Alpha suppression as a neural marker of task demands in voluntary vs involuntary retrieval in older and younger adults

Sarah Elizabeth Henderson

Psychology

Submitted in partial fulfillment
of the requirements for the degree of

Master of Arts

Faculty of Social Sciences,
Brock University
St. Catharines, Ontario

Abstract

Voluntary episodic memory relies on intentionally controlled retrieval, while involuntary episodic memory comes to mind automatically. Consistent with findings of reduced cognitive control with age, recent work suggests that voluntary memory declines with age while involuntary memory is relatively preserved. However, the neurophysiology underlying these age differences has yet to be established. The current study used EEG to test 31 young and 35 older adults during voluntary vs. involuntary retrieval (manipulated between-subjects). Participants first encoded sounds, half of which were paired with pictures, the other half unpaired. EEG was then recorded as they listened to the sounds, with participants in the involuntary group performing a sound localization task, and those in the voluntary group additionally attempting to recall the associated pictures. Participants later retrospectively reported which sounds brought the paired picture to mind during the sound task. Older adults said they remembered as many pictures as young adults, but their objective memory was lower on a final cued recall test. For the EEG analysis, older adults showed greater alpha event-related desynchronization (ERD; a neural marker of memory reactivation) for paired than unpaired sounds at occipital sites, possibly reflecting visual reactivation of the associated pictures. Young adults did not show memory-related alpha ERD effects. However, young adults did show greater alpha ERD during voluntary than involuntary retrieval at frontal and occipital sites, while older adults showed pronounced alpha ERD (indicative of effortful retrieval) regardless of condition. These data suggest that alpha ERD can be used as a neural marker of memory in older adults; however, a more naturalistic paradigm may be required to study true involuntary memory with age.

Keywords: memory, aging, oscillations, intentionality, cognitive control

Acknowledgements

I would like to thank everyone who supported me academically and personally through the completion of my Masters thesis. Firstly, my supervisor, Dr. Karen Campbell for her guidance and invaluable feedback throughout this project and for her continued support in my ongoing work. I would also like to thank my committee members Dr. Sidney Segalowitz and Dr. Veena Dwivedi for their expertise and encouragement throughout this process especially in guiding my understanding of EEG techniques.

I would like to thank the members of the CNA Lab especially Emily Davis who helped with this project from the start. Thank you also to the members of the BUCANL Lab especially James Desjardins, Tyler Kennedy Collins, Sara Stephenson, and Jessica Callegari for their expertise in EEG, programming, and technical assistance.

Thank you to my friends and family for their constant support and enthusiasm for my work even through my most stressful times.

Table of Contents

List of Tables

List of Figures

Alpha suppression as a neural marker of task demands in voluntary vs involuntary retrieval in older and younger adults

There is a prevailing view in the cognitive aging literature, and in western society more broadly, that aging is associated with general cognitive decline, a view that is especially prevalent as it pertains to age-related memory decline. While the presence of episodic memory decline with age is generally supported in the literature (Craik & Byrd, 1982), research has, until very recently, focussed largely on the study of voluntary episodic retrieval while ignoring the contributions of involuntary retrieval (Maillet & Schacter, 2016; Berntsen, 2010). These memory processes are distinct in that voluntary retrieval requires an active and intentional memory search, while involuntary memories are brought to mind without any effort, arising in response to internal or external cues, or in a seemingly random fashion (Berntsen, 1996). For example, the smell of poster paint may transport you to a childhood memory of a classroom with your favourite primary school teacher, or you may remember the details of a recent meeting while driving to work. While these involuntary memories are unique in their apparent spontaneity, the nature of their mental representation may be quite similar to voluntarily remembered episodes (i.e., specific in time and place, rich in detail and emotion).

Several studies suggest that involuntary memory is relatively well preserved with age (e.g., Berntsen, 2009), possibly because it relies less on frontally mediated control processes that have been shown to decline with age (Hasher & Zacks, 1979; West, 1996; Campbell et al., 2012). Recent functional magnetic resonance imaging (fMRI) work with younger adults has shown that involuntary retrieval does not recruit frontal control regions to the same extent as voluntary retrieval (Hall et al., 2014; Hall et al., 2018), though activation patterns in posterior regions associated with memory representation are similar across the two forms of retrieval. Thus, involuntary episodic memory may be preserved with age, while voluntary episodic memory declines because these two types of memory place markedly different demands on frontal control processes. The current study tests this theory by using electroencephalography (EEG) to investigate how voluntary and involuntary memory retrieval differs with age at a neural level.

Aging and Involuntary Memory

Recent work suggests that involuntary memory is preserved, at least in some capacities, with increasing age (Schlagman et al., 2009; Berntsen et al., 2015). Unlike voluntary retrieval, involuntary retrieval occurs spontaneously without an active memory search (Berntsen, 1996). Critically, these preserved involuntary memory processes are distinct from implicit memory in that they involve conscious recollection and are thus able to be cognitively monitored and evaluated by those experiencing them in terms of detail, vividness, and content (Berntsen & Hall, 2004). Naturalistic investigations of involuntary memory using diary reports (which rely on cognitive monitoring) have found that the frequency of involuntary autobiographical memories in daily life does not decline with age (Berntsen et al., 2015). In contrast, future thinking, daydreaming, and suppression of unwanted thoughts show declines (possibly due to limited attentional control associated with age; Berntsen et al., 2015). This effect has been replicated using a structured diary design directly comparing voluntary and involuntary retrieval, finding that older adults retroactively report fewer and less specific voluntary memories compared to younger adults, but show no difference in the number or specificity of reported involuntary memories (Schlagman et al., 2009).

More recently, Berntsen and colleagues (2017) examined age differences in voluntary vs involuntary memory using a movie-viewing paradigm, which allowed for greater experimental control over the to-be-recalled events. This greater control over memory content helped reduce the likelihood that any differences that arose between younger and older adults could be attributed to differences in the content of memory stores between groups. Participants viewed two short films with similar content (driving through a town) separated by an unrelated filler task. The number of spontaneous memories for details from the first film that arose while viewing the second film were recorded. In line with previous work, it was found that older adults did not differ from younger adults in the number of reported involuntary memories that arose during the second film. In contrast, older adults were slower to recall and reported fewer voluntary memories. Collectively, this work supports the preservation of involuntary retrieval with age both in naturalistic settings and those with more controlled content derived from experimental stimuli. However, the cognitive and neural mechanisms underlying the differential effects of age on voluntary and involuntary memory are still poorly understood.

Neural Underpinnings of Voluntary vs. Involuntary Memory

While the neural underpinnings of voluntary episodic memory have been studied extensively, investigation of the distinct processes underlying involuntary retrieval is still relatively new. Hall and colleagues (2014) examined this question in younger adults using experimentally encoded sound and picture pairs while manipulating retrieval conditions via task instructions. Their work suggests that both voluntary and involuntary retrieval are associated with increased activity in regions typically involved in memory retrieval including the medial temporal lobe, posterior midline, ventral parietal cortex, and sensory reactivation regions (in this case, superior occipital gyrus and precuneus reflecting the visual nature of the to-be-remembered stimuli). In contrast, voluntary memory was found to be uniquely associated with increased activity in the dorsolateral prefrontal cortex (dlPFC), which is in line with the notion that voluntary retrieval alone engages regions associated with effortful control. In further support of the unique role of frontal activation in intentional memory processes, activation of the dlPFC during memory tasks has been shown to be independent of retrieval success (Dobbins et al., 2003), supporting the view that activity in this region is associated with the intention to retrieve and not recollection itself.

Aging is typically associated with increased frontal activation during voluntary memory retrieval, which is often attributed to compensation (e.g., Grady et al., 1994; Cabeza, 2002; Gutchess et al., 2005; Reuter-Lorenz & Cappell, 2008). However, this increased activation does not always relate to better performance (Grady, 2012; Tays et al., 2008). It is possible that overactivation in frontal regions is at least partially attributable to declines in cognitive control, which necessitate compensatory over-recruitment to maintain task performance. Indeed, older adults have lower limits of attentional control capacity that are associated with reduced performance on tasks requiring effortful control (for a recent review, see Amer et al., 2016). This compensatory over-recruitment has been shown to be effective in maintaining performance at lower levels of task demands, but fails to improve performance when demands are increased beyond the limit of available resources (Cappell, et al., 2010). Thus, when task demands are high, as in voluntary retrieval, frontal activation may have reached its upper limit in older adults and frontal overactivation may therefore cease to be effective in improving performance. Since involuntary retrieval is less dependent on top-down control, age differences in frontal activation should be minimal when retrieval is not intentional.

Memory Effects in EEG

One of the most common ways to analyze EEG data is to examine event-related potentials (ERPs), that is, averaged EEG signal time-locked to an event. ERP studies of memory and aging suggest that there are dissociable effects of age on recollection (reflecting slower, more intentional retrieval) and familiarity (reflecting more automatic processes) such that older adults show reduced recollection-related parietal old/new effects around 500-700 ms post stimulus (Friedman et al., 2010) and relatively preserved mid-frontal familiarity effects around 300-500 ms (Nessler et al., 2007; Friedman et al., 2010). Since recollection is thought to depend on effortful control processes more than familiarity (Jacoby 1991; Jennings & Jacoby, 1993), we might expect a similar pattern of results when contrasting voluntary vs involuntary retrieval. Indeed, recent work investigating intentional and unintentional recognition supports the notion that unintentional recognition is associated with the rapid and automatic familiarity process, while intentional recognition additionally employs a slower and voluntarily controlled recollection process (Bergström et al., 2016). Further, older adults have been shown to have greater difficulty intentionally controlling retrieval orientation in a goal directed manner (for a review, see Morcom, 2016). ERP analysis has revealed that given identical cues, different retrieval orientations result in less distinctive retrieval orientation effects in older compared to younger adults (Morcom & Rugg, 2004). However, these ERP findings are controversial, and opposite patterns of effects have also been observed (Duarte et al., 2006; Friedman, 2013). These inconsistencies may be partially attributable to age-related increases in temporal variability of ERPs (Murray et al., 2019), which could lead to apparent age differences between conditions. Thus, despite their utility in providing precise temporal resolution, ERPs may not be ideal for studying age effects given that older adults' neural responses may not be as precisely time–locked as those of younger adults.

Another way to examine the neural correlates of memory is through event-related synchronization (ERS) and desynchronization (ERD) within specific frequency bands of the EEG signal (for a recent review, see Hanslmayr et al., 2016). In particular, alpha (8-12Hz) and beta (13-30 Hz) ERD have been positively associated with the encoding and reactivation of memories (Hanslmayr et al., 2012). This relationship between alpha and beta ERD and memory is thought to reflect the richness or detail of mental representations via increased neocortical firing rates (Hanslmayr et al., 2012). Accordingly, alpha ERD has been shown to vary systematically with the number of items retrieved as well as showing differences in topography according to the modality of the remembered stimuli (Burgess & Gruzelier, 2000; Khader & Rösler, 2011). Waldhauser et al. (2012) also demonstrated an association between alpha and beta power decreases and visual memory reactivation in their work investigating selective memory retrieval. Participants learned associations between centrally located shapes and paired colours that were presented in the left or right visual fields. Each shape was paired with either one or two colours. At retrieval, shapes were centrally presented with a cue to remember one of the associated colours. The alpha and beta ERD was greater over the hemisphere contralateral to the field in which the colour was presented at study, demonstrating a link between alpha and beta ERD and reactivation of visual information at retrieval (Waldhauser et al., 2012).

In addition to these oscillation-based memory effects, alpha ERD has also been linked more generally to cortical activation (Klimesch, 2012), or more precisely, the release from inhibition that is associated with spreading activation (Klimesch et al., 2007). Thus, frontal alpha ERD should be greatest when frontal regions are maximally active. Alpha ERD at frontal sites is thought to reflect activation of frontal control processes including executive control, directed attention, and top-down access to information (Klimesch, 2012; Misselhorn et al., 2019). Therefore, voluntary retrieval, which relies on engagement of frontal control regions (Hall et al., 2014), should be reflected by greater alpha ERD at frontal sites.

Current Study

The goal of the current study is to characterize neural activity associated with voluntary and involuntary retrieval in younger and older adults. To accomplish this, we used a two-part study adapted from Hall et al. (2014) which included a behavioural encoding session, followed by an EEG retrieval session that manipulated intention (voluntary vs involuntary), between subjects. In the first session, participants learned a series of semantically related sound-picture pairs and a series of unpaired sounds. To preserve the involuntary retrieval manipulation, participants were told that this was a study investigating age differences in the effect of context on sound localization, and that associating a picture with a sound is thought to affect our ability to localize a sound in space. This cover story was necessary to ensure that participants in the involuntary condition were not aware that their memory would be tested and reduce their likelihood of engaging in intentional retrieval.

In the second session, participants were randomly assigned to either the voluntary or involuntary retrieval condition. Sounds from the encoding phase were replayed and participants had to decide whether the sound was louder on the left or right. Participants in the voluntary condition were additionally instructed to retrieve the picture associated with each sound. After the localization task, participants listened to the sounds again and retrospectively reported for which sounds (during the sound localization task) they had remembered the associated picture. Retrospective reports of memory, rather than online reports during the sound localization task, were necessary in order to prevent participants in the involuntary group from switching to a voluntary retrieval strategy. Finally, explicit memory for the pairs was evaluated in a final cued recall task by having participants describe the images that corresponded to each paired sound. We examined age differences in ERD in both the alpha frequency band and across a broader frequency spectrum (3-30 Hz) in relation to memory evoked during the sound localization task (contrasting paired sounds that should evoke a visual memory with unpaired sounds that should not) and effortful retrieval (contrasting voluntary and involuntary retrieval groups).

Behaviourally, we expected no age difference in the number of reported memories in the involuntary retrieval condition, in line with previous work showing that involuntary memory is preserved with age (Schlagman et al., 2009; Berntsen et al., 2015; Berntsen et al., 2017). However, we expected older adults to perform worse than younger adults on the final cued recall task which requires explicit, voluntary retrieval. In regards to the EEG data, we expected visual reactivation of memories to be reflected by greater alpha ERD for paired than unpaired sounds (particularly over occipital sites, reflecting reactivation of the picture associated with the paired sounds; Waldhauser et al., 2012), and this difference in posterior alpha desynchrony should be similar for both voluntary and involuntary conditions (Hall et al., 2014). In the voluntary condition, older adults may show greater frontal alpha ERD than younger adults, reflecting frontal overactivation (e.g., Cappell, et al., 2010; Grady, 2012). In contrast, older adults are expected to show more similar patterns of activity to younger adults during involuntary retrieval, which places fewer demands on control regions known to decline with age. Finally, we expect occipital ERD to be greater for voluntary than involuntary retrieval across both age groups, reflecting increased external attention associated with the more demanding voluntary retrieval task (Klimesch, 2012).

Methods

Participants

Participants were 31 young adults (18-30 years; M = 21.06, SD = 2.83; 4 males) of which 15 were in the voluntary retrieval condition, and 35 older adults (65-80 years, M = 71.71, SD =

4.91; 10 males) of which 18 were in the voluntary retrieval condition. Two additional young and two additional older adults were recruited but failed to complete both sessions and were therefore excluded from analysis. Young adults were recruited from Brock University and received partial course credit for their participation. Older adults were recruited from the community and received monetary compensation of $10 per hour for their participation. All participants were right-handed and had normal or corrected to normal vision and hearing, and no history of neurological conditions which may interfere with electrophysiological recordings. Hearing was evaluated using a 12-item Hearing Screening Inventory (Coren & Hakstian, 1992), which has been shown to correlate highly with audiometric measures. The Montreal Cognitive Assessment (MOCA) (Nasreddine et al., 2005) was used to screen for mild cognitive impairment (see Table 1), and the Shipley vocabulary test was used to evaluate vocabulary knowledge (see Table 1). All questionnaires are provided in Appendix B.

Table 1

Demographics, Hearing, and Cognitive Assessments.

	Young Adults				Older Adults				*Young vs Old (t)*
	Overall (M(SD)) n=31	Voluntary (M(SD)) n=15	Involuntary (M(SD)) n=16	*t*	Overall (M(SD)) n=35	Voluntary (M(SD)) n=18	Involuntary (M(SD)) n=17	*t*	
Age	21.1 (2.83)	21.1(3.31)	21.0(2.39)	0.09	71.7(4.91)	72.3(4.74)	71.1(5.17)	0.83	49.9**
Years of Education	14.7(1.42)	14.7(1.16)	14.6(1.70)	0.11	16.0(1.56)	16.7(4.94)	15.1(3.04)	1.50	1.57
Hearing	20.6(3.93)	20.2(3.91)	20.9(4.04)	0.44	23.0(5.15)	22.9(4.18)	23.1(6.16)	.072	2.10*
MOCA	27.4(1.91)	27.6(1.96)	27.2(1.91)	0.54	25.5(2.47)	26.5(1.92)	24.5(2.62)	2.74*	3.58**
Shipley	28.8(4.24)	28.6(3.33)	29.1(5.05)	0.34	34.7(3.19)	35.0(2.95)	34.4(3.48)	0.51	6.29**

*$p<.05$, **$p<.001$

Stimuli.

Stimuli included 100 environmental sounds (e.g., dog panting, schoolyard sounds) and 100 semantically related coloured pictures (e.g., golden retriever on a beach, kids playing in a schoolyard) adapted from those used by Hall and colleagues (2014; see Figure 1). The images were primarily obtained from the International Affective Picture System (Lang et al., 2005), and the sounds were obtained from the SUN database (http://groups.csail.mit.edu/vision/SUN/). The paired sounds and images were divided into two lists of 50 and counterbalanced across the paired/unpaired and voluntary/involuntary conditions. The paired sounds and images were designed such that they were related to but could not be adequately described by simply describing the sound (e.g., panting sound with image of dog lying on a beach). The sounds were calibrated to be equal volume and have a duration of 700ms. During retrieval, the sounds were panned 50% to the left or right, such that the sounds were 50% louder on one side to facilitate the sound localization cover task.

Electroencephalography (EEG)

EEG was recorded with a 128-channel Active Two BioSemi system with CMS/DRL referencing. The sampling rate of the signals was 512 Hz which were digitized with a 24-bit analogue to digital converter. The recordings were made in a dimly lit, electrically shielded room and the visual stimuli were presented 60 cm from the participant. The auditory stimuli were presented through ER-2 headphones with 30 dB external noise exclusion and 70 dB isolation between ears. The volume was individually adjusted to a comfortable level using a calibration sound unrelated to the stimuli.

Procedure

Overview. Participants performed a two-part experiment with an encoding procedure on the first day, followed by a two-day break, after which participants returned for a recall session during which EEG was recorded. Older adult participants were met at designated parking spots and escorted to the testing rooms for both sessions. A cover story was used to preserve the involuntary retrieval manipulation which stated that the study was investigating the effect of contextual images on a sound localization task.

Session 1. Participants learned 50 semantically related sound and picture pairs and 50 unpaired sounds in a procedure adapted from Hall and colleagues (2014). Participants encoded the 50 paired stimuli three times: (i) the sound and picture were displayed simultaneously, the sound for 700 ms while the picture remained on screen for 4 s, and the participant verbally produced a sentence integrating the paired items, which was typed by the researcher; (ii) each sound-picture pair was presented again followed by the participant's previously generated sentence, which the participant was given the opportunity to edit; (iii) the sound was presented on its own followed by a 2 s break during which the participant could imagine the picture that was paired with it, immediately followed by the presentation of the pair together with a final opportunity to edit their sentence (Figure 1A). The unpaired sounds were then encoded by rating their uniqueness on an 8-point scale in comparison to the already encoded sounds (Figure 1B). The unpaired sounds were also 700 ms in length, followed by a 4 s response window. The sounds and pictures were counterbalanced such that each sound was in the paired category for half of the participants and in the unpaired category for the other half.

Session 2. Two days later, following EEG setup, the second session began with a re-encoding task for both the paired and unpaired sounds (Figure 1C). During the re-encoding run for the paired sounds, the sound (700 ms) and picture (4 s) were again presented simultaneously and participants were asked to consider the sentence they had previously generated (not represented this time) and rate on an 8-point scale how well the sound and picture went together given that sentence. The re-encoding of unpaired sounds was the same encoding task used in the first session, wherein participants were asked to rate the uniqueness of the sound on an 8-point scale.

The recall task was then performed, in which the 50 paired and 50 unpaired sounds were randomly mixed and panned 50 % to the left or the right (Figure 1D). Participants in the involuntary condition were asked to press with their index finger on the key that corresponded to the side from which the sound was louder through their headphones. A fixation cross was presented for a jittered amount of time between 500ms and 750ms before the sound onset. Each sound was presented for 700ms and participants were instructed to wait until after the sound and fixation cross (which persisted for 1000 ms) had offset before making their response. Participants in the involuntary group were instructed not to actively attempt to bring the pictures to mind but instructed that it was fine if the pictures came to mind spontaneously. This was in accordance with Hall and colleagues (2014) who found that ratings of effort during recall were lower in the involuntary group when explicitly instructed not to actively attempt to bring pictures to mind. Participants in the voluntary group were presented with the same sound localization task but were additionally asked to recall the pictures that had originally been paired with the sounds in as much detail as possible while performing the localization task. All sounds were played twice to maximize the number of trials for EEG analyses (200 trials in total, broken up into blocks of 50 trials).

Following the sound localization task, participants completed two tasks to assess their memory for the sound-picture pairs and to determine for which trials (during the sound localization task) they had picture memories come to mind. In the first of these tasks, participants were presented with both the paired and unpaired sounds intermixed and were asked to report whether a picture had come to mind when they heard the sound in the previous localization task (yes/no). They were additionally asked to report the vividness with which the picture had come to mind on an 8-point scale (0 = no picture, 7 = very clear), as well as whether they had put effort into recalling the picture (yes/no), and finally, how much effort they used on an 8-point scale (0 = no effort was made to remember, 7 = I tried quite hard to remember) (Figure 1E).

Finally, the 50 sounds that had been originally paired with pictures were then replayed and participants were asked to recall the associated picture in as much detail as possible. The picture descriptions were evaluated as either being an accurate or inaccurate description of the paired picture based on the criteria that the description contained accurate details about the image which could not be obtained from describing the sound alone.

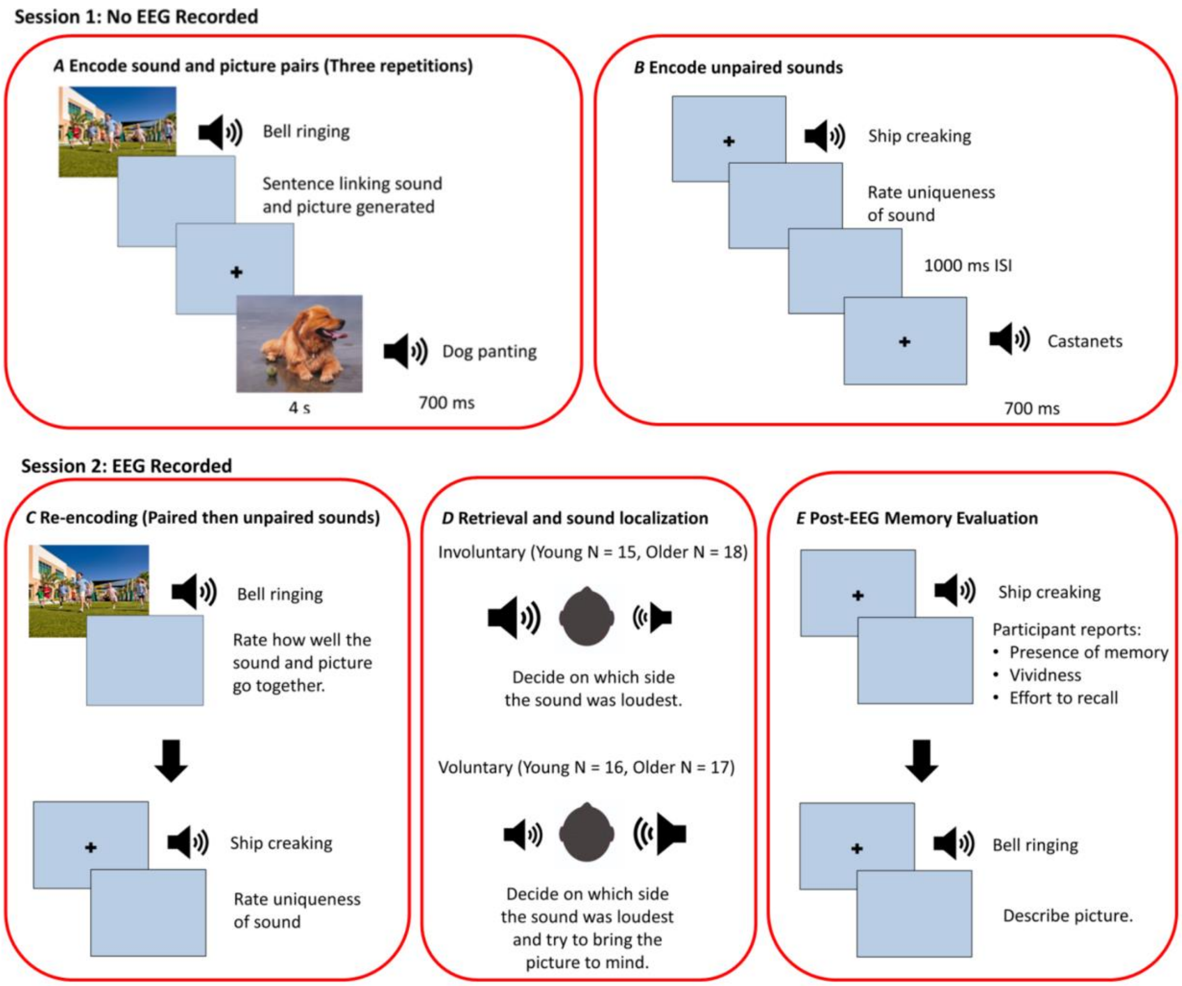


Figure 1. Experimental protocol for Session 1 (in which pairs were encoded) and Session 2 (in which retrieval was evaluated using EEG). A. Participants encoded paired naturalistic sounds and images by forming sentences to link them. B. Participants heard the unpaired sounds and judged them on their uniqueness. A two-day break preceded Session 2. C. Participants re-encoded the paired sounds and images learned in Session 1 by rating how well they went together given the sentence they had generated previously. D. Participants were randomly assigned to voluntary or involuntary retrieval conditions. Both groups performed the sound localization cover task where they were asked to judge from which side the sounds were louder. The voluntary retrieval group was additionally asked to try to bring the paired images to mind. E. Participants heard all the sounds again and were asked to report which ones they had had

memories for during the sound localization. Finally, they performed an explicit cued recall task to determine which pairs they could accurately remember.

Data Analysis Behavioural

Memory Data

Memory performance was scored according to responses during the retrospective memory task and the final cued recall task. First, using the responses from the retrospective memory task (which included both paired and unpaired trials), trials for which participants reported having a memory during the sound localization task were identified. Next, these trials (total said recalled) were separated into those sounds that were originally paired with a picture (paired said recalled), and those that were unpaired (unpaired said recalled, similar to false alarms). Finally, using the responses obtained from the final cued recall task, those trials which had descriptions containing sufficient detail (according to the criteria above) were identified as correctly recalled pairs.

Sound Localization Data

Percent accuracy for the sound localization task was calculated for each condition as the number of sounds correctly attributed to the correct source (left or right side) divided by the total number of sounds. Reaction times (RT) were also recorded for responses during the sound localization cover task. We reasoned that memory retrieval might interfere with the sound localization cover task, resulting in longer RTs when memories were recalled. For this purpose, trials were separated based on paired status (paired vs unpaired). RTs were limited to correct responses on the localization task, trimmed to retain those trials within 2.5 SD of the mean, and averaged for each individual/condition. The analysis was limited to those participants that retained at least half of the trials (young adult n = 26, older adult n = 23) to facilitate the within-subjects comparison of trial types.

Data Analysis EEG

Preprocessing. EEG data were pre-processed through an automated pipeline using custom code created using MATlab 2010b and executed on the Compute Canada network. The automated processing procedure followed the steps described by Desjardins and Segalowitz (2013), and van Noordt et al. (2015). In short, the preprocessing involved flagging channels and in-task time based on distribution of channel-neighbour correlations. This allowed the pipeline to identify and remove artifacts to improve blind source separation using independent components analysis (ICA). Cortical classifications of independent components were performed to remove non-cortical components such as biological artifacts and stationary noise. Three consecutive ICAs were run to check for consistency across analyses. Time frequency decomposition was accomplished with FFT using Hanning windows as tapers with a window length of 4000 ms that slid over the data in 50 ms increments. The analysis was performed with 1 Hz steps from 3-30 Hz between -1500 and 3000 ms around the sound stimulus onset at retrieval. Power changes were calculated in relation to the pre-fixation-cross window of -1000 to -500 ms pre stimulus onset to avoid eliminating important group differences that may have arisen after fixation cross onset.

Time frequency analysis. Given our a priori hypotheses that differences should arise at frontal and occipital sites, we selected two groups of electrodes to represent these regions of interest (ROIs) to allow for stronger claims to be made about the location of the effects than may otherwise be reasonable for the cluster-based statistical analysis we also employed (see below; Pernet et al., 2015). The frontal ROI was defined as the average across seven electrodes approximating the positions of Fz, F1, and F2. The occipital ROI was defined as the average across eight electrodes approximating the positions of Oz, O1, O2, and POz. These ROIs were selected to broadly represent the areas of interest defined by previous studies investigating visual long term memory effects (Waldhauser et al., 2011; Khader & Rösler, 2011) as well as frontal top-down control (Misselhorn et al., 2019). Within these ROIs, we examined age and condition differences across a range of frequencies (3-30 Hz). Though our main predictions in the memory domain focused on visual reactivation of memories reflected by occipital ERD, frontal sites were also assessed to determine whether frontal control regions showed greater ERD for paired than unpaired trials which might reflect controlled access of memories for the paired trials compared to relative dismissal of the unpaired trials (Klimesch, 2012).

In addition to the ROI analysis, we also ran a whole scalp analysis using individual alpha frequency (IAF). Previous work has consistently shown age-related slowing in IAF (Woodruff & Kramer, 1979, Knyazeva et al., 2018). IAF has been shown to represent a stable individual trait (Grandy et al., 2013) and its use in research within and beyond the aging literature has become increasingly common. Since our aim in the present study was to establish age-related differences in oscillatory power, especially in the alpha frequency range, it was important to consider individual differences in IAF instead of taking the more traditional approach of averaging across a predefined alpha range. Therefore, to ensure that the frequencies selected for analysis best represented each individual's true alpha activity we selected an individualized frequency range for each participant. We computed IAF for each individual by plotting the mean power spectrum with 0.5 Hz precision over the whole scalp and visually inspecting spectra to detect peaks between 7 and 13 Hz. This yielded an average IAF of 11.10 Hz (SD = 1.22) for younger adults, which was significantly higher than that of older adults, M = 10.37 Hz (SD = 1.14), $t = 2.50$, $p =$

.015. Whole scalp cluster analyses were subsequently run using the individualized frequency range which was averaged across IAF +/-2 Hz for each participant.

Trials were segmented according to paired and unpaired status as well as according to retroactive memory performance. Subsequent analyses used paired and unpaired sounds rather than paired sounds that were correctly recalled on the final cued recall test because 1) this was the approached used by Hall et al. (2014) and 2) older adults had fewer correctly remembered trials than younger adults (making group comparisons difficult; see Table 2). This choice was further validated by comparing older adults' neural activity during the sound localization task for all paired trials to only those that were later correctly remembered (this analysis was not possible for the young given their small number of paired but not remembered trials). This comparison yielded no significant differences (*p*s >= .169); thus, subsequent analyses used all paired trials.

Statistical analyses of the EEG data were performed using FieldTrip software (Oostenveld et al., 2011). To test for statistical differences between conditions we employed non-parametric permutation tests with 1000 iterations and cluster-based correction for multiple comparisons (Maris & Oostenveld, 2007). This process was used for both the whole scalp analysis using IAF (where clusters were determined according to neighbouring locations and timepoints) and the 3-30 Hz ROI analyses (where clusters were determined according to neighbouring timepoints and frequencies). FieldTrip could not be used to test the 2 age (young, old) x 2 voluntariness (voluntary, involuntary) fully between-subjects interaction. Thus, STATSLAB (Campopiano et al., 2018) was used for this comparison. For this analysis, the distribution of difference scores was generated through a bootstrapping procedure with 1000 iterations, differences across the entire time window were evaluated (-1 s to 3 s) and corrected for multiple comparisons with the Benjamini-Hochberg procedure for correction (Benjamini & Hochberg, 1995).

Results

Behavioural

Subjective Effort of Retrieval

Subjective effort ratings pertaining to memory retrieval during the sound localization cover task were collected during each trial of the retrospective memory task and averaged within each participant. They were then subjected to a 2 Age (young, old) x 2 Voluntariness (voluntary, involuntary) between-subjects ANOVA. There was no main effect of voluntariness, $F(1, 54) = 0.02$, $p = .895$, with the voluntary (M = 2.46 SD = 0.27) and involuntary (M = 2.42, SD = 0.23) groups reporting similar retrospective ratings of retrieval effort during the sound localization task. There was a significant main effect of age, $F(1, 54) = 11.32$, $p = .001$, $\eta^2 =.173$, such that older adults reported higher retrieval effort (M = 3.04, SD = 0.25) than younger adults (M = 1.84, SD = 0.26). There was no significant interaction between voluntariness and age, $F(1, 54) = 0.06$, $p = .809$. Thus, older adults reported higher effort of retrieval overall which was similar across voluntariness conditions.

Memory Performance

Paired Sounds. To determine whether age and retrieval intention affected the number of memories participants reported having for paired sounds during the sound localization task, retrospective “yes” responses for paired sounds were submitted to a 2 Age (young, old) x 2 Voluntariness (voluntary, involuntary) between-subjects ANOVA (see Table 2 for means). The ANOVA revealed a significant main effect of age, $F(1, 62) = 27.32$, $p < .001$, $\eta^2 = .303$, but no effect of voluntariness, $F(1, 62) = 0.01$, $p = .931$, and no interaction between age and voluntariness, $F(1, 62) = .821$, $p = .368$. Older adults reported fewer memories for paired sounds than younger adults overall, $t(64) = 1.84$, $p < .001$ (see Table 2). Indeed, even in the involuntary condition, older adults reported having fewer memories than younger adults during the sound localization task, $t(31) = 3.96$, $p < .001$, contrary to our hypotheses.

False Alarms. Reporting a memory for an *unpaired* sound during the retrospective memory task could be considered a false alarm of sorts, since these sounds did not have pictures associated with them at encoding and so should not have resulted in a pictorial memory. These false alarms were submitted to a 2 Age (young, old) x 2 Voluntariness (voluntary, involuntary) between-subjects ANOVA (see Table 2 for means). The ANOVA revealed a significant main effect of age, $F(1, 62) = 20.56$, $p < .001$, $\eta^2 = .245$, but no effect of voluntariness, $F(1, 62) = 1.02$, $p = .318$, and no age by voluntariness interaction, $F(1, 62) = 0.24$, $p = .625$. As shown in Table 2, older adults made more false alarms to unpaired sounds than younger adults, $t = 4.53$, $p < .001$, saying that they had recalled a picture when they heard the sound, even though that was not possible (or at least, they could not have remembered a picture from the encoding phase).

Total said Recalled. Combining retrospective memory responses to the paired and unpaired sounds together yields a measure of the total number of sounds for which participants said they had an associated visual memory on the sound localization task. This total recall score was submitted to a 2 Age (young, old) x 2 Voluntariness (voluntary, involuntary) between-subjects ANOVA (See Table 2 for means). The ANOVA revealed no significant main effect of age, $F(1, 62) = .293$, $p = .652$, no main effect of voluntariness, $F(1, 62) = 1.46$, $p = .232$, and no interaction between age and voluntariness, $F(1, 62) = 1.83$, $p = .181$. Therefore, there were no group differences in the total number of reported memories, even though (as already discussed) some of these memories were false.

Final cued recall. The number of correctly recalled pictures on the final cued recall task was submitted to a 2 Age (young, old) x 2 Voluntariness (voluntary, involuntary) between-subjects ANOVA (See Table 2 for means). There was a significant main effect of age, $F(1, 62) = 63.93$, $p < .001$, $\eta^2 = .504$, no effect of voluntariness, $F(1, 62) = .845$, $p = .362$, and no age by voluntariness interaction, $F(1, 62) = 0.16$, $p = .691$. Younger adults successfully recalled more pictures in response to the sounds on the final cued recall task than older adults, $t(64) = 8.09$, $p <$ 001.

In summary, older adults did not differ in the number of memories they reported having (total said recalled) but reported more false memories for unpaired sounds, and fewer correctly identified pairs on the final cued recall task. These effects did not differ according to voluntariness condition, possibly due to the voluntary nature of the retrospective reporting procedure. This indicates that older adults had poorer memory performance overall and that even involuntary memory differed with age within the current paradigm.

Table 2. *Memory Performance of Young and Older Adults in Voluntary and Involuntary Retrieval Conditions.*

	Young Adults				Older Adults				*t*
	Overall (M(SD))	Voluntary (M(SD))	Involuntary (M(SD))	*t*	Overall (M(SD))	Voluntary (M(SD))	Involuntary (M(SD))	*t*	
Total said recalled	48.3(2.15)	48.1(3.08)	48.5(2.99)	0.10	47.0(2.02)	50.7(2.82)	43.2(2.90)	1.87	0.45
Paired said recalled	43.7(1.34)	42.9(1.92)	44.4(1.86)	0.56	34.1(1.26)	35.0(1.75)	33.2(1.81)	0.73	5.23**
Unpaired said recalled (i.e. false alarms)	5.50(1.41)	6.00(2.03)	5.00(1.96)	0.36	14.3(1.33)	15.7(1.85)	12.9(1.90)	1.09	4.53**
Correctly recalled on final cued recall task	39.5(1.49)	39.0(2.14)	40.1(2.07)	0.36	23.2(1.40)	21.8(1.95)	24.53(2.01)	-0.96	7.99**

***p*<.001

Sound Localization Accuracy

Accuracy on the cover task (sound localization) was analyzed using a 2 Age (young, old) x 2 Voluntariness (voluntary, involuntary) between-subjects analysis ANOVA. The ANOVA revealed a significant main effect of age, $F(1, 62) = 4.13$, $p = .044$, $\eta^2 = .065$, such that older adults (M = 0.73, SD = 0.29) were less accurate on average than younger adults (M = 0.87, SD = 0.23). There was no significant main effect of voluntariness, $F(1, 62) = 0.44$, $p = .511$, and no age by voluntariness interaction, $F(1, 62) = 0.72$, $p = 0.400$. Thus, younger adults had better performance on the sound localization cover task than older adults, but voluntariness of retrieval did not influence cover task performance.

Reaction Times for Sound Localization Task

If participants were engaged in memory retrieval (either voluntary or involuntary) during the sound localization, then we might expect slower RTs for paired than unpaired sounds (as only the former should bring an associated picture to mind). To this end, sound localization RTs from correct trials only were submitted to a 2 Age (young, old) x 2 Voluntariness (voluntary, involuntary) x 2 Pair type (paired, unpaired) mixed ANOVA (see Figure 2). The main effect of age was not significant, $F(1, 46) = 2.53$, $p = .118$, $\eta^2 = .052$, while the main effect of voluntariness was significant, $F(1, 46) = 4.99$, $p = .030$, $\eta^2 = .098$, with slower RTs during voluntary (M = 526.6 ms, SD = 83.82 ms) than involuntary (M = 473.3 ms, SD = 84.85 ms) retrieval. Importantly, there was a main effect of pair type, $F(1, 46) = 6.56$, $p = .014$, $\eta^2 = .125$, such that participants were slower to respond to paired (M = 505.9, SD = 87.20) than unpaired (M = 494.0, SD = 84.66) sounds. None of the interactions were significant: age x voluntariness, $F(1, 46) = 0.64$, $p = .427$; voluntariness x pair type, $F(1, 46) = 1.80$, $p = .186$; age x pair type, $F(1, 46) = 1.62$, $p = .209$; age x voluntariness x pair type, $F(1, 46) = 0.60$, $p = .808$. Thus, participants were slower on average to respond on trials that were originally paired with an image at encoding compared to unpaired trials, suggesting that bringing the image to mind (at least on some trials) may have interfered with/slowed their localization response.

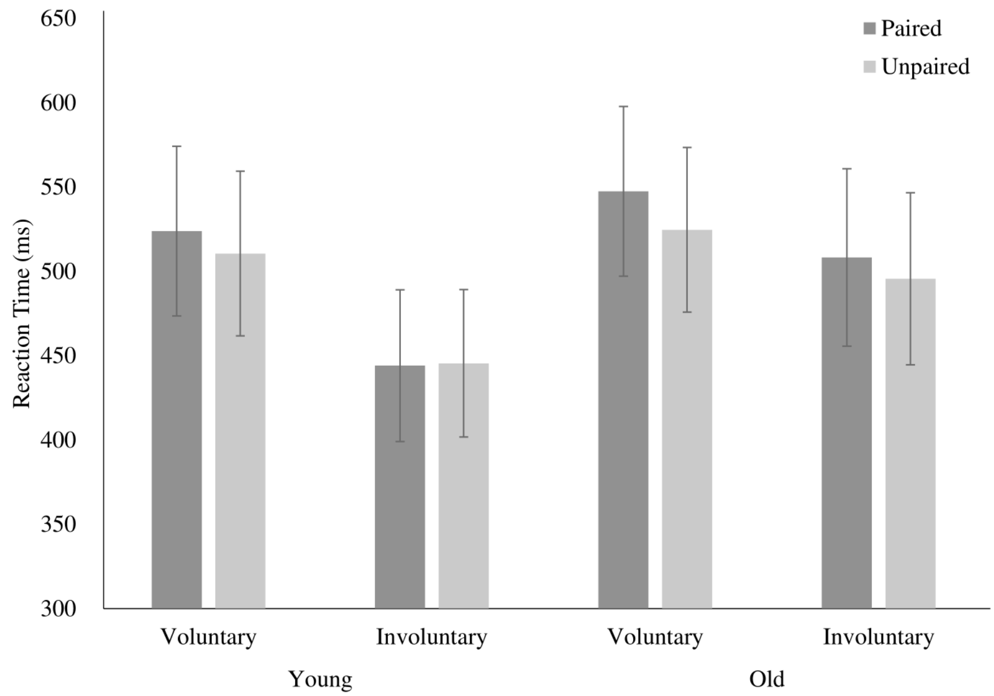


Figure 2. Reaction times for the sound localization task separated by age group and voluntariness condition. Error bars represent 95% CI. Effects separated for paired and unpaired trials. A main of effect of pair type was observed such that paired trials had slower reaction times than those with no associated image (p = .014). A main effect of voluntariness was also observed such that responses were slower during voluntary than involuntary retrieval (p = .030).

EEG

Memory Effects

Young. We expected greater alpha desynchrony for paired than unpaired sounds during the sound localization task reflecting reactivation of the associated pictures in visual regions. In young adults, whole scalp cluster analysis using IAF revealed no significant differences between paired and unpaired sounds (*p*s >= .348). Further, our ROI analysis found no significant differences between paired and unpaired trials at both frontal (*p*s >= .869) and occipital ROIs (*p*s >= .215; Figure 3) across all frequencies assessed (3-30 Hz).

Moreover, there was no significant interaction between voluntariness and pair type using IAF across the whole scalp (ps >= .611). Additionally, there was no significant interaction within either of the regions of interest (mid frontal, ps > .374; or occipital, ps >= .464).

Old. Whole scalp cluster analysis of alpha activity using IAF revealed a non-significant, but marginal memory effect ($p = .073$) that was driven by a cluster beginning at 900 ms post stimulus onset and persisted until 1300 ms with a midline topography mainly centred at mid frontal and occipital sites (Supplementary Figure 1 in Appendix A). In assessing activity at a predefined occipital ROI, we found a significant difference between paired and unpaired trials driven by a significant cluster in the alpha to low beta range with a time course between 1.5s to 2.1s ($p = .023$), as would be predicted by previous work linking alpha desynchrony to memory reactivation in related sensory areas (Figure 3). This effect was not significant at the mid-frontal ROI (ps > = .148).

No interaction between voluntariness and pair type was observed in older adults on alpha activity using IAF-based whole scalp cluster analysis (ps >= .434), or in either the frontal (ps >= .415) or occipital ROIs (ps >= .593), suggesting that ERD-related memory effects were similar for the older voluntary and involuntary retrieval groups.

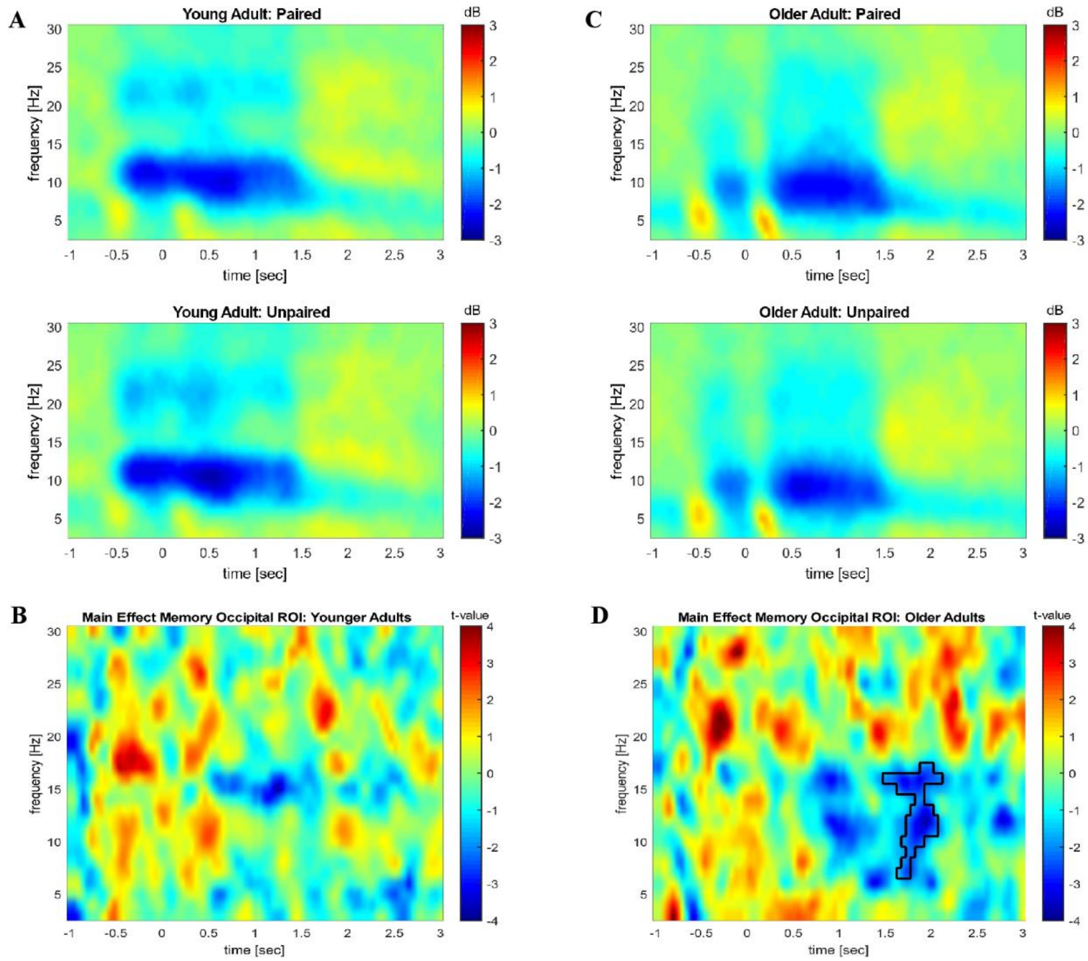


Figure 3. Time-frequency plots displaying memory-related differences separately in younger and older adults for the occipital ROI. A. Time-frequency plots of activity in paired (top) and unpaired (bottom) trials in young adults. B. Difference plot displaying t-values for the comparison between paired and unpaired trials in younger adults, no significant effects are observed. C. Time-frequency plots of activity in paired (top) and unpaired (bottom) trials in older adults. D. Difference plot displaying t-values for the comparison between paired and unpaired trials in older adults. Outlined cluster shows relative ERD in the alpha and beta range was significantly greater for paired than unpaired sounds (p = .023).

Voluntariness Effects

Interaction (Voluntariness by Age). The effects of retrieval intention and age were first examined by submitting time frequency data from the occipital and frontal ROIs (for paired sounds only) to two separate 2 Age (young, old) x 2 Voluntariness (voluntary, involuntary) between-subjects analyses (see methods for details). These analyses revealed significant interactions at both predefined ROIs (frontal and occipital) such that the observed desynchronization in the alpha frequency range (approximately 8-12 Hz) was greater for older adults than younger adults when retrieval was involuntary. This enhanced ERD during involuntary retrieval for older adults was present between 300 ms and 2500 ms post stimulus onset (Figure 4). We followed up on this interaction by examining the effect of age within the voluntary and involuntary groups separately, using both whole-scalp IAF and ROI (3-30 Hz) analyses.

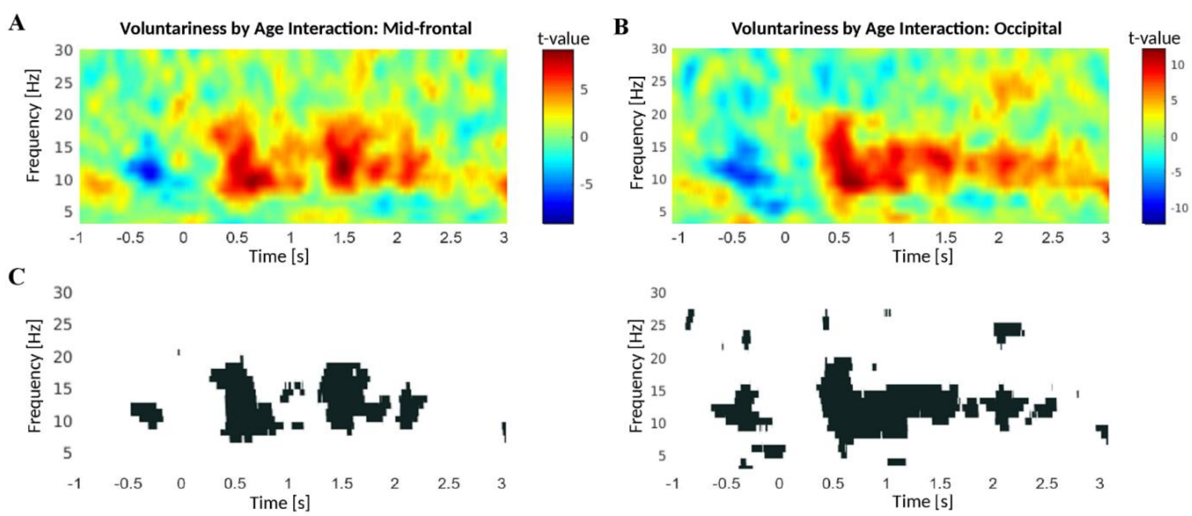


Figure 4. Time-frequency plots of the interaction between voluntariness and age at frontal and occipital ROIs. Voluntariness by age interaction ((voluntary old-voluntary young)-(involuntary old-involuntary young)) plotted by t-value over all frequencies analysed at the mid-frontal (A) and occipital (B) ROIs. C. Black regions indicate statistically significant points in the plots above (left: mid-frontal; right: occipital) (*p* < .05, after Benjamini-Hochberg correction).

Voluntary. Using IAF across the whole scalp, there were no significant age effects in the voluntary condition (*p*s >= .115). In the ROI analyses, the occipital ROI assessed across all frequencies did not significantly differ when comparing older and younger adults in the voluntary condition, suggesting that older and younger adults similarly engaged occipital regions under the voluntary retrieval condition. There were also no age differences in the frontal ROI across all frequencies (*p*s >= .214), suggesting that older and younger adults similarly activated frontal regions under voluntary retrieval conditions. In Figure 5, ERSPs from mid-frontal and occipital ROIs are plotted to illustrate similar response patterns across groups between 3-30 Hz.

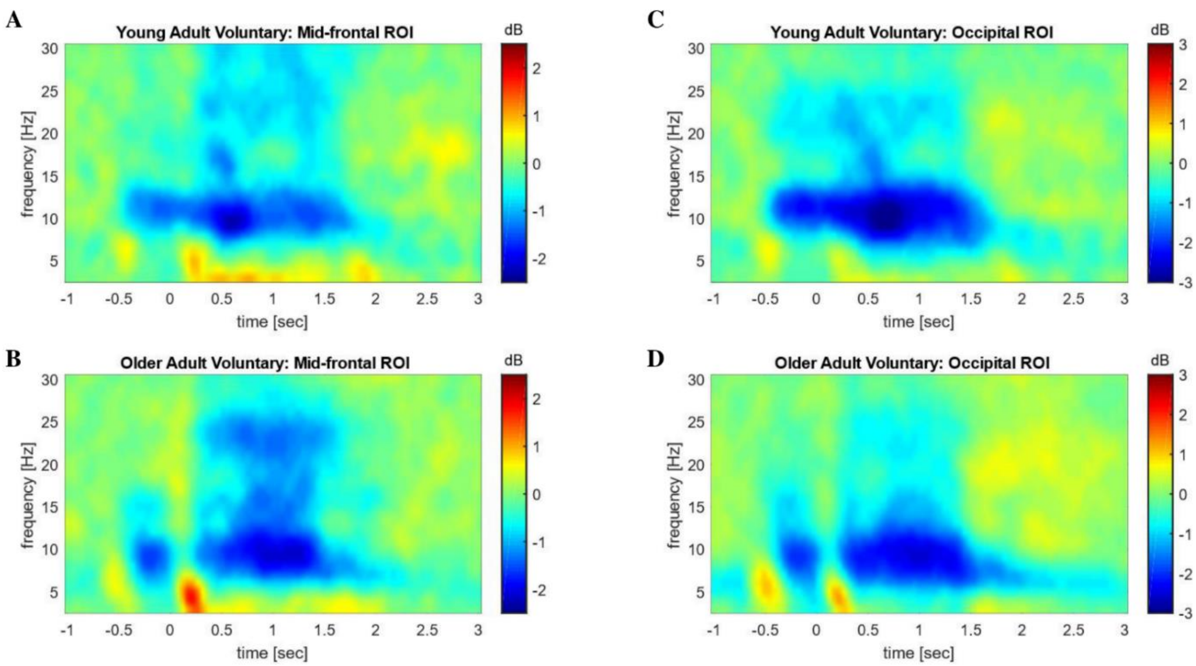


Figure 5. Time-frequency plots showing similar patterns of alpha desynchronization across age groups at frontal (A and B) and occipital (C and D) ROIs in the voluntary retrieval condition.

Involuntary. Using IAF across the whole scalp in the involuntary condition, we found a significant difference between young and older adults ($p = .018$). This difference was driven by a cluster spanning between 1.4 s and 3 s post stimulus onset with a combined frontal and occipital topography (see Figure 6A).

In the ROI analyses, we also found a significant difference between young and older adults at the mid-frontal ROI, this difference was driven by a cluster in the high alpha to beta range, spanning from 500 ms to 2400 ms post stimulus onset (*p* = .003; see Figures 6B and C). Additionally, we identified a significant difference between young and older adults at the occipital ROI (*p* = .044). This difference was driven by a later cluster in the alpha range, spanning from 1600 ms to 3000 ms post stimulus onset (see Figures 6D and E). Taken together, these effects suggest that older adults show greater engagement of frontal control and occipital regions than younger adults during involuntary retrieval.

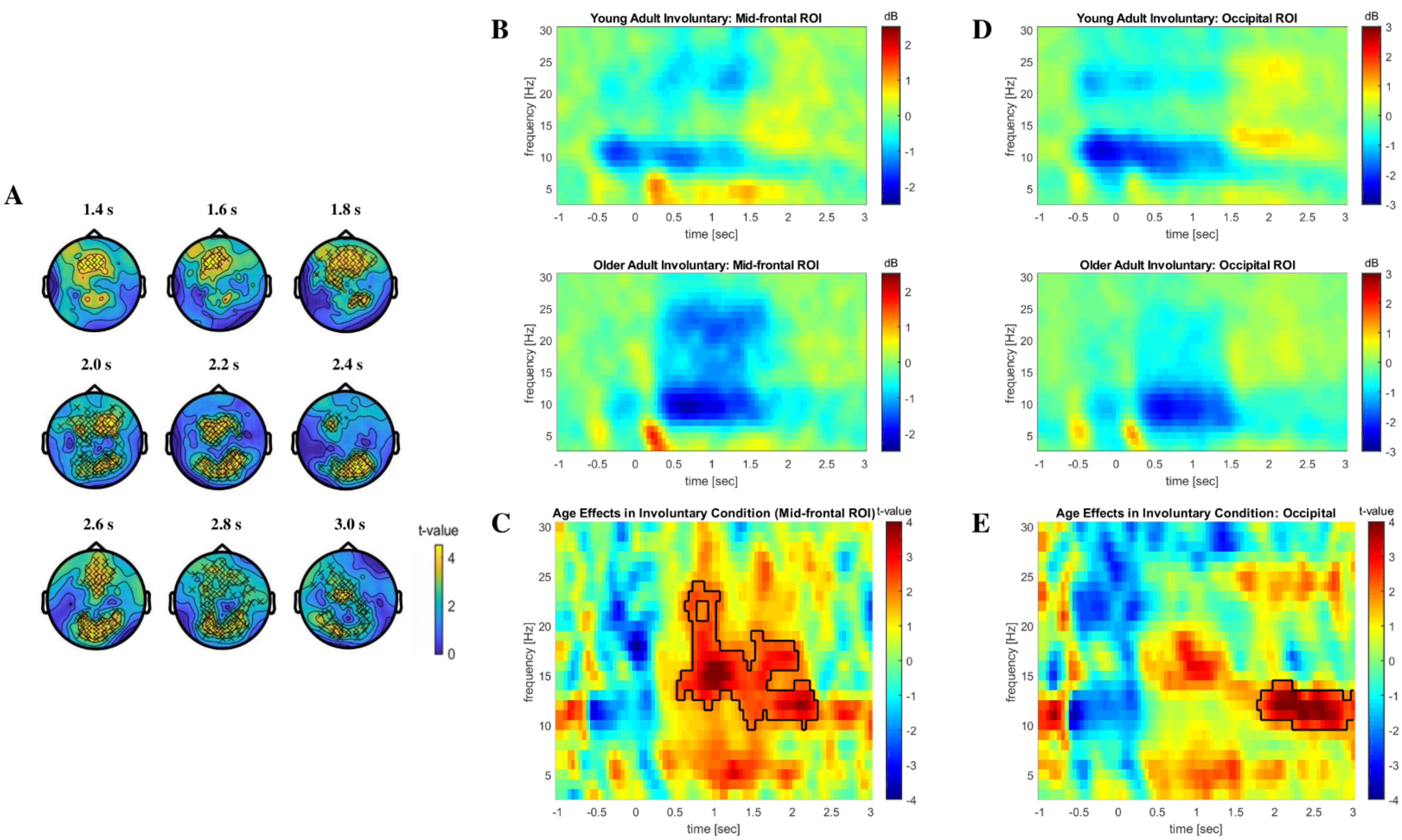


Figure 6. Age differences during involuntary retrieval. A. Topographies illustrating significant clusters observed using IAF to compare older and younger adults in the involuntary condition, ‘x’s represent electrodes that are part of a significant cluster at a given time. B. Time frequency plots for the frontal ROI in young and older adults relative to pre-fixation baseline. C. Outlined

cluster showing significantly greater ERD in older than younger adults in the alpha/beta range for the frontal ROI (p = .003). D. Time frequency plots for the occipital ROI in young and older adults relative to pre-fixation baseline. E. Outlined cluster showing significantly greater ERD in older than younger adults in the alpha/beta range for the occipital ROI late in the trial (p = .044).

Hearing and Alpha

Finally, to rule out the possibility that age differences in alpha desynchrony were caused by hearing loss (Petersen et al., 2015; Peelle & Wingfield, 2016), we examined whether Hearing Inventory Scale scores correlated with alpha ERD (using IAF across all sites and the entire trial length and for paired trials only) separately in our young and older adult groups. In young adults, Hearing Inventory Scale scores did not correlate with alpha ERD in either the voluntary (*p*s >= .486) or involuntary conditions (*p*s >= .192), or in the two groups combined (*p*s >= .434). Similarly, Hearing Inventory Scale scores did not correlate with alpha ERD in older adults in either the voluntary (*p*s >= .232) or involuntary (*p*s >= .261) conditions, or in the two groups combined (*p*s >= .163).3.

Discussion

A well-established finding in the aging literature is that cognitive functions that place greater demands on cognitive control, such as explicit voluntary memory, show greater age-related declines than relatively automatic functions (Hasher and Zacks, 1979; Amer et al., 2016). Our study expands on past literature by examining the neural underpinnings of involuntary memory, which places fewer demands on cognitive control (Schlagman et al., 2009; Berntsen et al., 2017). To do this, we investigated the effects of age and voluntariness on behavioural memory performance and EEG activity using a paradigm that involves retrieval of experimentally encoded memories. Older adults retrospectively reported a similar number of memories as younger adults during the sound localization task, but some of these memories were false (i.e., for unpaired sounds) and they objectively recalled fewer correct pairs on the final cued recall task. Moreover, contrary to our expectations, memory performance did not vary according to voluntariness condition. Nevertheless, both older and younger adults responded more slowly to paired than unpaired sounds on the sound localization task, suggesting that they did bring the image to mind (at least on some trials) and this slowed their localization response. The EEG data showed that older, but not younger, adults exhibited the expected memory effect of increased alpha ERD over occipital sites in response to paired relative to unpaired sounds, suggesting that they reactivated the associated pictures at retrieval. This effect did not vary with voluntariness condition, possibly because older adults were engaged in voluntary retrieval regardless of condition. Unlike young adults, who showed greater alpha ERD over frontal and occipital sites during voluntary retrieval relative to involuntary retrieval, older adults showed pronounced alpha ERD across both conditions indicative of top-down control.

In regards to the EEG memory effects, older adults' increased alpha ERD to paired relative to unpaired sounds suggests that they were reactivating the visual memory in response to the associated sounds (Khader & Rösler, 2011; Waldhauser et al., 2012). Most previous studies investigating event related desynchronization as a neural correlate of memory retrieval have used intentional (voluntary) retrieval tasks (for reviews, see: Klimesch, 1999; Hanslmayr et al., 2012). It is therefore not surprising that older adults, who possibly engaged in voluntary retrieval across both voluntariness conditions, showed the expected main effect of memory with greater alpha ERD for paired than unpaired trials, while younger adults did not. Unlike older adults, young adults showed greater alpha ERD during voluntary than involuntary retrieval (Figures 4 & 5), suggesting that they only engaged in effortful retrieval in the former condition. While the voluntariness x pair type interaction was not significant in the younger group, it is possible that collapsing across voluntariness in this group washed out any memory effects that may have present in the voluntary group alone.

While these memory effects are thought to reflect memory reactivation and thus be independent of retrieval orientation (Dobbins et al., 2003), there may be other factors that contributed to the non-significant memory effect in our younger adults. The nature of the naturalistic auditory stimuli used in the present study (700 ms in length) may have reduced the time locking of memory reactivation between trials, as well as between subjects. This in turn may have reduced the likelihood of finding memory effects in the EEG signal, particularly when retrieval is involuntary and therefore held in mind for a shorter duration. In support of this difference in retrieval duration, older adults have been shown to display greater neural activation in post retrieval monitoring (McDonough et al., 2012), which may explain the late (1400 to 2500 ms post stimulus) memory effects observed solely in the older adults here. Additionally, temporal differences in involuntary memory onset have been observed using similar paradigms in patients with PTSD, wherein patients had later onset of involuntary memory effects than controls (Hall et al., 2018). This supports the notion that different populations may have systematically different timing of involuntary memory retrieval. Finally, the encoding procedure, which involved learning of both the sound-image pairs and the unpaired sounds, was unique from previous EEG work which often compares old vs new memory stimuli (e.g. Nessler et al., 2007). Familiarizing participants with both types of stimuli was necessary for the current paradigm, but it may have limited the size of the difference in alpha ERD between remembered and ‘not remembered’ trials because all stimuli were old in this case (i.e., the unpaired sounds were not new to participants, unlike the new condition in most memory studies).

Turning to the effects voluntariness, a significant interaction between age and voluntariness was observed wherein older adults showed greater alpha ERD than younger adults in the involuntary condition both at frontal sites previously associated with cognitive control (e.g. Koechlin et al., 1999; Vincent et al., 2008) and occipital sites which may reflect heightened attention through relative release from inhibition (Klimesch, 2012). There were no age-related differences in the voluntary retrieval condition and older adults demonstrated similar patterns of activity during voluntary and involuntary retrieval. This finding does not support our predictions that 1) age differences would be minimal during involuntary retrieval and 2) older adults would over-recruit frontal regions during voluntary retrieval. However, our data are consistent with previous demonstrations of older adults reaching peak engagement of frontal sites during less demanding conditions (Reuter-Lorenz & Cappell, 2008; Cappell et al., 2010) – in this case, involuntary retrieval. Older adults may have maxed out control regions during the relatively less demanding involuntary retrieval condition. This is also consistent with previous work showing widespread over-recruitment associated with retrieval success in old compared to younger adults (Morcom et al., 2007; Duverne et al., 2008). This over-recruitment does not always predict greater retrieval success and may predict poorer performance in some cases, either because it is related to attempts to compensate for more limited resources (Cabeza, 2002; Duarte et al., 2006), or cortical dedifferentiation associated with poor efficiency (Cabeza, 2002; Morcom et al., 2003; Duverne et al., 2008).

However, older adults' increased frontal activation during involuntary retrieval in this study likely does not reflect a change in the way the aging brain carries out involuntary memory, but rather their use of voluntary retrieval. We suspect that our older participants were engaged in voluntary retrieval regardless of condition, as older adults often suspect that their memory will be tested in the lab due to increased concerns about memory performance (e.g., Barber & Mather, 2014). Young adults, on the other hand, showed greater alpha ERD at frontal and occipital ROIs during voluntary than involuntary retrieval. This may reflect their heightened attention (occipital) and effortful cognitive control (frontal) during voluntary compared to involuntary retrieval. These findings are in line with those of Hall and colleagues (2014), who showed that dlPFC activity was uniquely associated with voluntary retrieval in younger adults. Critically, older adults showed significantly greater alpha ERD than younger adults in the involuntary condition both at frontal (500 to 2400 ms post stimulus onset) and occipital (1600 to 3000 ms) ROIs, suggesting that older adults were engaging in voluntary retrieval in both conditions, while younger adults showed distinct patterns of alpha ERD between conditions. This supports the notion that older adults were engaged in effortful retrieval in the involuntary as well as voluntary conditions while younger adults differentiated between retrieval modes (Morcom, 2016).

Further evidence of older adults' effortful retrieval in the involuntary condition can be taken from their effort ratings. Participants provided effort ratings during the retrospective memory task, reflecting back on how much effort they put into retrieval during the sound localization task. Older adults rated their effort higher than younger adults, with no influence of voluntariness condition, suggesting that the voluntariness manipulation did not affect their effort to recall (though it is possible that these ratings are not very meaningful when comparing between groups due to differences in use of the scale). Young adults gave overall very low effort ratings suggesting that despite the success of the voluntariness manipulation in terms of producing neural differences in younger adults, younger adults did not expend much effort in trying to retrieve the associated pictures in either condition. This may be because retrieving the overly learned, semantically related pairs was indeed easy for them (as suggested by their near perfect final cued recall performance). Thus, the relatively high effort ratings of older adults across conditions suggests that despite the apparently effective manipulation in younger adults in the present study and in previous work (Hall et al., 2014), older adults did not differentiate between retrieval conditions and instead always engaged in more effortful retrieval.

Another factor that may have contributed to the non-significant difference between voluntary and involuntary retrieval in our older adults is the type of paradigm used here. While previous work investigating involuntary memory has primarily used autobiographical memory (Schlagman et al., 2009; Berntsen et al., 2015; Berntsen et al., 2017), the current task used paired associates which are particularly difficult for older adults to learn/recall (Old & Naveh-Benjamin, 2008). Additionally, the autobiographical memories used in previous studies may be more salient or memorable for older adults than the experimentally induced associations used here, possibly contributing to older adults' greater success in involuntary retrieval in previous work. Given that age-related memory deficits typically observed in associative memory tasks are not as large when the items are semantically related (e.g., Sharps & Antonelli, 1997), we used semantically related pairs to facilitate optimal performance in older adults. Despite this measure, we found overall worse performance in older adults, suggesting that even semantically related pairs do not come to mind as automatically as contextually cued autobiographical memories in everyday life (Berntsen, 2010).

Finally, the current paradigm was also distinct from previous studies investigating involuntary memory in older adults in that it involved a dual task scenario with the sound localization cover task coinciding with the main memory retrieval task. Dual task conditions require divided attention and have been linked to greater performance costs in older adults

(McDowd & Craik, 1988; Fernandes & Moscovitch, 2003). Thus, the dual task demands may have been detrimental to memory performance, particularly in the older group, countering the expected preservation of involuntary memory in older adults. Although both the cover task (sound localization) and the memory encoding paradigm were designed to be relatively easy, with the goal of keeping task demands low and facilitating group differences in retrieval orientation, the inclusion of a secondary task may have interfered with automatic retrieval in the older group.

In summary, we found age differences in memory performance that did not differ according to voluntariness of retrieval. This may be attributable to the use of paired associates as memory stimuli in contrast to autobiographical memories (Schlagman et al., 2009; Berntsen et al., 2017). However, older adults' high effort ratings across voluntariness conditions and similar neural activity across conditions suggests that older adults engaged in effortful retrieval regardless of condition. Future work may benefit from a more naturalistic approach, including experimentally encoded naturalistic memories (Berntsen et al., 2017), or movie stimuli which have been shown to minimize task demands (Campbell et al., 2015, 2016). Importantly, we also found that older, but not younger, adults showed increased alpha ERD for paired relative to unpaired sounds at occipital sites during retrieval, suggesting that changes in oscillatory power can also be used as a neural marker of memory reactivation in older adults.

References

Amer, T., Campbell, K. L., & Hasher, L. (2016). Cognitive control as a double-edged sword. *Trends in cognitive sciences, 20*(12), 905-915.

Barber, S. J., & Mather, M. (2014). Stereotype threat in older adults: When and why does it occur and who is most affected? In P. Verhaeghen & C. Hertzog (Eds.), *Oxford library of psychology*. *The Oxford handbook of emotion, social cognition, and problem solving in adulthood* (p. 302–319). Oxford University Press.

Benjamini, Y., & Hochberg, Y. (1995). Controlling the false discovery rate: A practical and powerful approach to multiple testing. *Journal of the Royal Statistical Society: Series B (Methodological)*, *57*(1), 289–300. doi: 10.1111/j.2517-6161.1995.tb02031.x

Bergström, Z., Williams, D., Bhula, M., & Sharma, D. (2016). Unintentional and intentional recognition rely on dissociable neurocognitive mechanisms. *Journal of Cognitive Neuroscience*, *28*, 1838-1848. doi:10.1162/jocn_a_01010

Berntsen, D. (1996). Involuntary autobiographical memories. *Applied Cognitive Psychology, 10*, 435–454.

Berntsen, D. (2009) *Involuntary Autobiographical Memories*. New York: Cambridge University Press.

Berntsen, D. (2010). The unbidden past: Involuntary autobiographical memories as a basic mode of remembering. *Current Directions in Psychological Science*, *19*(3), 138–142. doi: 10.1177/0963721410370301

Berntsen, D., & Hall, N. M. (2004). The episodic nature of involuntary autobiographical memories. *Memory & Cognition*, *32*(5), 789–803. doi: 10.3758/bf03195869

Berntsen, D., Rubin, D. C., & Salgado, S. (2015). The frequency of involuntary autobiographical memories and future thoughts in relation to daydreaming, emotional distress, and age. *Consciousness and Cognition, 36*, 352–372.

Berntsen, D., Rasmussen, A. S., Miles, A. N., Nielsen, N. P., & Ramsgaard, S. B. (2017). Spontaneous or intentional? Involuntary versus voluntary episodic memories in older and younger adults. *Psychology and Aging, 32*(2), 192-201.

Burgess, A. P., & Gruzelier, J. H. (2000) Short duration power changes in the EEG during recognition memory for words and faces. *Psychophysiology, 37*, 596–606.

Cabeza, R. (2002). Hemispheric asymmetry reduction in older adults: the HAROLD model. *Psychology and Aging, 17*(1), 85–100.

Campbell, K. L., Grady, C. L., Ng, C., & Hasher, L. (2012). Age differences in the frontoparietal cognitive control network: Implications for distractibility. *Neuropsychologia, 50*, 2212-2223.

Campbell, K. L., Samu, D., Davis, S. W., Geerligs, L., Mustafa, A., & Tyler, L. K. for Cam-CAN (2016). Robust resilience of the frontotemporal syntax system to aging. *Journal of Neuroscience, 36*, 5214-5227.

Campbell, K. L., Shafto, M. A., Wright, P., Tsvetanov, K. A., Geerligs, L., Cusack, R., Cam-CAN, & Tyler, L. K. (2015). Idiosyncratic responding during movie-watching predicted by age differences in attentional control. *Neurobiology of Aging, 36*, 3045-3055.

Campopiano, A., Noordt, S. J. V., & Segalowitz, S. J. (2018). STATSLAB: An open-source EEG toolbox for computing single-subject effects using robust statistics. *Behavioural Brain Research*, *347*, 425–435. doi: 10.1016/j.bbr.2018.03.025

Cappell, K. A., Gmeindl, L., & Reuter-Lorenz, P. A. (2010). Age differences in prefrontal recruitment during verbal working memory maintenance depend on memory load. *Cortex*, *46*(4), 462–473. doi: 10.1016/j.cortex.2009.11.009

Coren, S., & Hakstian, A. R. (1992). The development and cross-validation of a self-report inventory to assess pure-tone threshold hearing sensitivity. *Journal of Speech Language and Hearing Research*, *35*(4), 921.

Craik, F. I., & Byrd, M. (1982). Aging and cognitive deficits. *Aging and Cognitive Processes*, 191-211.

Desjardins, J. A., & Segalowitz, S. J. (2013). Deconstructing the early visual electrocortical responses to face and house stimuli. *Journal of Vision.*, *13*(5), 1–18.

Dobbins, I. G., Rice, H. J., Wagner, A. D., & Schacter, D. L. (2003). Memory orientation and success: Separable neurocognitive components underlying episodic recognition. *Neuropsychologia*, *41*, 318–333.

Duarte, A., Ranganath, C., Trujillo, C., & Knight, R. T. (2006). Intact recollection memory in high-performing older adults: ERP and behavioral evidence. *Journal of Cognitive Neuroscience*, *18*(1), 33–47. doi: 10.1162/089892906775249988

Duverne, S., Habibi, A., & Rugg, M. D. (2008). Regional specificity of age effects on the neural correlates of episodic retrieval. *Neurobiology of Aging*, *29*, 1902–1916.

Fernandes, M. A., & Moscovitch, M. (2003). Interference effects from divided attention during retrieval in younger and older adults. *Psychology and Aging*, *18*(2), 219-230. doi:10.1037/0882-7974.18.2.219

Friedman, D. (2013). The cognitive aging of episodic memory: A view based on the event-related brain potential. *Frontiers in Behavioral Neuroscience*, *7*, 111. doi: 10.3389/fnbeh.2013.00111

Friedman, D., Chastelaine, M. D., Nessler, D., & Malcolm, B. (2010). Changes in familiarity and recollection across the lifespan: An ERP perspective. *Brain Research*, *1310*, 124–141. doi: 10.1016/j.brainres.2009.11.016

Grady, C. (2012) The cognitive neuroscience of ageing. *Nature Reviews Neuroscience*, *13*, 491–505.

Grady, C. L., Maisog, J. M., Horwitz, B., Ungerleider, L. G., Mentis, M. J., Salerno, J. A., et al. (1994). Age-related changes in cortical blood flow activation during visual processing of faces and location. *Journal of Neuroscience*, *14*(3), 1450–1462.

Grandy, T. H., Werkle-Bergner, M., Chicherio, C., Schmiedek, F., Lövdén, M., & Lindenberger, U. (2013). Peak individual alpha frequency qualifies as a stable neurophysiological trait marker in healthy younger and older adults. *Psychophysiology*, *50*(6), 570–582. doi: 10.1111/psyp.12043

Gutchess, A. H., Welsh, R. C., Hedden, T., Bangert, A., Minear, M., Liu, L. L., & Park, D. C. (2005). Aging and the neural correlates of successful picture encoding: Frontal activations compensate for decreased medial-temporal activity. *Journal of Cognitive Neuroscience*, *17*(1), 84–96. doi: 10.1162/0898929052880048

Hall, S. A., Brodar, K. E., Labar, K. S., Berntsen, D., & Rubin, D. C. (2018). Neural responses to emotional involuntary memories in posttraumatic stress disorder: Differences in timing and activity. *NeuroImage: Clinical*, *19*, 793–804. doi: 10.1016/j.nicl.2018.05.009

Hall, S. A., Rubin, D. C., Miles, A., Davis, S. W., Wing, E. A., Cabeza, R., & Berntsen, D. (2014). The neural basis of involuntary episodic memories. *Journal of Cognitive Neuroscience*, *32*(5), 519-532.

Hanslmayr, S., Staresina, B. P., & Bowman, H. (2016). Oscillations and episodic memory: Addressing the synchronization/desynchronization conundrum. *Trends in Neurosciences*, *39*(1), 16–25. doi: 10.1016/j.tins.2015.11.004

Hanslmayr, S., Staudigl, T., & Fellner, M. C. (2012). Oscillatory power decreases and long-term memory: the information via desynchronization hypothesis. *Frontiers in Human Neuroscience*, *6*. doi: 10.3389/fnhum.2012.00074

Hasher, L., & Zacks, R. T. (1979). Automatic and effortful processes in memory. *Journal of experimental psychology: General*, *108*(3), 356-388.

Jacoby, L. L. (1991). A process dissociation framework: Separating automatic from intentional uses of memory. *Journal of Memory and Language*, *30*(5), 513–541. doi: 10.1016/0749-596x(91)90025-f

Jennings, J. M., & Jacoby, L. L. (1993). Automatic versus intentional uses of memory: Aging, attention, and control. *Psychology and Aging*, *8*(2), 283–293. doi:10.1037/0882-7974.8.2.283

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (2005). International Affective Picture System (IAPS): Affective ratings of pictures and instruction manual. Gainesville, FL: NIMH, Center for the Study of Emotion and Attention.

Khader, P. H., and Rösler, F. (2011). EEG power changes reflect distinct mechanisms during long-term memory retrieval. *Psychophysiology, 48*, 362–369.

Klimesch, W. (2012). Alpha-band oscillations, attention, and controlled access to stored information. *Trends in Cognitive Sciences*, *16*(12), 606–617. doi: 10.1016/j.tics.2012.10.007

Klimesch, W., Sauseng, P., & Hanslmayr, S. (2007). EEG alpha oscillations: The inhibition–timing hypothesis. *Brain Research Reviews*, *53*(1), 63–88. doi: 10.1016/j.brainresrev.2006.06.003

Klimesch, W. (1999). EEG alpha and theta oscillations reflect cognitive and memory performance: a review and analysis. *Brain Research Reviews*, *29*(2-3), 169–195. doi: 10.1016/s0165-0173(98)00056-3

Knyazeva, M. G., Barzegaran, E., Vildavski, V. Y., & Demonet, J. F. (2018). Aging of human alpha rhythm. *Neurobiology of Aging*, *69*, 261–273. doi: 10.1016/j.neurobiolaging.2018.05.018

Koechlin, E., Basso, G., Pietrini, P., Panzer, S., & Grafman, J. (1999). The role of the anterior prefrontal cortex in human cognition. *Nature*, *399*, 148–151.

Maillet, D., & Schacter, D. L. (2016). From mind wandering to involuntary retrieval: Age-related differences in spontaneous cognitive processes. *Neuropsychologia*, *80*, 142–156. doi: 10.1016/j.neuropsychologia.2015.11.017

Maris, E., & Oostenveld, R. (2007). Nonparametric statistical testing of EEG- and MEG-data. *Journal of Neuroscience Methods*, *164*(1), 177–190. doi: 10.1016/j.jneumeth.2007.03.024

McDonough, I. M., Wong, J. T., & Gallo, D. A. (2012). Age-related differences in prefrontal cortex activity during retrieval monitoring: Testing the compensation and dysfunction Accounts. *Cerebral Cortex*, *23*(5), 1049–1060. doi: 10.1093/cercor/bhs064

McDowd, J. M., & Craik, F. I. M. (1988). Effects of aging and task difficulty on divided attention performance. *Journal of Experimental Psychology: Human Perception and Performance, 14*(2), 267-280. doi: 10.1037/0096-1523.14.2.267

Misselhorn, J., Friese, U., & Engel, A. K. (2019). Frontal and parietal alpha oscillations reflect attentional modulation of cross-modal matching. *Scientific Reports*, *9*(1). doi: 10.1038/s41598-019-41636-w

Morcom, A. M. (2016). Mind over memory: Cuing the aging brain. *Current Directions in Psychological Science*, *25*(3), 143–150. doi: 10.1177/0963721416645536

Morcom, A. M., Good, C. D., Frackowiak, R.S., & Rugg, M. D. (2003). Age effects on the neural correlates of successful memory encoding. *Brain*, *126*, 213–229.

Morcom, A. M., Li, J. & Rugg, M. D. (2007). Age effects on the neural correlates of episodic retrieval: Increased cortical recruitment with matched performance. *Cerebral. Cortex 17*(11), 2491–2506.

Morcom, A. M., & Rugg, M. D. (2004). Effects of age on retrieval cue processing as revealed by ERPs. *Neuropsychologia*, *42*(11), 1525–1542. doi: 10.1016/j.neuropsychologia.2004.03.009

Murray, J. G., Ouyang, G., & Donaldson, D. I. (2019). Compensation of trial-to-trial latency jitter reveals the parietal retrieval success effect to be both variable and thresholded in older adults. *Frontiers in Aging Neuroscience*, *11*, 179. doi: 10.3389/fnagi.2019.00179

Nasreddine, Z. S., Phillips, N. A., Bã Dirian, V., Charbonneau, S., Whitehead, V., Collin, I., et al.. (2005). The Montreal cognitive assessment, MoCA: A brief screening tool for mild cognitive impairment. *Journal of the American Geriatrics Society, 53*(4), 695-699.

Nessler, D., Friedman, D., Johnson, R., & Bersick, M. (2007). Does repetition engender the same retrieval processes in young and older adults? *NeuroReport*, *18*(17), 1837–1840. doi: 10.1097/wnr.0b013e3282f16d9f

Old, S. R., & Naveh-Benjamin, M. (2008). Differential effects of age on item and associative measures of memory: A meta-analysis. *Psychology and Aging, 23*(1), 104–118. doi: 10.1037/0882-7974.23.1.104

Oostenveld, R., Fries, P., Maris, E., & Schoffelen, J. M. (2011). FieldTrip: Open source software for advanced analysis of MEG, EEG, and invasive electrophysiological data. *Computational Intelligence and Neuroscience*, 1–9. doi: 10.1155/2011/156869

Peelle, J. E., & Wingfield, A. (2016). The neural consequences of age-related hearing loss. *Trends in Neurosciences 39*, 486–497.

Pernet, C., Latinus, M., Nichols, T., & Rousselet, G. (2015). Cluster-based computational methods for mass univariate analyses of event-related brain potentials/fields: A simulation study. *Journal of Neuroscience Methods*, *250*, 85–93. doi: 10.1016/j.jneumeth.2014.08.003

Petersen, E. B., Wöstmann, M., Obleser, J., Stenfelt, S., & Lunner, T. (2015). Hearing loss impacts neural alpha oscillations under adverse listening conditions. *Frontiers in Psychology, 6*, 177. doi: 10.3389/fpsyg.2015.00177

Reuter-Lorenz, P. A., & Cappell, K. A. (2008). Neurocognitive aging and the compensation hypothesis. *Current Directions in Psychological Science*, *17*(3), 177–182. doi: 10.1111/j.1467-8721.2008.00570.x

Schlagman, S., Kliegel, M., Schulz, J., & Kvavilashvili, L. (2009). Differential effects of age on involuntary and voluntary autobiographical memory. *Psychology and Aging, 24*, 397–411.

Sharps, M. J., & Antonelli, J. R. S. (1997). Visual and semantic support for paired-associates recall in young and older adults. *The Journal of Genetic Psychology, 158*(3), 347-355. doi: 10.1080/00221329709596673

Tays, W. J., Dywan, J., Mathewson, K. J., & Segalowitz, S. J. (2008). Age differences in target detection and interference resolution in working memory: an event-related potential study. *Journal of Cognitive Neuroscience, 20*(12), 2250-2262.

van Noordt, S. J. R., White, L. O., Wu, J., Mayes, L. C., & Crowley, M. J. (2015). Social exclusion modulates event-related frontal theta and tracks ostracism distress in children. *NeuroImage*, *118*, 248–255.

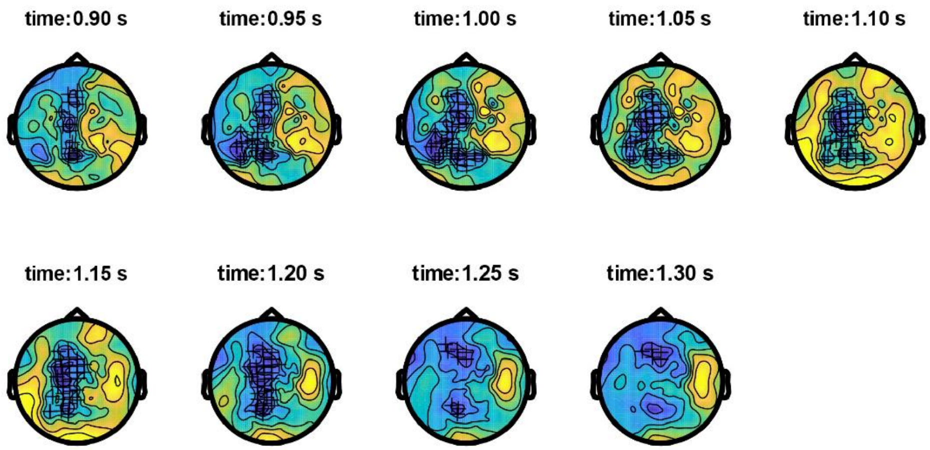
Vincent, J. L., Kahn, I., Snyder, A. Z., Raichle, M. E., & Buckner, R. L. (2008). Evidence for a frontoparietal control system revealed by intrinsic functional connectivity. *Journal of Neurophysiology, 100*, 3328–3342.

Waldhauser, G., Johansson, M., & Hanslmayr, S. (2012). Brain oscillations indicate inhibition of interfering visual memories. *Journal of Neuroscience*, *32*, 1953–1961.

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

Woodruff, D. S., & Kramer, D. A. (1979). Eeg alpha slowing, refractory period, and reaction time in aging. *Experimental Aging Research*, *5*(4), 279–292. doi: 10.1080/03610737908257205

Appendix A



Supplementary figure 1. Topographies illustrating memory effects observed using IAF to compare paired and unpaired sounds in older adults (collapsed across voluntariness conditions), ‘x’s represent electrodes that are part of a cluster approaching significance (*p* = .0729).

Appendix B

STUDY:__________________________ **PARTICIPANT ID ____________**

BACKGROUND INFORMATION VOCAB:

Campbell Lab, Department of Psychology, Brock University

Today's Date: __________________________

Age: ______ **Sex:** ( ) Female ( ) Male **Date of birth:** _______________________
Month Day Year

Are you right or left-handed? ( ) Right ( ) Left

Were you born in Canada? ( ) Yes ( ) No
-If not born in Canada, how old were you when you first came here? _________

What is your first (native) language? ___________________________________
-If not English, how old were you when you first learned English? ___________

Please list all the languages you speak:

- ____________________**Age learned:** __________**used daily?:** __________
-
- ____________________**Age learned:** __________**used daily?:** __________
-
- ____________________**Age learned:** __________**used daily?:** __________
-
- ____________________**Age learned:** __________**used daily?:** __________
-
- ____________________**Age learned:** __________**used daily?:** __________
-

Please rate the following for your FIRST LANGUAGE :_______________

Speech comprehension:	1	2	3	4	5	6	7
Conversational fluency:	1	2	3	4	5	6	7
Reading:	1	2	3	4	5	6	7
Writing:	1	2	3	4	5	6	7

Please rate the following for your SECOND LANGUAGE :_______________

Speech comprehension:	1	2	3	4	5	6	7
Conversational fluency:	1	2	3	4	5	6	7
Reading:	1	2	3	4	5	6	7

Writing: 1 2 3 4 5 6 7

Education (NOT including this year):
Please specify the *number of years* at each educational institute.
_____ Grade school (grades 1-12/13) _____ University
_____ Community college _____ Continuing education
_____ Vocational/technical school _____ Other: _____________________
_____ Total number of years of education (Add *all* years including grade school)

Field of Study: ______________________________

Please check the appropriate box regarding the following health conditions:
Vision problems: ( ) Yes ( ) No
-If yes, do you wear glasses/contacts? ( ) Yes ( ) No
- Is your vision corrected to 20/20 with glasses/contacts? ( ) Yes ( ) No
Hearing problems: ( ) Yes ( ) No
-If yes, do you wear a hearing aid? ( ) Yes ( ) No
-Is your hearing corrected to normal with the hearing aid? ( ) Yes ( ) No
Neurological problems (e.g., epilepsy): ( ) Yes ( ) No

What medications do you take on a regular basis?
<u>Drug Name</u> <u>For which ailment?</u>
____
____

Have you ever been knocked unconscious (e.g., sports injury or accident)?
( ) Yes ( ) No
-If yes, how old were you? ________ What was the cause? ________________________
-How long were you unconscious? _____________________
-Did you have trouble remembering events after regaining consciousness? ( ) Yes ( ) No
-If yes, please explain:____

Please continue on the back.

In general, how satisfied are you with your health and physical condition?
( ) Satisfied ( ) Somewhat satisfied ( ) Somewhat dissatisfied ( ) Dissatisfied

On a scale from 1 (poor) – 10 (excellent), how would you rate your overall health? _______

What is your ethnic background? (Try to be as specific as possible).
____

STUDY:____________________________ **PARTICIPANT ID** ____________

BACKGROUND INFORMATION

Campbell Lab, Department of Psychology, Brock University

Today's Date: _______________________________________
Day Month Year

Age: _______ **Sex:** ( ) Female ( ) Male **Date of birth:** ___________________
Month Day Year

Are you right or left-handed? ( ) Right ( ) Left

Were you born in Canada? ( ) Yes ( ) No
--If not born in Canada, how old were you when you first came here? _________

What is your first (native) language? _______________________________________
--If not English, how old were you when you first learned English? ___________

Please list all the languages you speak:

- _____________________ **Age learned:** __________ **used daily?:** __________
-
- _____________________ **Age learned:** __________ **used daily?:** __________
-
- _____________________ **Age learned:** __________ **used daily?:** __________
-
- _____________________ **Age learned:** __________ **used daily?:** __________
-
- _____________________ **Age learned:** __________ **used daily?:** __________
-

Please rate the following for your FIRST LANGUAGE :________________

Speech comprehension:	1	2	3	4	5	6	7
Conversational fluency:	1	2	3	4	5	6	7
Reading:	1	2	3	4	5	6	7
Writing:	1	2	3	4	5	6	7

Please rate the following for your SECOND LANGUAGE :________________

Speech comprehension:	1	2	3	4	5	6	7
Conversational fluency:	1	2	3	4	5	6	7
Reading:	1	2	3	4	5	6	7

Writing: 1 2 3 4 5 6 7

Education:
Please specify the ***number of years*** at each educational institute.
_____ Grade school (grades 1-13) _____ Community college
_____ Vocational/technical school _____ University
_____ Continuing education _____ Other: ______________________

_____ Total number of years of education (Add *all* years including grade school)

Please check any diplomas/degrees you have completed:
( ) Grade/highschool diploma ( ) Community college diploma
( ) Vocational/technical school diploma
( ) B.A./B.Sc. ( ) M.A./M.Sc. ( ) Ph.D. ( ) Other: ___________________

What is your marital status? ( ) Single ( ) Common law ( ) Married
( ) Widowed ( ) Divorced ( ) Separated

What has been your major occupation during most of your life?
____

What has been your spouse's major occupation?
____

Are you retired? ( ) Yes ( ) No
--If you are retired, in what year did you retire? ____________________________

HEALTH INFORMATION

How many days have you been bothered by illness during the past 6 months? ________ --How serious an illness was it? ( ) Very serious ( ) Serious ( ) Not serious

Please check the appropriate box regarding the following health conditions:

Hearing problems: ( ) Yes ( ) No
--If yes, do you wear a hearing aid? ( ) Yes ( ) No
--Is your hearing corrected to normal with the hearing aid? ( ) Yes ( ) No

Vision problems: ( ) Yes ( ) No
--If yes, do you wear glasses/contacts? ( ) Yes ( ) No

--Is your vision corrected to 20/20 with glasses/contacts? ( ) Yes ( ) No
Neurological problems (e.g., epilepsy): ( ) Yes ( ) No

Arthritis: ( ) Yes ( ) No
--If yes, is it serious enough to impinge on daily activities? ( ) Yes ( ) No
Diabetes ( ) Yes ( ) No
Cancer ( ) Yes ( ) No
Stroke ( ) Yes ( ) No
--If yes, when did you have a stroke? ___________________
High blood pressure ( ) Yes ( ) No
Heart problems ( ) Yes ( ) No
Stomach ulcers ( ) Yes ( ) No
Other: ____
Are you colourblind? ( ) Yes ( ) No If yes, what type? ______________________

What medications do you take on a regular basis?
Drug Name For which ailment?
____
____
____
____
____

Have you ever been knocked unconscious (e.g., sports injury or accident)?
( ) Yes ( ) No
-If yes, how old were you? ________________
-What was the cause? ____
-How long were you unconscious? ____
-Did you have trouble remembering events after regaining consciousness? ( ) Yes ( ) No -If yes, please explain ____

Indicate if you are often bothered by any of the following:
( ) Colds/flu ( ) Depression ( ) Feeling generally run down
( ) Headaches ( ) Difficulty sleeping ( ) Difficulty eating
( ) Nervousness/tenseness

In general, how satisified are you with your health and physical condition?
( ) Satisfied ( ) Somewhat satisfied ( ) Somewhat dissatisfied ( ) Dissatified

On a scale from 1 (poor) -10 (excellent), how would you rate your overall health? _____

PERSONAL INFORMATION

Race/Ethnicity (please choose one)

______ White ______ Aboriginal/First Nations _____ Hispanic/Latino

______ African Canadian ______ Middle Eastern ______ Indian/Pakistani/Sri Lankan

______ Japanese/Korean/Chinese ______ Filipino/Malaysian/Indonesian

Other: ____

Caffeine consumption

How many caffeinated servings of each of the following do you consume, on average, daily?

______ coffee (1 cup) ______ tea (1 cup) ______ cola (1 can)

______ chocolate bar ______ hot chocolate (1 cup)

How many servings of caffeine have you consumed in the last 2 hours?

______ coffee (1 cup) ______ tea (1 cup) ______ cola (1 can)

______ chocolate bar ______ hot chocolate (1 cup)

Hearing Screening Inventory

Coren and Hakstian (1992)

Instructions:

This questionnaire deals with a number of common situations. For each question you should select the response that describes ***you*** and your behaviors best. You can select from the following alternatives:

Never (or almost never) **Seldom** **Occasionally** **Frequently** **Always** (or almost always)

	Never	Seldom	Occasionally	Frequently	Always
1) Are you ever bothered by feelings that your hearing is poor?					
2) Is your reading or studying easily interrupted by noises in nearby rooms?					
3) Can you hear the telephone ring when you re in the same room in which it is located?					
4) Can you hear the telephone ring when you are in the room next door?					
5) Do you find it difficult to make out the words in recordings of popular songs?					
6) When several people are talking in a room, do you have difficulty hearing an individual conversation?					
7) Can you hear the water boiling in a pot when you are in the kitchen?					
8) Can you follow the conversation when you are at a large dinner table?					
For the last four questions use these labels as your answers	**Good**	**Average**	**Slightly Below Average**	**Poor**	**Very Poor**
9) Overall, I would judge my hearing in my **right** ear to be...					
10) Overall, I would judge my hearing in my **left** ear to be…					
11) Overall, I would judge my ability to make out speech or conversation to be …					
12) Overall, I would judge my ability to judge the location of things by the sound they are making alone to be…					

SHIPLEY INSTITUTE OF LIVING SCALE -- VOCABULARY TEST

S #__________________________ DATE _______________________

Instructions: In the test below, the first word in each line is printed in capital letters. Opposite it are four other words. Circle the *one word* which means the *same thing*, or most nearly the same thing, as the first word. If you don't know, guess. Be sure to circle the *one word* in each line that means the same thing as the first word.

EXAMPLE:

	LARGE	red	big	silent	wet
(1)	TALK	draw	eat	speak	sleep
(2)	PERMIT	allow	sew	cut	drive
(3)	PARDON	forgive	pound	divide	tell
(4)	COUCH	pin	eraser	sofa	glass
(5)	REMEMBER	swim	recall	number	defy
(6)	TUMBLE	drink	dress	fall	think
(7)	HIDEOUS	silvery	tilted	young	dreadful
(8)	CORDIAL	swift	muddy	leafy	hearty
(9)	EVIDENT	green	obvious	skeptical	afraid
(10)	IMPOSTOR	conductor	officer	book	pretender
(11)	MERIT	deserve	distrust	fight	separate
(12)	FASCINATE	welcome	fix	stir	enchant
(13)	INDICATE	defy	excite	signify	bicker
(14)	IGNORANT	red	sharp	uninformed	precise
(15)	FORTIFY	submerge	strengthen	vent	deaden
(16)	RENOWN	length	head	fame	loyalty
(17)	NARRATE	yield	buy	associate	tell

(18)	MASSIVE	bright	large	speedy	low
(19)	HILARITY	laughter	speed	grace	malice
(20)	SMIRCHED	stolen	pointedremade	soiled	
(21)	SQUANDER	tease	belittle	cut	waste
(22)	CAPTION	drum	ballast	heading	ape
(23)	FACILITATE	help	turn	strip	bewilder
(24)	JOCOSE	humorous	paltry	fervid	plain
(25)	APPRISE	reduce	strew	inform	delight
(26)	RUE	eat	lament	dominate	cure
(27)	DENIZEN	senator	inhabitant	fish	atom
(28)	DIVEST	dispossess	intrude	rally	pledge
(29)	AMULET	charm	orphan	dingo	pond
(30)	INEXORABLE	untidy	involatile	rigid	sparse
(31)	SERRATED	dried	notched	armed	blunt
(32)	LISSOM	moldy	loose	supple	convex
(33)	MOLLIFY	mitigate	direct	pertain	abuse
(34)	PLAGIARIZE	appropriate	intend	revoke	maintain
(35)	ORIFICE	brush	hole	building	lute
(36)	QUERULOUS	maniacal	curious	devout	complaining
(37)	PARIAH	outcast	priest	lentil	locker
(38)	ABET	waken	ensue	incite	placate
(39)	TEMERITY	rashness	timidity	desire	kindness
(40)	PRISTINE	vain	sound	first	level