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Comparable mechanisms of working memory interference by auditory and visual motion in youth and aging

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ABSTRACT

Intrasensory interference during visual working memory (WM) maintenance by object stimuli (such as faces and scenes), has been shown to negatively impact WM performance, with greater detrimental impacts of interference observed in aging. Here we assessed age-related impacts by intrasensory WM interference from lower-level stimulus features such as visual and auditory motion stimuli. We consistently found that interference in the form of ignored distractions and secondary task interruptions presented during a WM maintenance period, degraded memory accuracy in both the visual and auditory domain. However, in contrast to prior studies assessing WM for visual object stimuli, feature-based interference effects were not observed to be significantly greater in older adults. Analyses of neural oscillations in the alpha frequency band further revealed preserved mechanisms of interference processing in terms of post-stimulus alpha suppression, which was observed maximally for secondary task interruptions in visual and auditory modalities in both younger and older adults. These results suggest that age-related sensitivity of WM to interference may be limited to complex object stimuli, at least at low WM loads.

1. Introduction

External interference has been evidenced to negatively impact the ability to maintain information in WM (Baddeley, 2003; Sakai, 2003; Sakai & Passingham, 2004; Yoon, Curtis, & D'Esposito, 2006; Sreenivasan & Jha, 2007; Clapp, Rubens, & Gazzaley 2010; Clapp, Rubens, Sabharwal, & Gazzaley, 2011; Clapp & Gazzaley, 2012). Clapp et al. (2010) classified external interference as either distracting or interrupting: distractions involve task-irrelevant stimuli intended to be ignored, while interruptions are attended as part of a secondary task. Conceptually, engaging with interruptions while simultaneously maintaining information in WM can be considered dual tasking (Salvucci & Taatgen, 2008). Thus, in the present study, interference effects are investigated for both distractions and secondary task interruptions.

In a visual WM task consisting of object stimuli such as faces and scenes Clapp et al. (2010) found distinct mechanisms of WM interference for distractions versus secondary task interruptions in young adults. Interestingly behavioral performance in older adults compared to younger adults was more negatively impacted by interference (Clapp et al., 2011; Clapp & Gazzaley, 2012). Using EEG and fMRI based neuroimaging measures it was additionally shown that distractor-related early visual processing in extrastriate cortex was suppressed in younger but not older adults, when compared to a passive baseline with non-distracting stimuli. Furthermore, the exacerbated impact of secondary task interruptions in aging was shown to be due to deficits in dynamically engaging the functionally connected prefrontal and visual cortical memory maintenance networks that emerge during the task period.

While the greater impact of WM interference in older relative to younger adults has been behaviorally and neurally dissected for complex visual object stimuli, the age-related impacts of interference on WM maintenance for visual or auditory motion is not known. Here, we define auditory motion as a sound sweep across a frequency range. Although the real-world utility of auditory motion WM is diverse, it is commonly used in processing speech patterns where intonations are held in WM while new sounds are received that subsequently form words and sentences. Similarly, visual motion WM is prevalent in every day cognition, such as when trying to cross a busy street. This scenario requires the memory maintenance of vehicular motion in one direction while traffic in the other direction is assessed. Thus, WM for both visual and auditory motion are critical cognitive operations that permit

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tracking of our environment and the impact of interference on motion WM can have serious consequences.

Since visual motion is processed via the dorsal visual stream, distinct from object processing that predominantly engages the ventral visual stream (Ungerleider & Mishkin, 1982; Goodale & Milner, 1992), it is not clear that the recent evidence of an age-related impact on visual object-based interference in WM is generalizable to visual motion. Interestingly, only certain aspects of global visual motion perception are affected by aging. Motion perception studies in aging using random dot kinematogram (RDK) stimuli show age-related deficits in motion perception specific to very slow dot motion speeds, high spatial dot displacements and low dot contrasts, but not otherwise (reviewed in Hutchinson, Arena, Allen, & Ledgeway, 2012). Given such differences in motion perception in aging, it is best practice that a study assessing the impact of motion as interference on WM first equates the perception of the motion stimuli across individuals. If participants were to engage in the task with perceptually non-thresholded motion stimuli, it would be unclear whether the interference effects are truly due to intrusions in the primary WM task or due to differences in motion perception abilities across individuals and age groups. Thus, in the present study we investigate whether interference differentially impacts visual motion WM in aging after equating motion stimulus perception across individuals using thresholding procedures. Use of perceptually thresholded stimuli ensures that the study findings are truly driven by interference effects.

In parallel to studies on intrasensory visual interference during WM, research on auditory interference during auditory WM has also progressed. However, a debate exists as to whether auditory distractibility is exacerbated in aging. Auditory distraction equally affects younger and older adults in some listening-in-noise experiments and simultaneous speech studies that require selective attention to one of the speech streams (Murphy, McDowd, & Wilcox, 1999; Schneider, Daneman, Murphy, & See, 2000; Li, Daneman, Qi, & Schneider, 2004) as well as in an auditory n-back task study (Guerreiro, Murphy, & Van Gerven, 2013). Yet, other experiments suggest an age-related decline of intrasensory auditory interference control with age (Sommers & Danielson, 1999; Tun & Wingfield, 1999; Tun, O'Kane, & Wingfield, 2002; Chao & Knight, 1997; Alain & Woods, 1999; Fabiani, Low, Wee, Sable, & Gratton, 2006; Passow et al., 2012). Of note, while the effect of auditory distractions on audition-based cognitive tasks has been explored, no study to our knowledge has investigated the impact of auditory secondary task interruptions on WM performance in aging. Such auditory dual-tasking, for example, occurs when evaluating approaching traffic auditory cues or attending to auditory speech while being interrupted by a cell phone conversation. In contrast, there are a handful of studies of auditory and visual dual-tasking in the context of aging that generally suggest greater impairments with age (Andrés, Parmentier, & Escera, 2006; Chaparro, Wood, & Carberry, 2005; Parmentier and Andrés, 2010; Thompson et al., 2012 but see Schneider et al., 2000). In the present research we exclusively focus on behavioral and neural influences of intrasensory interference, and hence investigate auditory distractions and auditory dual-tasking impacts on WM. Again, we use perceptually thresholded auditory stimuli in each individual, similar to the visual task, to ensure that the results are driven by WM interference effects and not perceptual differences.

To summarize, in the visual domain, we sought to investigate the influence of visual distractions and secondary task interruptions on visual motion WM. As noted above, age impacts of interference in visual motion WM are unexplored. As a parallel experiment in the auditory modality, we investigated age impacts of auditory interference on auditory motion WM. The experiments were based on a delayed-recognition task design with dot motion kinematograms in the visual modality and sound sweeps across a frequency range in the auditory modality as the to-be-remembered stimuli. Thus, in the context of auditory and visual motion stimulation, we specifically sought to investigate: (1) do distractions and secondary task interruptions affect WM performance?, (2) are interference effects different in older relative to younger adults? and finally, (3) how do the observed intrasensory interference effects and associated age impacts compare across the auditory and visual modalities? In addition to addressing these questions in human behavior, we used EEG recordings concurrent with the behavioral tasks to investigate neural correlates underlying the interference effects on WM performance.

Neural processing of interfering stimuli, both distractions and interruptions, was analyzed relative to a baseline condition when these same interfering stimuli were passively perceived without concurrent WM goals. This was done to facilitate interpretation whether neural representations of distractions and secondary task interruptions are enhanced or suppressed relative to a passive baseline. Enhanced representations would suggest attentional allocation to the interfering stimuli. As we aimed to compare interference processing in the auditory and visual modalities, we focused on neural modulations in the spectral domain. Spectral measures especially in the alpha (8–14 Hz) range are known to be sensitive to changes in attention allocation irrespective of sensory modality (Klimesch, Sauseng, & Hanslmayr, 2007; Foxe & Snyder, 2011), and hence, were analyzed as a common marker for attention to both types of interference (distraction/interruption) in each modality (auditory/visual) and age group (younger/older). In contrast to our prior studies (Clapp et al., 2010, 2011; Clapp & Gazzaley, 2012), event-related potentials (ERPs) were not analyzed here as early ERP components, such as the P1-N1-P2, in the auditory and visual modalities are not known to have similar underlying neural activities across the senses, and thus are not easily amenable to cross-sensory comparisons. We hypothesized that intrasensory interference would indeed impact visual and auditory motion-based WM, and based on prior evidence, aging may exacerbate these interference effects.

2. Materials and methods

2.1. Participants

A total of seventy-nine healthy volunteers participated in the study. All participants gave written informed consent in accordance with the guidelines set by the Committee on Human Research at the University of California, San Francisco, and were monetarily compensated to participate in the study. Twenty-one younger adults (mean age 24 years, range 20–30 years, 11 females) and nineteen older adults (mean age 68 years, range 60–87 years, 14 females) participated in the auditory experiment, recruited from the San Francisco bay area community using print and web-based research study advertisements. All participant data for the visual experiment was obtained from prior studies (younger: Berry, Zanto, Rutman, Clapp, & Gazzaley, 2009; older: Berry et al., 2010). Visual task raw (performance and neural) data for twenty younger adults (mean age 24 years, range 21–29 years, 9 females) was from a single assessment visit reported in Berry et al. (2009). Visual task raw data for nineteen older adults (mean age 71, range 62–82 years, 9 females) was from the first of two assessment visits conducted in the prior cognitive training study (Berry et al., 2010). Note that data for the nineteen older adults in the visual task is a subset of the thirty-two older adult cohort described in Berry et al. (2010), for which data across all visual task conditions was available. Also note that all age comparisons and statistical analyses on these previously acquired raw data are novel to the current study.

There was no participant overlap across the visual and auditory experiments. All participants included in the study had normal or corrected-to-normal vision examined using a Snellen chart, did not have any history of stroke, traumatic brain injury, psychiatric illness, substance abuse and none used any medication known to affect cognitive state. All participants had a minimum of 12 years of education. Participants in the auditory experiment were additionally screened for normal hearing. Prior to the lab visit, these participants answered a 12-point multiple-choice questionnaire regarding hearing abilities in daily life situations. To screen for normal hearing in the lab, audiometric thresholds in the 250–6000 Hz frequency range were determined