

Identifying a Shared Source of Age-related Decline in Working Memory and Decision-making

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Abstract:

As population aging burgeons globally, a major imperative exists to identify mechanisms of cognitive decline associated with aging. Working memory (WM) and decision-making (DM) are key cognitive functions that deteriorate with age. Emergent evidence from computational and empirical work has pointed to shared neural mechanisms underpinning both processes. The present study leverages this consolidative framework to identify shared and distinct sources of age-related decline in WM and DM. Younger and older adults (YA & OA) completed psychophysical tasks tailored to parse sources of variance in WM and DM reports, while scalp EEG and pupil data were recorded. Analyses of noise and bias in WM and DM behavior, decoding of EEG signals, and interrogation of phasic pupil-linked arousal converge to suggest that a leading source of age-related dysfunction - degraded sensory encoding - gives rise to decline across both domains. Taken together, these findings provide novel insights into the neural basis of WM and DM and their susceptibility to the inimical effects of aging.

Keywords: Decision-making; Working memory; Electroencephalography (EEG); Pupillometry; Cognitive Aging

Introduction

WM and DM are building blocks of cognition that decline with age (Dully et al., 2018; Grady, 2012). Despite the wealth of research into these processes, the source of their age-related decline remains poorly understood (Dully et al., 2018; Gazzaley et al., 2005). Recent computational (Murray et al., 2017; Yang et al., 2019) and empirical (Murphy et al., 2022) studies suggest that both WM and DM may emerge from a common neural circuit mechanism that maintains (for WM) and integrates (for DM) information over time through shared attractor dynamics. These circuit mechanisms are subject to shared sources of noise (Schapiro et al., 2022; Wimmer et al., 2014) and bias (Barbosa et al., 2020; Murphy et al., 2022) that shape WM and DM behavior. In this study, we leverage these insights to interrogate the origins of age-related decline in a unified way. Through tailoring task paradigms to disentangle shared and unique variance in WM and DM, in tandem with the analysis of high-density scalp EEG and pupillometry, the contribution of a single locus of age-related decline was identified as engendering decrements across both domains.

Methods

Behavioral, EEG, and pupil data were collected from 33 cognitively healthy YA and 33 OA. Participants completed sensory-motor (SM), WM, and DM tasks (Figure 1), the key demand of which was to estimate the spatial location of checkerboard patch stimuli that could be presented anywhere along a circle centered on fixation. In SM trials, participants were tasked with immediately reproducing the location of a single, briefly presented target via a directed mouse click. The WM task was identical to the SM task in sensory and motor demands but with the addition of a i) variable WM delay between target and response cue, and ii) a distractor stimulus during the delay on a subset of trials. In the DM task, variable-length sequences of stimuli were presented, and participants were required to estimate their circular mean location. Matching the design characteristics across tasks meant that behavior across the three tasks can be considered subject to shared and distinct sources of variability, in sensory encoding (all three), motor execution (all three), WM maintenance (WM and DM), and temporal integration (DM only).

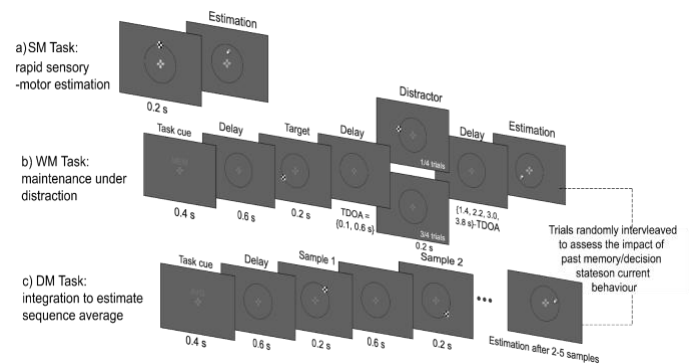


Figure 1: Task schematics. a) SM, b) WM, c) DM.

Results

OA exhibited a larger absolute response error on the SM task compared with YA ($p=.002$; Figure 2a), suggesting an increase in sensory encoding and/or motor execution noise with age. Across both groups, error increased in the WM task compared with the SM task ($p<.001$) and with delay duration in the WM task ($p<.001$), suggesting the presence of a time-dependent 'memory noise'. Notably, neither the difference in error from SM to WM task ($p = .10$) nor the impact of delay ($p = .94$) differed by age, thus indicating no

difference in the magnitude of memory noise across groups. Error in the DM task was larger than WM error at matched trial lengths - a pattern that could be explained by compounded sensory noise from the processing of multiple samples in the DM task, and/or the presence of distinct 'integration noise' ($p < .001$ for both age groups). The increase in DM error with sequence length was uniform across age groups ($p = .94$). Altogether, the pattern of age-related differences can most parsimoniously be explained by age-related increases in sensory and/or motor noise, possibly accompanied by increased integration noise. Notably, OA also exhibited greater attraction of behavioral reports towards distractors during WM (Figure 2b: $p < .001$, suggesting decreased stability of underlying attractor states in the face of new sensory input) and a larger general spatial bias of reports away from cardinal and toward oblique (diagonal) locations during both the SM and WM tasks (Figure 2c: $p < .002$; perhaps arising from structural biases in the underlying neural circuit), each of which help to further clarify the nature of performance decrements in OA. No age differences were observed in either psychophysical kernels (capturing the weight given to evidence at each sample position) or choice history biases (Figure 2d-e).

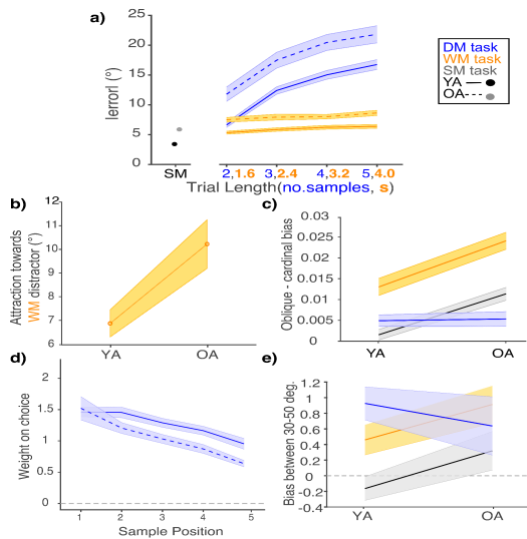


Figure 2: Task performance and adaptation effects

On the WM task, target stimulus locations could be reliably decoded from EEG alpha-band activity (8-12Hz) in both age groups (on-diagonal decoding in Figure 3a-b). Decoding accuracy was above chance for the entirety of the shortest delay duration (epoch used for this analysis). Temporal generalization analyses revealed a strong generalization from stimulus onset in YA (indicated by significant off diagonal decoding in Figure 3a). By contrast, generalizing patterns in OA only emerged during the WM

delay, 0.6-0.8 s after stimulus onset (Figure 3b). Group comparisons (Figure 3c) demonstrate that age-related differences were confined to early time periods (0.2-1s: possibly reflecting sensory rather than mnemonic activity). This may reflect a less precise sensory code in OA, in keeping with the greater SM noise identified above (Figure 2). A novel cross-task generalization analysis revealed that after accounting for autocorrelation in the decision variable, the WM code generalizes to represent the evolving decision variable in the DM task in YA - key support for the shared neural circuit mechanism (Figure 3d&f). However, this effect was not present in OA (Figure 3e). Further decoding analyses are planned to explore additional frequency bands and account for possible age group differences in alpha peak frequency ($p < .05$).

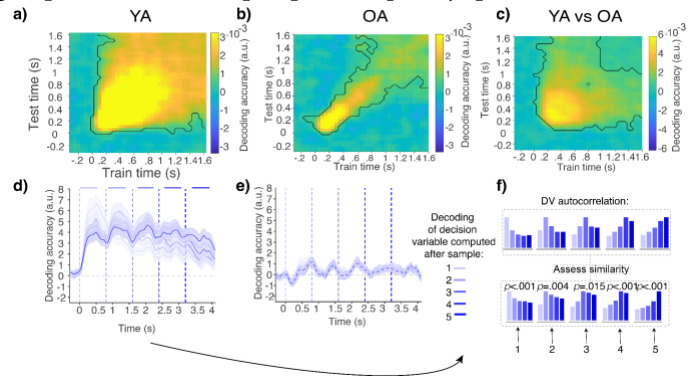


Figure 3: EEG decoding analyses from alpha power

In a final analysis, we found that degradation of ascending arousal systems cannot explain the observed age-related behavioral differences. In fact, OA showed enhanced trial-related pupil responses compared with YA (cluster-based permutation tests, $p < .05$: Figure 4).

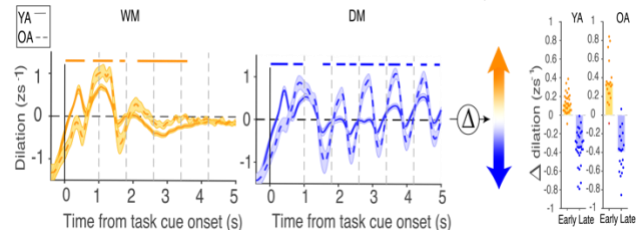


Figure 4: Trial-related pupil-linked arousal responses

Discussion

The combined analysis of behavioral, EEG, and pupil data has identified sensory processing as a leading source of age-related decline in WM and DM tasks. Our hope is that these data can be used to inform a unified model of WM and DM, in health and old age.

Acknowledgments

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