). Using Sensecam images, boundary details can be presented to participants at recall to see if those specific details are in fact a major driving force in the variability observed in flexibility scores.

The aim of this final experiment was twofold: to clarify the role of boundary details on event definitions during retrieval and to clarify whether the differences between older and younger adults are due to differences in event definitions in general. Specifically we tested whether presenting Sensecam images at retrieval led to more rigid event boundaries, and whether this critical manipulation had an equal influence on younger and older adults. If older adults do differ from younger adults merely because they are unable to recall as many specific details, providing Sensecam cues at recall should negate any age-differences in boundary flexibility by equalizing the availability of specific details. However, if event definitions actually change in older adults and do not merely reflect a difference in available detail, then boundary flexibility scores should differ between older and younger adults in perceptual scenarios, memory scenarios, and memory scenarios using Sensecam images as an aid.

Method

Participants

Twelve older adults (Mean Age = 67.25, Standard Deviation = 8.42) and twelve younger adults (M = 26.36, SD = 2.73) were recruited from American University and the surrounding communities. Older adults were compensated at a rate of $10/hour, and younger adults received extra credit for their participation, or elected to take monetary compensation at the same rate. The local Institutional Review Board approved the research protocol for this study and informed consent was obtained for all participants.

Materials, Design, and Procedure

Participants were first screened for recruitment criteria (proper age and had not been diagnosed with cognitive impairment) and were shown how to use the Sensecam. They were then asked to take a Sensecam home and wear it for at least eight hours during their normal daily activities. Participants were scheduled for an interview two weeks after wearing the Sensecam. The interview included three critical within-subjects variables, Cue (boundary cue v. no cue), Sensecam Images (before or after viewing the Sensecam images for the event), and Process Type (memory v. perception).

Sensecams take images based on changes in light, so the sampling rate varied slightly by subject, but was on average about 3 images per minute. The images were viewed on a macbook pro using the Preview program so that all images could be viewed sequentially using the arrow keys.

Prior to the interviews, the experimenter went over Sensecam images to find two events that could be cued during the interview using a few images at the beginning of the event. The experimenter chose events that appeared to have clear beginning points, such as entering a new location. Two events were chosen in case the participant could not recall one of them, or used one of them in the uncued condition. The following three parts of the interview were counter balanced across subjects to control for order effects.

During the interview, participants were first asked to recall any event from the day when they were wearing the camera. If the participant was unable to recall an event, an image from the middle of an event was shown to cue a memory (a boundary cue was never used in this condition. Only two subjects were unable to recall an event without a cue). Once an event came to mind the interview proceeded as in Experiment 1 including boundary questions. Following the interview, participants were allowed to view the Sensecam images for that event, going beyond the described boundaries to help them remember all detail surrounding that particular event as well. Subjects typically went 15-20 images beyond the event boundaries in each direction (about 5 – 10 minutes worth of images in each direction), just to the point that they were able to describe what was happening prior to the retrieved event. Finally participants were asked the boundary questions a second time. This condition allowed us to investigate boundary flexibility in memory situations with only details from memory available compared to situations with additional details from Sensecam images. If the presence of boundary details at recall is the critical element, than event boundaries should be quite stable after Sensecam images are presented, and more flexible prior to their presentation.

In the second part of the experiment, participants were presented with the 3-4 images, selected prior to the interview (see above), representing the beginning boundary of one of the events from the day they wore the Sensecam. The interview then proceeded as in Experiment 2. Following the interview, participants were allowed to view the Sensecam images as in the first condition. Finally participants were asked the boundary questions a second time. These procedures allowed us to investigate the flexibility of an event boundary when cued with episodic details from that boundary. If the presence of boundary details is the critical factor influencing boundary flexibility, then presenting the starting boundary cue should result in more stable beginning boundaries and more variable ending boundaries. All boundaries should become stable after the presentation of all Sensecam images.

Finally, participants were presented with Sensecam images from a day in which the experimenter wore the camera. This control condition allowed us to investigate difference in event definitions in general, and boundary flexibility in particular, in a perceptual scenario using the same questions used during retrieval. Participants were told that the event was "the experimenter speaking to his coworker" and were asked to identify the beginning and end of the event. Participants were not restricted in how far forward or backward they could go in choosing the event boundaries (all images from the day wearing the camera were available), but the event basically included the experimenter sitting at his computer working, getting up from his computer and walking to his coworker's office, speaking with his coworker, another coworker entering, leaving his coworkers office, and returning to his desk where he began working again. Following event definition, participants were asked if images from before and after those boundary markers were in fact part of that event, using the same boundary questions from Experiment 2. If boundary details influence boundary flexibility than the perceived boundaries should always be stable in this condition in which all information is readily available.

Results

Boundary Scoring

As in Experiment 2, all scores reflect the answers of the participants during the Specific Probe phase. Flexibility, Extra-Event Information, and Hierarchy scores are thus self-report measures reflecting perceived boundary locations and inter-event relationships. Flexibility scores reflect how participants moved event boundaries and were scored on a 3-point scale. A score of zero indicated that the participant did not include any details recalled prior to the first boundary or after the last boundary as part of the originally reported event. A score of one indicated that the participant included information in one direction and a score of two indicated that the participant included information in both directions.

Extra-Event Information scores refer to whether information just beyond event boundaries could be recalled at all. That is, this score reflects whether or not boundary movement was possible and is also on a 3-point scale. A score of zero indicated that no information on either side of the event could be recalled. A score of one indicated that information on only one side of the event could be recalled. A score of two indicated information on both sides of the event could be recalled. This factor was used primarily as a selection variable in that by looking at events based on the Extra-Event Information score, we were able exclude events in which it was impossible to move the boundary (a score of zero).

Hierarchy scores refer to how participants viewed events in relation to other events (cf. Conway, 2005) and in this experiment was broken into binary scores of larger event (present or not) and smaller event (present or not).

As in Experiment 2, we also included self-reported ratings of vividness, personal importance during retrieval and during encoding, and emotional change during the event. Each of these variables was rated on a scale of one to six (1 = low, 6 = high). In general older adults rated their events as more important during encoding, Wald's $\chi^2 = 4.28$, $p = 0.039$, and during retrieval, $\chi^2 = 7.40$, $p = 0.007$. There were no age-differences in visualization or emotionality.

Effect of Age and Sensecam Images on Boundary Flexibility

We used a Generalized Estimating Equations (GEE) model to investigate whether older and younger adults differed on extra-event information, hierarchy scores, and self-reported rating scales. As expected, there was a significant difference between the amount of extra-event information reported before and after Sensecam presentation, Wald $\chi^2 = 18.24$, $p < 0.001$. There was no main effect of age and no significant interaction ($p > 0.381$) signifying that older and younger adults reported similar levels of extra-event information in all conditions. There were no age differences in reporting smaller hierarchy scores and no differences in hierarchy scores pre- to post-Sensecam presentation.

Effect of Cue and Age on Boundary Flexibility

In order to clarify the role of boundary details on event flexibility we first tested whether there was an effect of presenting boundary details as a cue during retrieval. A Generalized Estimating Equations (GEE) model was used with the condition entered as the within subject index. We restricted the analysis to only those memories that included details beyond at least one event boundary during retrieval to ensure that we were comparing those events in which boundary movement was a possibility. The condition (boundary cue v. no cue) was entered as a within subject factor and age group was entered as a between subject factor. A full factorial model was used to model both the main effects and the interaction term. There were no significant main effects or interactions ($p > 0.60$). It appears that using images from event boundaries as cues did not have an effect on boundary flexibility in memory regardless of age.

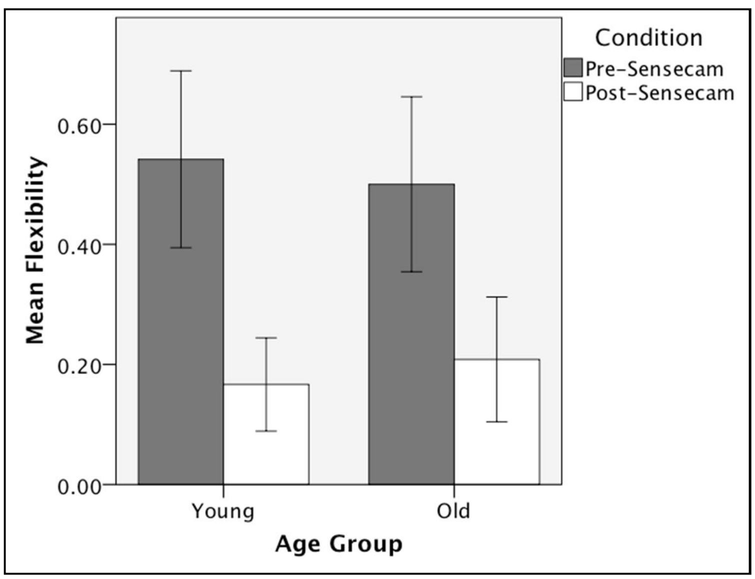

Figure 8: Effect of Sensecam Images on Boundary Flexibility

Effect of Sensecam Images and Age on Boundary Flexibility

Next we compared boundary flexibility before and after presenting Sensecam images. A GEE model was again used with the condition entered as the index. In this case we entered the Sensecam condition (retrieval before Senseam presentation v. retrieval following Sensecam presentation) as a within subject factor and age group as a between subject factor. We again included the interaction term in the model.

There was a main effect of condition, Wald $\chi^2 = 8.99$, $p = 0.003$ reflecting the tendency to report more rigid event boundaries after Sensecam presentation (**Figure 8)**. This tendency did not vary by age as there was no interaction and no main effect of age ($p > 0.90$).

Age Differences in Event Definitions and Boundary Flexibility during Perception

Finally, we investigated whether there were age differences in the boundary flexibility and event definitions while perceiving an event (the event taken from experimenter's Sensecam images). As previously described, participants were asked to define the event by choosing an image that represented the beginning of the event and an image that represented the end of the event. Participants were then asked whether images beyond those boundaries (two in each direction) were in fact part of that event.

First we tested whether there were age differences in the location of the event boundary. There was a significant age difference in the frame selected as the beginning boundary, Mann-Whitney U (24) = 20, $p < 0.001$. It appears that older adults were more likely to define the event as beginning later than younger adults. In fact, older adults chose either frame 1841 or later, while younger adults chose 1841 or earlier as the beginning boundary (**Figure 9)**. The frame number just represents the counter number when the picture was taken, so this was image 1841 from the time the camera had been turned on. The difference between the earliest frame selected (1836) and the latest (1844) is two minutes. That is, when younger adults did not choose the largely agreed upon beginning boundary, they seemed to favor a transitional image prior to entering the room, while older adults never defined the event as beginning prior to entering the room. The ending boundary showed the same location-dependent trend with older adults typically choosing an earlier end point, U(24) = 39, p = 0.044, although it was not as clean of a split between the groups.

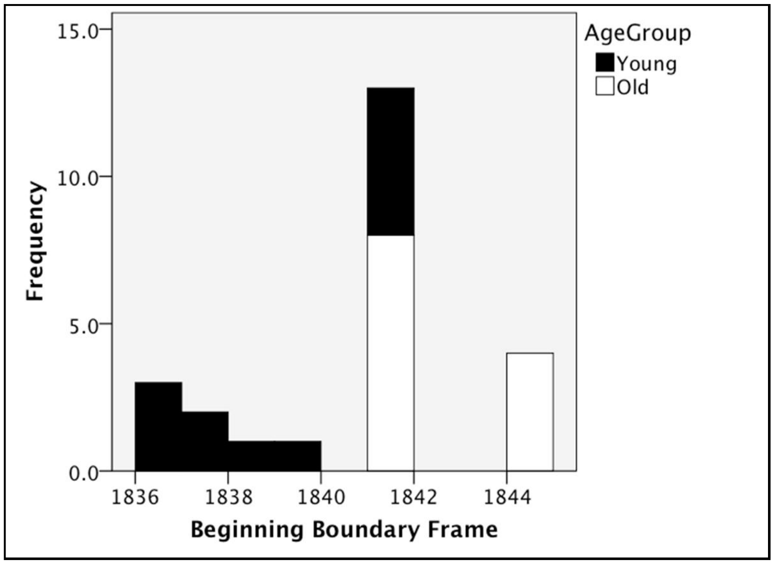

Figure 9: Age Differences in Boundary Placement while Defining an Event during Perception. Note that older adults are at frame 1841 or later, and younger adults are at frame 1841 or earlier.

Finally, we tested whether there was a difference in event flexibility for this same control event. Older adults showed a trend of reporting more flexible event boundaries for the event defined during perception (5/12 individuals had a flexibility score greater than 0 in the older group, compared to 2/12 in the younger group); however, most likely due to lack of power, the difference did not reach statistical significance, U(24) = 52, p = 0.074 (one-tailed given the difference in Experiment 2).

Discussion

As predicted, it appears that boundary details do have an effect on boundary flexibility. It also appears that both older adults and younger adults are able to make use of Sensecam information at retrieval in a similar manner, and thus curtail boundary flexibility at a similar rate. Interestingly, and in line with previous research (Kurby & Zacks, 2010), older adults differed from younger adults in the manner in which events were defined during perception. This may influence the way older adults encode events, consistent with other work from the same group (Swallow, Zacks, & Abrams, 2009). Further, this leaves open two possible mechanisms for the age differences in Experiment 2: a difference in specific recall in older adults leads to reduced recall of boundary details, or a difference in event processing in older adults during perception leads to altered event definitions during retrieval.

Boundary Details and Boundary Flexibility during Retrieval

In line with our hypothesis that boundary flexibility may be due to a lack of accessible boundary details during retrieval, presenting Sensecam images did reduce boundary flexibility. Regardless of age, participants were less likely to move event boundaries after they had viewed all the Sensecam images for that event. Indeed, the strong visual cues provided at retrieval allowed both younger adults and older adults to define an event in a manner that took into account all the original detail. This was also consistent with the stable event boundaries during the control condition, suggesting that the boundary movement during retrieval reported in previous experiments does not merely reflect some artifact of the questioning itself. Indeed, particularly in the case of the younger adults, the distribution of boundary movement in the control condition and the event memory condition following Sensecam administration was virtually identical.

Most surprisingly, the current experiment did not replicate the age differences in boundary flexibility from Experiment 2. In light of that key difference, it is not surprising that there was not a significant interaction between age and Sensecam presentation in the current experiment. Older adults showed far less boundary flexibility than in Experiment 2, making it very difficult to draw any definitive conclusions on how Sensecam images may alter boundary flexibility in those adults who show the highest levels of flexibility in previous experiments. In addition, the current experiment may have had less sensitivity to the age differences in boundary flexibility due to the younger participants in our old group (median age of 64.5 in the current experiment compared to a median age of 76 in Experiment 2), older adults in the younger group (median age of 25 in the current experiment compared to 20 in Experiment 2), and a restriction on the events recalled to the rather mundane events from two weeks prior when wearing the Sensecam. Given the trends in the data, increasing power with an increase in sample size, stricter control of the type of event, a more pronounced age difference, or using more recent events which seemed to show the largest age difference in Experiment 2 would likely help pick up the age differences previously observed. A study implementing one of these alterations needed in future work to clarify how age differences in event definitions influence boundary flexibility during retrieval.

Contrary to our expectations, there was also no effect of presenting boundary cues prior to event retrieval. In fact, in the boundary cue condition, participants changed the boundary location after seeing all Sensecam images for the event about 50% of the time. This suggests that we may have failed to use images that represented the proper boundary location about half the time, due in part to having only visual information available without the thought process or ongoing auditory information that often ended up dictating the final boundary location. Sensecam cues may not provide the proper amount of detail for viewers who did not experience the event to properly identify the original encoding boundary.

Age Differences in Defining Events during Perception

Results from the control event during perception seem to indicate a more general schematic difference in the way older and younger adults define events. In the present experiment, older adults always defined the beginning of the event during perception as either the first image in the room in which the conversation took place, or a later image (in which the coworker looked up at the camera). Younger adults on the other hand defined the event as beginning at the first image in the room or an earlier image in which the camera-wearer was transitioning from his desk to the room where the conversation took place. This difference may be related to the increased reliance on schematic processing associated with normal aging (Mather & Johnson, 2003; Mather, Johnson, & De Leonardis, 1999). That is, the normal schema for a conversations beginning and ending point relate directly to the presence of that individual; however in the case of the presented event, one could infer that the experimenter got up from his desk with the intention of having the conversation, in which case frames that were not consistent with a normal conversational schema might be included in the event definition. Indeed, this tendency in older adults may have also led toward a trend of moving event boundaries during questioning. When forced to consider frames outside of the chosen boundaries, older adults were more likely than younger adults to redefine an image outside of their original boundaries to be included in the event. Future work with a more pronounced age range may clarify the role of schematic support in boundary stability both at encoding and retrieval.

Conclusions

Results from Experiment 3, in which the presentation of strong cues at retrieval curtailed boundary flexibility, suggest that differences in the amount of accessible detail do play a critical role in the age differences shown in boundary stability. In the present experiment, older adults did not show differences in boundary flexibility or in the amount of extra-event information, suggesting that this particular sample may not have had such a large discrepancy in accessible detail during retrieval. Further, in this sample, older adults and younger adults showed a similar pattern of reduced flexibility after being presented with Sensecam images, suggesting that both groups were able to return event boundaries to the original encoding location when presented with strong cues. Yet to best understand the role of available detail a sample that shows clear age differences in flexibility and extra-event information, like that of Experiment 2, is needed when memories are recorded via Sensecam. The age-differences in event definitions during perception suggest that although the segmentation during encoding and retrieval might be related, it may be possible to experimentally manipulate factors that selectively influence event definitions at either encoding or retrieval.

These results offer intriguing possibilities for future work. For instance, the trend toward age differences in the flexibility of events defined during perception using Sensecam images, and the lack of an age difference for events in memory using Sensecam images, suggests that there may be a critical difference in the way events are defined in memory and perception. One possibility is that the tendency of older adults to rely on schematic information does not have as strong of an effect in memory (at least after only two weeks) when the encoding boundaries are cued. That is, perhaps older adults will rely on schematic information to define events in memory only when the encoding boundaries are clearly not accessible, suggesting there may be a long-term role for encoded boundaries in line with previous findings (Swallow et al., 2009). These results also suggest that age differences in both the amount of detail that can be recalled, and the type of information that is used to define an event, may play a role in the age differences seen in Experiment 2. Although the present experiment adds further evidence of a more general age difference in event definitions (Kurby & Zacks, 2010), future work is needed to more clearly tease these two factors (amount of detail and type of information) apart.

CHAPTER 5

GENERAL DISCUSSION

This work aimed to delineate the neural differences between older and younger adults during autobiographical memory retrieval using the AMT; establish the way those differences might relate to age-differences in event definitions during retrieval; and establish whether such differences are due primarily to age differences in retrieval strategies or to a more general age-related shift in the use of event schemas. As expected, older adults showed differences in brain activity and connectivity during autobiographical retrieval that may lay the foundation for the cognitive differences reported in the literature. Further, older adults showed differences in the way they defined events from memory, at least with respect to boundary stability, although these differences were not as apparent in the earlier years of aging. Finally, older adults seemed to show differences in event definitions that were consistent with a differential use of event schemas in both perceiving and recalling events.

Relating the Differences in Brain Activation to the Differences in Boundary Flexibility

Older adults showed a very interesting pattern of brain activation during autobiographical memory, which when compared to younger adults, included a more diffuse network of task activation and less differentiation from the semantic control task. The primary differences were observed in the prefrontal cortex and the anterior cingulate. Given the overgeneral tendency of older adults, one may infer that this deficit primarily affects the search process during retrieval (Piolino et al., 2010; Ros et al., 2010), which is consistent with the more general age differences observed in tasks requiring sustained retrieval (e.g., Craik & McDowd, 1987). However, these brain regions are also involved in the process of event segmentation. In particular, the anterior cingulate and the prefrontal cortex have been implicated in maintaining and utilizing event models during the normal segmentation process (Zacks, Speer, Swallow, Braver, & Reynolds, 2007). That is to say the prefrontal cortex may be involved in the selection and maintenance of retrieval strategies used to choose a specific event as suggested in previous work, but is likely also involved in the process of defining and elaborating on the retrieved event. This suggests that our result could be translated either as a deficit in the executive role in the “search” process during retrieval, or a deficit in the executive role in the “elaboration” process during retrieval.

Our design and procedure collapsed the search and elaboration phases of event recall into a single block, and thus we were unable to investigate the search and elaboration phases separately. This leaves open the possibility that the largest age-related brain activation differences may be prevalent in one of these phases. A recent study implementing a similar design found that the largest age related differences in the lateral prefrontal cortex activation were seen during the elaboration phase, particularly in relation to strategic retrieval during elaboration (St. Jacques et al., 2010), perhaps reflecting differences in accessing specific details. This suggests that the frontal deficits in our study likely do not reflect impairment in the search process used to identify a specific event, but rather in retrieving specific details from the chosen event.

These findings also suggest that, in line with the work and suggestions of Piolino et al. (2010) and Ros et al. (2010), the deficits in prefrontal function during normal aging are related to differences in brain activation during normal autobiographical retrieval using AMT cue words. Older adults not only show differences in the way they differentially activate the prefrontal cortex and cingulate gyrus during autobiographical retrieval, but also show critical differences in the manner in which these regions functionally relate to the hippocampal formation. These differences were present during successful retrieval of specific episodes, but may relate to the group differences that were observed behaviorally. The age-related differences in neural function during successful retrieval may increase susceptibility to overgeneral recall, as older adults were indeed more likely to recall overgeneral memories. Experiment 1 confirms that age-differences in prefrontal function are observed during autobiographical recall, and suggests that these differences may be related to overgeneral recall in older populations. These findings also lead into our second hypothesis that a strategic reliance on gist-based processes during retrieval may also contribute to age-differences in autobiographical recall (e.g. Koutstaal, Schacter, Galluccio, & Stofer, 1999). Further, the findings from Experiment 1 left open the possibility that the frontal deficits detected during autobiographical recall may also lead to age-differences in event definitions during perception and encoding, in line with the findings of Kurby & Zacks (2010).

Consistent with the idea that older adults are merely adopting a strategy to make best use of the available detail, older adults showed more boundary movement than younger adults in Experiment 2. In addition, older adults reduced boundary movement when presented with Sensecam images in Experiment 3, although this finding is difficult to interpret given there were no age-differences in boundary flexibility in Experiment 3. Together these findings could be interpreted as evidence that older adults strategically accommodate available detail when defining events during retrieval, as in Experiment 2, and are able to alter that strategy when presented with additional information during retrieval, as they did in Experiment 3. In opposition to this interpretation, it could be argued that the sample in Experiment 3 did not have sufficient age-related differences in retrieval processes to necessitate an alteration in strategy. This argument, that the sample in Experiment 3 had not yet developed deficits in the retrieval processes, is further supported by the Extra-Event Information data from Experiments 2 and 3. The older adults in Experiment 3 did not show age-differences in the amount of Extra-Event

Information reported, while the older adults in Experiment 2 did show differences on this measure. This suggests that the older adults in Experiment 3 may have been able to retrieve detail at a similar rate to younger adults, nullifying a major factor in flexibility scores from previous research and leaving open the possibility that the strategy used by the Experiment 3 sample may not be the same as that used by an older sample with more severe differences in retrieval processes.

In line with the idea that older adults show a more general schematic shift in the way events are understood, older adults showed differences in the way they defined events during perception in Experiment 3. This cannot be overlooked because it has important implications about event definitions at retrieval. The older adults in Experiment 3 who showed differences when defining events during perception did not show differences in defining events from memory. That is, the age-related differences in defining events during perception may be necessary for the observed age differences in Experiment 2, but they clearly are not sufficient to produce differences in event definitions during retrieval. This may also suggest that age-related differences can be first seen in encoding rather than retrieval, at least in the case autobiographical memory, perhaps reinforcing the importance of the medial temporal lobe and hippocampus in the earliest stages of normal aging. In the current experiment, it is difficult to conclude too much about time course given the vast differences in processing that were taking place in the perceptual condition and the autobiographical condition, but it may be a fruitful path for future research on autobiographical memory.

It is possible that age-related differences in event definitions during perception and during retrieval occur simultaneously based on a single process of event segmentation, and that in Experiment 3 we lacked the measurement sensitivity to pick up on these differences in memory. It is also possible that age influences event definitions during perception lead to age-differences in the manner in which events are encoded and ultimately remembered. Finally, it is possible that event definitions in memory and during perception are largely unrelated processes, both of which are changed at some point during the aging process, and perhaps in the case of memory, only under specific retrieval scenarios. Future work systematically testing event definitions during perception and memory for tightly controlled events could help clarify the interplay between event definitions during perception and retrieval. From the current results, it can be concluded that older adults show differences in brain activity during autobiographical retrieval, that they implement different strategies than younger adults when defining events during retrieval, and finally that a more general shift in the way events are understood during perception and encoding may in fact play a role in differences in episodic memory retrieval.

Age-Related Differences in Narrative Style

One possible explanation of the age differences in autobiographical recall is that older adults implement a narrative style that differs from younger adults, either due to demand characteristics of the interview environment, or due to an age-related shift in social motivations as claimed by Socioemotional Selectivity Theory (Carstensen, Isaacowitz, & Charles, 1999).

In terms of the demand characteristics of the interview, it is possible that the tendency of older adults to recall a greater proportion of external details (Levine et al., 2002) may in fact be due to a common social convention of desiring mutual understanding when telling a story. That is, perhaps given the stories from older adults are often more remote than younger adults, it may be that the added factual information is due to placing a necessary context, especially when being interviewed by a younger individual. In the current work, such a bias could certainly be present given the interviewer was in his 20’s. Future work could investigate this possibility by varying the age of the experimenter to see whether such a bias exists. From past work it does not seem likely that the external bias could be explained entirely by placing necessary context that is unfamiliar to the researcher given that the age differences in external v. internal details recalled exist even when restricting analyses to events within one year (Levine et al., 2002, p. 682). However, even within a year of recall, it is possible that objects or tasks performed by older adults are indeed more antiquated than younger adults and thus necessitate additional explanation, so future work on such a possibility is certainly warranted.

In terms of an age-related shift in social motivations, it is possible that the increased importance that is placed on meaningful social relationships in older adulthood (Carstensen et al., 1999) leads to a more collective focus during event recall and event perception. In support of this possibility, data from Experiment 3 highlight the manner in which such a bias could alter the definition of an event during perception. Older adults always defined the control event as beginning when both conversational parties were present in the image, whereas younger adults were more likely to define the event earlier and include images that had no obvious social value. In this case it is clear that the older adults' shift in event definition may not be a deficit as such, but rather an outcome of a shift in social values. In the same way, it is possible that the lack of specific detail recalled by older adults does not reflect a deficit in the ability to recall those details, but rather a bias toward a more global understanding of events that could actually be quite valuable. When looking closer at the data from Levine et al. (2002), older adults do recall fewer internal details and a greater number of external details than younger adults, however the overall level of detail is actually higher in older adults. Further, when comparing the narrative quality of older adults to that of younger adults some work has shown that older adults actually produce better stories (Pratt & Robbins, 1991). Yet, other data have shown that within older populations, increasing age is related to decreased narrative quality and cohesion when telling stories based on pictorial representations (Juncos-Rabadan, 1996; Juncos-Rabadan, Pereiro, & Rodriguez, 2005). If future work is able to show that older adults are able to alter this more global approach to event understanding when it is detrimental, it may clarify whether the tendency is a deficit, a strategic alteration that can be modified, or some blend of these two factors.

Cue Specificity

One of the major differences between the experiments in the current work is the type of cues used to elicit autobiographical memories. From Experiments 1 – 3, the cues become increasingly specific and increasingly helpful. The cues used in the scanner in Experiment 1 were particularly abstract and non-specific, while Experiment 2 used more specific though still quite general cues (time periods), and Experiment 3 used very specific cues to very specific episodes. The difference in cue specificity may explain the different age-related findings from one experiment to the next, in particular the lack of an age difference in Experiment 3. Perhaps the increased specificity used in Experiment 3 helped mitigate the age differences in executive control related to specific event retrieval. It also suggests that the abstract cues used in Experiment 1 may have placed an even greater burden on the executive role in the search process of autobiographical retrieval. Future work could clarify the role of specificity by looking at activation differences in response to different types of cues. If abstract cues place an increased burden on the executive system, and the more specific cues mitigate that burden, then there may be more obvious frontal differences in older compared to younger adults during the search process when using abstract cues.

In addition to the effect of cue specificity, these results may have been unique to the type of events that were cued: specific episodic memories. The data from Experiment 3, and the age differences in event segmentation during perception previously reported (Kurby & Zacks, 2010), suggest that the differences in event definitions during retrieval may extend to all types of events in memory. In opposition to this possibility, work on semantic and episodic autobiographical memory in older adults has shown that the age-differences in autobiographical memory are only observed in episodic events and do not seem to be present in semantic autobiographical memories, including general or generic events (Piolino, Desgranges, Benali, & Eustache, 2002). Investigating the different event types may help to clarify whether detail accessibility or more generic differences in event understanding (as discussed in Experiment 3) are driving the age-related differences in boundary flexibility. If the differences were due primarily to detail accessibility then we would not expect to see age differences when eliciting more coarse events from a higher level of the memory hierarchy. For those events, the amount of accessible detail should be similar between younger and older adults. If, however, the age differences were due to a shift in the application of cognitive schemas and an alteration in event understanding, then the age-related differences in boundary flexibility should be present even for more generic events. Future work teasing apart these factors will help clarify an age differences in the processing of events during perception, encoding, and retrieval.

Event Boundaries from Encoding to Retrieval

A considerable amount of effort has gone into to understanding how events are defined at encoding, and how those definitions influence retrieval (Kurby & Zacks, 2008; Swallow et al., 2009; Zacks et al., 2007; Zacks et al., 2006). From this work it appears that events are defined in a consistent manner from one person to the next, that this process of segmentation is somewhat altered during normal aging, and that how events are defined at encoding influences the way they are recalled during retrieval. Recent work also argues that encoded boundaries are in some way maintained in memory (Ezzyat & Davachi, 2011). The present study supports age differences in the way events are defined, both during perception and at retrieval. Further, Experiment 3 suggested that differences in event definitions at encoding do not necessitate similar age differences at retrieval.

Results from the current study suggest that event definitions can be altered at retrieval without any change to the encoding scenario. We found that event definitions during retrieval are related to age at retrieval and distance from encoding, even when holding age at encoding constant. Yet, these findings seem to oppose the suggestion of Ezzyat & Davachi (2011) that event boundaries are maintained in memory. One possibility for this discrepancy is that event boundaries are maintained in memory, but as with all memories, they lose accessibility over time. This forces individuals to define events using available detail and the event schemata used at encoding (Zacks, Speer, Swallow, Braver, & Reynolds, 2007). In relation to the current findings, this would mean that boundaries were maintained for a time in memory, as argued by Ezzyat, but with time (or in older ages) those boundaries are forgotten and events must be defined without them. The specific boundary details from the encoding scenario are susceptible to interference and decay in memory, and when they cannot be recalled, events must be defined making best use of the successfully retrieved details from the retrieved event or from event schemas (typical beginning and ending points for this type of event).

Cognitive process used to segment events at encoding may also be applied to the flow of details available at retrieval, so that when the details recalled closely match those in the encoding scenario, the event will be defined in the same way. In contrast to Ezzyat's suggestion that boundaries are actually maintained *as boundaries* in memory, it may be that the appearance of boundary maintenance in memory is byproduct of the processing that takes place at both encoding and retrieval. In such a framework, the event segmentation process used at encoding is also used at retrieval, and the details at event boundaries during perception are encoded in a deeper manner (e.g. Zacks, Speer, Swallow, Braver, & Reynolds, 2007). It follows that when an event is recalled, the details at original boundaries will be recalled as well, and the segmentation process will result in the same boundaries at retrieval. In this case, boundary details are not maintained as boundaries per se, but rather the processing at encoding increases the likelihood that those particular details will be recalled. Further, because the same process is used during retrieval, it also increases the likelihood that they will again be classified as the event boundary. This would reconcile our results with the findings of Ezzyat, in that boundary details are just like any other detail and thus fade over time and with age.

It may be possible to compare these two alternatives in future work. In particular, if a misinformation approach can be used to alter what should be perceived as the event boundary at retrieval, without actually hindering recall of the encoded boundary, it may be possible to clarify whether re-segmentation is ongoing at retrieval. In such a scenario, the first alternative would suggest that the maintained boundary should be recalled as the boundary, while the second alternative would suggest that the event should be redefined in line with the new boundary imputed via misinformation. From the current data it can only be concluded that age differences exist in the way events are defined at encoding and retrieval, and that these differences may be related to the known, and now expanded, age differences in cognitive and neural processes.

Models of Memory

Conway's (2005) hierarchical model of memory provides a useful tool for understanding the age differences in autobiographical memory. It is useful to think of overgeneral memory in terms of recall at a higher level of the hierarchy, and it is simple to think of the tendency toward external focus in specific recall as a deficit when a memory from the bottom of the hierarchy is recalled. However, Conway has had many iterations of his hierarchical model, and the most recent may not be the best fit for the data presented in this experiment.

As previously alluded to, an early version of Conway's model focused on the construction of events from memory, and rather than building out discrete units at the bottom of his hierarchy, Conway included "event specific knowledge" at the bottom of the hierarchy, which included all specific details that could be used to reconstruct an event during retrieval (Conway & Pleydell-Pearce, 2000, p.262). This model is perhaps more appropriate when considering data from Experiment 2 in which older adults showed a tendency to move event boundaries during retrieval, and younger adults showed that same tendency for more distant events. In order for memories to maintain the structure suggested by Conway's more recent model, it is necessary that boundary information remain intact in memory and that memory recall included particular discrete units. What is less clear is why the retrieval of a given event would seamlessly transition into adjoining details beyond event boundaries. In order to explain such a finding two different processes must be at play under Conway's current model (2005), one a direct retrieval of a discrete episode related to a lifetime period, and another process of self-cueing details stored in memory as an entirely separate event. When considering the model that only includes event specific knowledge (2000) on the other hand, one single process of cueing can explain both the recall of an episode and the recall of surrounding details from other episodes. As details are recalled, the same process of prediction that leads to segmentation during perception leads to cueing of related details (increasing the likelihood of recalling surrounding details regardless of their originally perceived location relative to boundaries), and ultimately event segmentation (either when details that act as a natural boundary are recalled or when a natural ending to the schema used during reconstruction is reached). In such a case, the structure of an event is understood to be a phenomenon of retrieval as is the temporal order of event details when present, both based on the process of self-cueing using retrieved details.

Conway's model is not the only model of autobiographical memory, and some other models may help place the findings in the present work in their proper context. One model that makes similar claims to my own (though certainly better formulated and articulated) about the use of cognitive processes during encoding and retrieval is the Basic-Systems Model (e.g., Rubin, 2006). Although Rubin's model does not take a clear stance on what type of information is stored in memory (one reason this model was not primarily referred to throughout this work), it does draw some very interesting aspects of the processing that takes place during retrieval and may explain some of the age-related differences observed in our data. Rubin highlights the important role of the frontal cortex in the selective search process during autobiographical retrieval, further supported by data discussed in Experiment 1, and suggests that modality specific details are stored in modality specific regions of the brain (2006, p.293). In support of this claim, Rubin discusses evidence from his research, and the research of others, that provides evidence for a memory deficit to sensory memory when there is focal damage to the sensory systems. Moreover this memory deficit is present for sensory information encoded prior to the sensory damage experienced by a given patient. This finding is perhaps most relevant to the suggestion that details in memory may not be bound at all, especially given the fact that the vast majority of recalled detail falls into the category of sensory detail (visual).

Further, thinking of the process of autobiographical memory retrieval in terms of different systems is helpful for relating our findings to those in the event segmentation literature, and to the suggestion of other researchers that boundaries are maintained in memory (Kurby & Zacks, 2010; Ezzyat & Davachi, 2011). Specifically, my suggestion that the process of prediction (which leads to event segmentation during perception and encoding) is applied during retrieval becomes more palatable in the context of the basic systems model. If this process of prediction is not a part of perception per se, or memory per se, but rather a part of the more basic narrative system, then the notion that such a process would be applied during autobiographical reconstruction would not only be possible, but in fact expected. The narrative schema applied during retrieval would necessitate the same boundary locations as previously described, while also falling into a larger framework of narrative style within various age groups. In support of such an argument, the event segmentation theory is based on models of narrative comprehension, suggesting there may indeed be a large role of the basic narrative system in event definitions during perception, encoding, and retrieval (e.g., Zacks et al., 2007).

Future work may need to consider whether the inclusion of episodic units is in fact necessary in any hierarchical model of autobiographical memory. All other levels of the hierarchy are in fact semantic in nature, and perhaps it would be better to think of Conway's hierarchy as a hierarchy of cues rather than an "event" hierarchy. Tulving (2001) suggests in his SPI model that sensory information is encoded first, followed by semantic information, and finally episodic events. Perhaps what is encoded in the autobiographical memory system is merely a set of semantic cues in relation to specific sensory details, all of which are used during reconstruction to produce an episodic event. That is, perhaps episodic memories are difficult to locate in memory, and seem to have elements stored in various locations throughout the brain, because they are in fact a phenomenon constructed only at retrieval based on a re-activation of sensory details, narrative schemas used at both encoding and retrieval, and semantic cues stored in a semantic hierarchy in relation to a semantic representation of the self. The current data do not prove such a hypothesis, but perhaps reducing memory to the fewest necessary parts may help as we attempt to reconcile data from imaging studies, amnesic studies, lab-based memory studies, and observational memory studies.

Caveats

The behavioral data from Experiment 1 indicate age-differences in the memory task performed during scanning. In particular, older adults recalled events from the more distant past, and seemed to retrieve events at a slightly quicker pace. The reaction time data is quite surprising given the differences in processing speed associated with normal aging (e.g, Salthouse, 2000); a deficit that has been directly associated with age differences in memory (e.g., Baudouin, Clarys, Vanneste, & Isingrini, 2009). Indeed, past research on autobiographical memory has shown that older adults tend to recall events at a slower rate than younger adults (Rubin & Schulkind, 1997). One possible explanation is that older adults altered their retrieval strategy to ensure the retrieval of a memory in the allotted time. Given that subjects reported events between each run, it is possible that those older adults who struggled to retrieve an event in the first few runs made some sort of change to try and speed up this process, leaving open the possibility that the age-related differences in activation reflect an altered retrieval strategy rather than differences during normal autobiographical memory retrieval. However, recent findings in line with those reported in Experiment 1 from studies in which older and younger adults did not differ in their reaction time suggest that this possible confound is not driving the group differences (St-Laurent et al., 2011; St. Jacques et al., 2010). It is also not clear how older adults could speed up retrieval through a simple change in strategy. Perhaps a simpler explanation is that the time restriction in the current experiment presented a selection bias in which older adults were only able to retrieve those events that were strongly cued by the presented words, whereas younger adults were able to retrieve strongly cued events and weakly cued events. A closer inspection of the reaction time data supports this possibility, because when including overgeneral events in the reaction time comparison, the age difference disappears. This possibility can be further investigated by removing the time restraint on event retrieval in a future work to test whether the time restraint has an effect on the reported results.

The tendency of older adults to retrieve more remote events than younger adults, perhaps a statistical outcome of having a larger pool of memories over a longer interval, is in line with previous findings in the literature. In particular, it has been demonstrated that older adults tend to recall more events from their teenage years than any other time period in response to cue words (Jansari & Parkin, 1996; Janssen, Chessa, & Murre, 2005). This tendency toward more remote recall in the older group was also reported in recent work looking at age-related activation patterns during autobiographical memory retrieval (St. Jacques et al., 2010), leaving open the possibility that age related differences observed in these studies could be due in part to differences in remoteness. This is a particularly important caveat given the recent findings of Söderlund et al. (2011) that suggest hippocampal connectivity may change as a function of the remoteness of a memory. In their study, more remote events (> 10 years) showed an initial decrease in the connectivity between the prefrontal cortex and the hippocampus, followed by increased connectivity between the hippocampus and the anterior cingulate. The role of the hippocampus in remote autobiographical memory continues to be debated (Moscovitch et al., 2005; Squire & Alvarez, 1995; Squire & Bayley, 2007), but at the very least it can be stated that the exact of role of the hippocampus seems to change in some way from recent to remote retrieval. Other results have shown that the hippocampus and other medial temporal lobe structures show equal activation relative to semantic memory activation for both recent and remote events, particularly during the search phase (Steinvorth, Corkin, & Halgren, 2006). From the current work it can be concluded that older adults show differences in hippocampal connectivity compared to younger adults, and that those differences might be related to a tendency toward the retrieval of more remote events.

Despite these caveats, the current work has demonstrated differences in prefrontal and anterior cingulate activation and connectivity during normal autobiographical recall, confirming that differences in autobiographical memory retrieval may be related to executive dysfunction. Further it has highlighted age differences in the way events are defined and understood both during perception and during retrieval, and demonstrated how event definitions in memory can be fundamentally altered during retrieval.

APPENDIX A

TIME PERIODS

Older adults	Younger adults	College Students
Early childhood:	Early childhood:	Early childhood:
Up to age 11	Up to age 11	0 – 5 years
Teenage years:	Teenage years:	Childhood:
Age 11 - 18	Age 11 - 18	6 - 11
Early Adulthood:	Early Adulthood: Age 18-30	Teenage years:
Age 18-30	(2 events)	Age 12 - 18
Middle Adulthood:	Last year	Last year
Age 30-55		
Last year	Last month	Last month
Last month	Last week	Last week
Last week	Yesterday	Yesterday
Yesterday	1 hour ago	1 hour ago
1 hour ago		

APPENDIX B

INTERVIEW FORM WITH QUESTIONS

Pt. ID:______________ Date:___________ Examiner:______ Memory #:_______	
Recall	
General Probe	
Specific probing (If necessary, work with subject to establish the "story" before proceeding to specific cues below).	Was event list used? Yes _____ No______

Arriving at the Event	
Explain the thought process by which you arrived at the event you are about to describe	
When did this event take place?	
Year	
Month/Season	
Date/time of month	
Day of week	
Time of day	
Where did this take place?	
Country	
Region/State/Province	
City	
Street	
Address/Building	
Room/Part of building	
Part of room	
How clearly can you visualize this event?	**1** **2** **3** **4** **5** **6** Vague memory No recollection now … Extremely clear as if it were happening

How much did your emotional state change from before the event occurred to after it happened?	**1** **2** **3** **4** **5** **6** No change in how I felt ... Underwent tremendous emotional change
Personal Importance	
How personally important is this event to you now?	**1** **2** **3** **4** **5** **6** No importance at all ... Of great importance
How personally important **was** this event to you **then**?	**1** **2** **3** **4** **5** **6** No importance at all ... Of great importance
Rehearsal	
On average, how often do you think or talk about this event?	**1** **2** **3** **4** **5** **6** (see cue sheet)
Length of Event?	
What Marks the Beginning?	
What Marks the End?	
What happened right before your Beginning boundary? Same Event?	
What happened right after your End boundary? Same event?	
Right after your Beginning Boundary what happened? Could that be considered the beginning?	
Right before the memory ends you said what happened? Could that be considered the end?	
Is it in the context of a larger event? What is that event?	
Were there smaller events within this event? Name them	

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