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Young and Restless, Old and Focused:

Age-Differences in Mind-Wandering Frequency and Phenomenology

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Abstract

The consistently observed age-accompanied diminution in mind-wandering stands seemingly opposed to accounts that present mind-wandering as a failure of executive control. This study examined the impact of aging on the frequency and phenomenology of mind-wandering and investigated distinct variables mediating age-related differences in unintentional and intentional mind-wandering. Thirty-four younger and 34 healthy older adults completed a neuropsychological test battery and contrast change detection task embedded with experience sampling probes asking participants to discriminate the nature of their thoughts. Results revealed age-related decreases in unintentional and intentional mind-wandering, but equivalent task accuracy. Parallel mediations demonstrated that older adults reduced their unintentional mind-wandering through having less anxiety and greater task engagement than younger adults. Despite evidence of age-related decline on cognitive function tests, neither executive function nor task demand variables further contributed to the model. Our results adjudicate between competing theories, highlighting the roles of affective and motivational factors in unintentional mind-wandering. Intentional mind-wandering showed no significant associations with the neuropsychological measures; however, intentional mind-wandering was associated with more false alarms, which was mediated by greater reaction time variability (RTV). In the context of the exploration/exploitation framework, we suggest that younger adults were more inclined to intentionally mind-wander, indexed by increased RTV, while preserving comparable performance accuracy to older adults. Conversely, older adults exploited greater task focus, marked by reduced RTV, with less bias toward, or resources for, exploration of the mind-wandering space. Therefore, dispositional and strategic factors should be considered in future investigations of mind-wandering across the lifespan.

Keywords: cognitive aging, mind-wandering, intentionality, negative affect, motivation

What is the Nature of Mind-Wandering in Aging?

Our inner mental life is subject to a constant, freely-evolving, discursive stream of thoughts (Christoff, Irving, Fox, Spreng, & Andrews-Hanna, 2016). In ‘mind-wandering’, attention disengages from processing the perceptual environment and shifts inward toward endogenously-generated mental content (Smallwood & Schooler, 2006, 2015). In recent decades, there has been an explosion in mind-wandering research with a proliferation of studies exploring mind-wandering within healthy aging populations. Research has consistently shown mind-wandering to decrease as a function of age in healthy individuals (see meta-analysis Jordao, Ferreira-Santos, Pinho, & St Jacques, 2019; see review Maillet & Schacter, 2016). This finding has been widely corroborated across lab paradigms (Frank, Nara, Zavagnin, Touron, & Kane, 2015; Giambra, 1989; Jackson & Balota, 2012; Krawietz, Tamplin, & Radvansky, 2012; Maillet, Yu, Hasher, & Grady, 2020; McVay, Meier, Touron, & Kane, 2013; Shake, Shulley, & Soto-Freita, 2016; Zavagnin, Borella, & De Beni, 2014), as well as in online (Jackson, Weinstein, & Balota, 2013; Seli et al., 2020) and daily-life (Maillet et al., 2018) settings. Considering the global phenomenon of population aging, and in view of the adaptive and maladaptive corollaries of mind-wandering (see Mooneyham & Schooler, 2013) with implications for the wellbeing, independence, and safety of older adults, the extent to which mind-wandering is disrupted, or influenced, by the natural aging process is a timely issue.

Despite a lacking universal consensus on nomenclature (see Christoff et al., 2016; Christoff et al., 2018; Seli et al., 2018; Smallwood & Schooler, 2015), mounting empirical evidence supports an operational distinction of mind-wandering as occurring due to the unintentional or intentional redirection of attentive resources (Forster & Lavie, 2009; Golchert et al., 2017; Grodsky & Giambra, 1990; Seli, Maillet, Smilek, Oakman, & Schacter, 2017; Seli, Ralph, Konishi, Smilek, & Schacter, 2017; see review Seli, Risko, Smilek, &

Schacter, 2016). Whereas *unintentional* mind-wandering involves an involuntary and unguided decoupling of attention (e.g. drifting off while reading), *intentional* mind-wandering is the deliberate deployment of attention away from an ongoing task, or environmental referent, toward unrelated self-generated thought (e.g. planning your to-do list while driving) (Seli et al., 2016). There is a modest emergence of studies showing older adults report fewer incidences of unintentional and intentional mind-wandering using self-caught (Grodsky & Giambra, 1990) and probe-caught (Seli, Maillet, et al., 2017) experience sampling (ES; a self-report technique whereby participants judge their mental state at discrete moments (Kahneman, Krueger, Schkade, Schwarz, & Stone, 2004)). The validity of this intentionality distinction is supported by differential associations between unintentional and intentional mind-wandering reports and distinct content, neural, behavioral and clinical correlates (Corbetta & Shulman, 2002; Golchert et al., 2017; Seli, Ralph, et al., 2017; Seli, Risko, Purdon, & Smilek, 2017; Seli et al., 2016; Seli, Smallwood, Cheyne, & Smilek, 2015). Research on aging and mind-wandering intentionality, however, remains underdeveloped, and further research is needed to clarify to what extent, if any, aging has on dissociable mind-wandering experiences.

What Theoretical Approaches Have Evolved to explain Mind-Wandering in Aging?

The preceding findings have prompted numerous research questions. Does age-related mind-wandering have its own proprietary phenomenology? What mechanisms contribute to the age-related effect? Do existing models enable consideration of different mind-wandering dynamics? In response, several competing theoretical frameworks have evolved to account for mind-wandering in aging. One framework considers the role of executive function; most notably, 1) the ‘Executive Control Hypothesis’ (Smallwood & Schooler, 2006) and 2) the ‘Control Failure X Concerns theory’ (McVay & Kane, 2010). Alternatively, 3) the ‘Exploitation/Exploration’ framework (Sripada, 2018) postulates the underlying oscillatory

dynamics of mind-wandering. A final framework underscores the roles of non-cognitive, dispositional factors, namely 4) affective (e.g. Frank et al., 2015), and 5) motivational (e.g. Jackson & Balota, 2012) accounts.

Role of Executive Function

Firstly, the *Executive Control Hypothesis* (Smallwood & Schooler, 2006) suggests that mind-wandering requires controlled processing to facilitate the shift of resources away from an ongoing task/activity toward personally relevant goals. Given older adults have fewer cognitive resources than younger adults (Braver & West, 2008; Foster, Cornwell, Kisley, & Davis, 2007), and hence, fewer resources available during a task to deploy to off-task thought, this model predicts a reduction in mind-wandering frequency with age. The role of executive function, and how efficient an individual is at consigning mind-wandering, is further constrained and modulated according to the ongoing context and primary task demands. According to the ‘context regulation hypothesis’ (Smallwood & Schooler, 2015), difficult tasks that require considerable controlled processing should see a corresponding attenuation in mind-wandering as more executive resources are required for successful task performance (Giambra, 1989; Jackson & Balota, 2012). By this view, a trade-off in competing resources for mind-wandering and task will incur performance impairments. It follows that the involvement of executive functions in age-related mind-wandering varies depending on task demands. In particular, age-related differences in mind-wandering should be more pronounced in non-demanding tasks (Jordao et al., 2019). Age-accompanied reductions in mind-wandering, however, have been observed across conditions that were more or less demanding (Jackson & Balota, 2012).

Secondly, the *Control Failure X Concerns theory* (McVay & Kane, 2010) proposes that ‘concerns’, cued from the environment or personal goals, prompt the automatic initiation of mind-wandering as a consequence of momentary inhibition failure. This model suggests

that executive control is required to impede thoughts triggered by current concerns from breaching consciousness and detracting from goal maintenance. Hence, with declining executive functions in advanced age, or ‘*control failure*’, older adults should be more susceptible to mind-wandering. Given the converse finding, it has been suggested that older adults’ self-reports may be unreliable due to their orientation toward social desirability (Soubelet & Salthouse, 2011) and/or poorer metacognition (Maillet & Schacter, 2016). However, there is established validity for older adults’ self-reports (Frank et al., 2015). Klinger’s (1971) original ‘*current concerns*’ hypothesis, however, proffers that despite older adults having poorer inhibition capacities (Lustig, Hasher, & Zacks, 2007), they may have fewer concerns to inhibit (Parks, Klinger, & Perlmutter, 1989); thereby leading to reduced mind-wandering. Although, the over-arching Control Failure X Concerns perspective does not sufficiently explain the consistent finding of age-accompanied decreases in mind-wandering, the ‘current concerns’ component offers a promising avenue for future enquiry (McVay & Kane, 2010).

These accounts highlight the complex, and often confusing, relationship between mind-wandering and executive control. There is a more nuanced view that if we take account of different mind-wandering types, executive control aids the regulation of cognition and supports coordination of intentional mind-wandering, whereas it is the loss of task-related executive control that yields unintentional mind-wandering. In support, intentional mind-wandering involves greater integration between fronto-parietal control networks and the Default Mode Network than unintentional mind-wandering (Golchert et al., 2017).

Role of Oscillatory Dynamics

Thirdly, and more broadly, are there different oscillatory dynamics of mind-wandering in younger and older adults? The *Exploitation/Exploration* framework (Sripada, 2018), typically applied to learning models (e.g. Sutton & Barto, 1998) and attention (Aston-

Jones & Cohen, 2005), frames goal-directed thinking as an exploitative process that capitalizes on current cognitive resources in the service of a specific goal. Mind-wandering is more explorative; entailing an open-ended search strategy for possible opportunities and information, that can enable pattern learning and enhance creativity. Although this framework has provided a relatively new viewpoint on mind-wandering functionality, neuroimaging evidence has shown differential activation of distinct neural regions supporting an antagonistic alternation between goal-directed thinking and mind-wandering (see Sripada, 2018). Optimal performance is enhanced by a balance of strategies relative to the context and is modulated by an inner drive that exhibits temporal oscillations. Indeed, performance variability, most notably Reaction time variability (RTV), has been suggested as a quantitative index measuring oscillatory attention cycles. In support, lower RTV has been observed during periods of goal-directed thought, with higher variability during mind-wandering (Allan Cheyne, Solman, Carriere, & Smilek, 2009; see Mooneyham & Schooler, 2013). Given evidence for an exploration bias in younger adults (Mata, Wilke, & Czienskowski, 2013), a further proposition for how mind-wandering changes with age is that reduced executive resources may limit older adults' capacity to optimize and adaptively oscillate between competing strategies, especially within the context of intentional mind-wandering.

Role of Dispositional Factors

Fourthly, *affective accounts* (e.g. Frank et al., 2015) have been proposed to explain age-related reductions in mind-wandering, drawing from two observations; a) mind-wandering has been associated with negative affect in younger adults (Kane et al., 2007; Killingsworth & Gilbert, 2010; McVay, Kane, & Kwapil, 2009; Smallwood, O'Connor, Sudbery, & Obonsawin, 2007), and b) older adults report less negative affect, greater positive orientation and life satisfaction, and better emotional regulation than younger adults

(Carstensen, Isaacowitz, & Charles, 1999; Grühn, Kotter-Grühn, & Röcke, 2010; Zavagnin et al., 2014). Indeed, during a reading comprehension task, the effect of age on mind-wandering was partially mediated by older adults' greater positive affect (Frank et al., 2015).

Fifthly, *motivational accounts* (e.g. Jackson & Balota, 2012) have gained momentum, attributing age-differences in mind-wandering to task-related engagement and interest. An increasingly documented finding is that older adults tend to be more conscientious and motivated while completing traditional lab-based tasks than younger adults (Jackson & Balota, 2012; Krawietz et al., 2012; Maillet & Rajah, 2013; Shake et al., 2016). In studies with younger adults, higher levels of interest were correlated with reduced overall mind-wandering (Unsworth & McMillan, 2013), as well as with less unintentional and intentional mind-wandering (Seli, Wammes, Risko, & Smilek, 2015), and with reduced proportional intentional mind-wandering (Seli, Cheyne, Xu, Purdon, & Smilek, 2015). It follows that older adults, through their greater task interest, should mind-wander less. Indeed, in two reading task studies covarying for text interest (Krawietz et al., 2012), or interest and age (Shake et al., 2016), attenuated the age-related reduction in mind-wandering with no additional contribution from cognitive variables. Recent mediation analyses have also supported an indirect effect of motivation/interest, showing older adults mind-wander less frequently due, in part, to their higher engagement (Frank et al., 2015; Seli et al., 2020). This effect was consistent when motivation ratings were taken post-lab task, allowing the possibility of performance bias (Frank et al., 2015), but also when recorded prior to an online-task (Seli et al., 2020). Moreover, experimentally increasing motivation minimised the degree of mind-wandering in younger adults (Seli, Schacter, Risko, & Smilek, 2019) and further decreased age-related differences in mind-wandering (Seli et al., 2020). Few studies, however, have investigated the impact of age-related differences in motivation on unintentional and intentional mind-wandering separately; although initial research demonstrated a negative

correlation between motivation and unintentional, but not intentional, mind-wandering for both age groups (Seli, Maillet, et al., 2017).

What Mechanisms Contribute to the Age and Mind-Wandering Effect?

The phenomenon of age-accompanied diminution in mind-wandering contradicts perceived wisdom and stands seemingly opposed to accounts that present mind-wandering as executive control failure. Although dispositional accounts hold promise, there is no unanimity on how best to reconcile the paradoxical decrease in mind-wandering with age. The best explanation may derive from some amalgamation of these frameworks or they may, perhaps, partially explain different aspects of mind-wandering generation or continuity (Smallwood, 2013). Regardless, the presupposed broad definition of mind-wandering neglects the established role of intentionality. Closely allied is the paucity in conclusive research elucidating the distinct neuropsychological mechanisms underlying unintentional and intentional mind-wandering. Given the potential far-reaching consequences of mind-wandering for the wellbeing and safety of older adults, future studies must investigate the forgoing to decompose the impact of intentionality and to clarify the impact of the natural aging process on mind-wandering.

The Present Study

The present study aimed to investigate whether the frequency and phenomenology of mind-wandering changed as a function of age and examine the distinct neuropsychological mechanisms mediating age-related differences in unintentional and intentional mind-wandering. We capitalized on evolving methodologies for measuring and classifying the frequency and nature of mind-wandering by employing a multi-faceted approach comprising a comprehensive neuropsychological test battery and Gradual Contrast Change Detection task (McGovern, Hayes, Kelly, & O'Connell, 2018; O'Connell, Dockree, & Kelly, 2012) with built-in experience sampling (GradCCD-ES) mind-wandering probes. Our methodological

approach captured self-reported mind-wandering episodes during a continuous task featuring smooth and gradually evolving target transitions extending typical tasks that employ discrete, sudden-onset and predictably occurring target and non-target stimuli (e.g. the SART). The gradually unfolding stimulus features minimized the need for rapid information processing and response demands and hence, required greater reliance on endogenous control. The GradCCD-ES was therefore well suited to induce and measure off-task thought.

In the GradCCD-ES, healthy younger and older adults monitored a continuously presented flickering annulus to identify intermittent contrast reductions and pseudo-randomly responded to probes asking participants to classify their current cognitive experience as ‘focused on the task’, or ‘unintentionally’ or ‘intentionally’ mind-wandering (Seli, Cheyne, et al., 2015). Given the low-task demands, we did not anticipate appreciable age-related decrements in performance (Hypothesis one). Indeed, a study using an earlier version of this task (McGovern et al., 2018) found similar between-group RTs and false alarm rates but increased correct target detections and reduced RTV by older adults. In response to the ES probes, we predicted that older adults would report fewer incidences of unintentional and intentional mind-wandering throughout the task (Hypothesis two). The finding that mind-wandering has a pernicious effect on concurrent performance on sustained attention tasks led to our next prediction that unintentional and intentional mind-wandering would negatively impact behavioral performance (Hypothesis three). Additionally, based on research showing dissociable correlates of unintentional and intentional mind-wandering, we postulated differential associations with key neuropsychological outcomes (Hypothesis four). Finally, to dissociate between prominent mind-wandering theories, we examined the indirect effects of cognitive function, task demand, affective, and motivation variables. We hypothesized that distinct theoretically derived neuropsychological factors would mediate the age effect for unintentional and intentional mind-wandering (Hypothesis five).

Methodology

Participants

Eighty-one community-dwelling older adults were contacted from a university research participant panel, comprising older adults aged between 65 and 80 years. Of those contacted, 47 older adults expressed interest and were assessed for eligibility. Initial inclusion criteria were normal or corrected-to-normal vision, no personal or family history of neurological or psychiatric illness, no personal or family history of brain injury or unexplained fainting, no sensitivity to flickering light, and no recent history of drug, alcohol or pharmaceutical abuse. From this pool, 40 older adults were selected and participated. Six participants were later excluded from the analyses: five were excluded based on a Montreal Cognitive Assessment (MOCA; Nasreddine et al., 2005) score of less than 24, indicating possible cognitive impairment (O'Caoimh, Timmons, & Molloy, 2016), and one participant was excluded due to illness. This resulted in a sample of 34 cognitively normal healthy older adult participants (mean age 71 years, standard deviation (*SD*) = 3.54, 20 female).

Younger participants, aged between 18 and 35 years, were recruited from the TCD student population. Forty-three younger adults expressed interest, 35 of whom were selected after pre-screening. One participant was excluded due to technical issues. Consequently, data from 34 younger adult participants (mean age 22 years, *SD* = 4.59, 16 female) were included in the per-protocol analyses (see Figure S1 consort flow diagram, online supplement).

Participants took part in the study across two sessions (median days apart = 2, inter-quartile range (IQR) = 5) and received partial course credit or a €20 gratuity to cover travel costs. Participation was entirely voluntary, and all participants provided willful and explicit written informed consent to the procedures that were approved by the School of Psychology Research Ethics Committee, TCD and were conducted in accordance with the principles of the Declaration of Helsinki.

Sample Size and Study Power

A recent meta-analysis (Jordao et al., 2019) demonstrated a significant between-groups difference in mind-wandering frequency, reporting an average large effect size (Hedges' $g = -.89$). Using this parameter and an alpha of .05, 34 participants per group provided a .95 power for a two-tailed independent samples t -test. Calculations for the partial Pearson's r correlations (total sample size of 60 participants, controlling two variables Age Group and NART Errors, with an alpha of .05) revealed power values of .89 and .99 to detect medium ($r_{\text{partial}} = +/- .4$) and large ($r_{\text{partial}} = +/- .6$) effects, respectively. While these calculations were conducted after data collection, the effect sizes used are independent of this dataset and thus, do not have the same issues with bias as 'post hoc' power calculations using obtained effect sizes.

Materials and Procedures

Session 1: Background Neuropsychological Measures

The battery comprised assessments of *cognitive function*: National Adult Reading Test (NART; Nelson & Willison, 1991), Tests of Everyday Attention (TEA; Robertson, Ward, Ridgeway, & Nimmo-Smith, 1996), Stroop Color and Word test (Golden & Freshwater, 2002) and the Controlled Oral Word Association Test (COWAT; Benton, Hamsher, & Sivan, 1994; Spreen & Strauss, 1998). Participants completed self-report questionnaires assessing *negative affect* using the Hospital Anxiety and Depression Scale (HADS; Zigmond & Snaith, 1983) and *daily life attentional difficulties* with the Connor's Adult ADHD Rating Scale (CAARS; Conners, Erhardt, & Sparrow, 1999). Details on the neuropsychological measures are provided in the online supplement (see Table S1).

Session 2: Behavioral Task

Participants returned to the lab on a separate day for the behavioral session that included a computerized sustained attention task with embedded ES probes. Concurrent

electroencephalography (EEG) and pupillometry were recorded to investigate age-related differences in the temporal dynamics of momentary attentional fluctuations. These neurophysiological results will be reported in a forthcoming dissemination.

Gradual Contrast Change Detection with Experience Sampling (GradCCD-ES)

Task. The GradCCD-ES task (McGovern et al., 2018; O'Connell et al., 2012) required participants to continually monitor a flickering annulus stimulus (25Hz) to detect intermittent targets, characterized as smooth and gradual contrast changes, to assess sustained attention. The checkerboard annulus stimulus comprised 8° outer and 3° inner radii with interchanging light and dark radial segments, against a dark grey background. The linear contrast reductions unfolded gradually from 65% to 35% over 1.6 seconds and ramped back to baseline over 0.8 seconds (Figure 1). The targets occurred pseudo-randomly with inter-target intervals of three, five, or 7-seconds. The target stimuli were presented in the center display of a 40cm CRT monitor operating at 100Hz with 1024x768 resolution using Matlab software version R2016b (The MathWorks, Natick, 2016) and Psychtoolbox-3 interface (Brainard, 1997; Pelli, 1997). Participants sat opposite the monitor in a dark, sound-attenuated room, and fixated on the central point to identify target contrast changes. As soon as participants noticed the annulus contrast decreasing, they made a speeded left-button press with their right index finger. Participants performed 8 blocks; each lasted approximately 7-8 minutes and included 48 target trials (totaling 384 targets). Participants carried out two brief practice blocks prior to the main experiment to ensure adequate comprehension of the procedures. Behavioral performance indices included: a) hit rate (proportion of correctly identified targets), b) RT for correct target trials (in seconds), c) RT coefficient of variance (CoV) for correct trials, calculated as the standard deviation of RT divided by the mean RT, multiplied by 100, and d) the number of false alarms. Outcomes were averaged across the task for each participant.

To capture mind-wandering events in real time, the task was intermittently interrupted by built-in ES probes. When a probe appeared, the task halted temporarily, and participants were instructed to “Choose the response that best describes your [their] mental state right before this screen appeared”. Participants responded with a keyboard press (numbers 1-3) as to whether they had been 1) ‘focused on the task’, 2) ‘unintentionally lost focus on the task’, or 3) ‘intentionally disengaged from the task’ in the moments prior to the probe (Seli, Cheyne, et al., 2015). Once the probe was answered, the task resumed. Each block contained 16 probes (128 in total). The probes occurred pseudo-randomly with a minimum constraint of two-trial separation imposed to minimize task interruptions, facilitate possible occasions for mind-wandering, and curtail probe predictability. Prior to administration, participants were provided with explanations of the probe responses and told that mind-wandering is a normal feature of everyday cognition, to engender more honest responding. ES outcomes included the frequency and percentage of each probe response: a) focus, b) unintentional, and c) intentional mind-wandering, as well as d) a composite total mind-wandering frequency (summed frequency of unintentional and intentional mind-wandering responses). These measures were averaged across the total task for each participant.

Figure 1

Experimental Schematic of the Continuous Gradual Contrast Detection Task with Experience Sampling Probes.

Note. Participants continuously monitored the flickering annulus stimulus for gradual contrast changes, representing a stimulus contrast reduction from 65% to 35% over 1.6 seconds, and responded to intermittent experience sampling probes asking about current mental state.

Task-related Motivation Measures. The Stanford Sleepiness Scale (SSS; Hoddes, Zarcone, Smythe, Phillips, & Dement, 1973) was administered prior to the task to assess alertness. The Dundee Stress State Questionnaire (DSSQ; Matthews et al., 1999) was administered pre- and post-task to measure task-induced motivation changes, see Table S1 (online supplement).

Data Management

Data from 68 participants, who completed the study per-protocol, were initially assessed for normality (by inspecting skewness and kurtosis values, histograms, and Kolmogorov-Smirnov tests). Outliers, defined as data points extending greater than three times the IQR within a particular outcome measure, were removed and excluded from subsequent analyses (representing less than .05% of values in each group). Two participants had a combined total of three missing CAARS items. Subscale total scores for these participants were adjusted according to the number of items answered (Conners et al., 1999).

Statistical Analysis Plan

To assess hypotheses **one** and **two** that predicted between-group differences in behavioral performance and subjective ES probe responses, a series of two-tailed independent *t*-tests were conducted. Where Levene's test for equality of variance was significant, the appropriate tests with corrected degrees of freedom were reported. Where normality was violated, a non-parametric test equivalent, Mann-Whitney *U* test, was conducted and the associated medians and IQR reported. A test statistic was deemed significant if the *p*-value was less than .05. For each comparison, Cohen's *d* was calculated as a measure of effect size and interpreted by rule of thumb as representing small ($d = .2$), medium ($d = .5$) or large ($d =$

.8) effects (Cohen, 1988). Bayesian analyses were also applied to the group comparisons to establish the presence or absence of a group effect, using a default scaling parameter of .707. Bayes Factor (BF) provided a relative measurement of the predictive ability of the null versus the alternative hypothesis (Dienes, 2014). The Bayesian approach was applied here to support the frequentist between-group comparisons; specifically, in situations where a non-statistically significant result was observed, BF demonstrated whether there was support for the null hypothesis of no group difference (i.e. evidence of absence) or whether there was a dearth of evidence (i.e. absence of evidence) (Dienes, 2014). Guidelines for the strength of the evidence in favor of the alternative hypothesis were classified as weak/inconclusive ($BF_{10} = 1-3$), moderate ($BF_{10} = 3-10$), or strong ($BF_{10} > 10$). A BF value lower than a third indicated support for the null hypothesis, that no effect was present (Dienes, 2014).

Two-tailed partial Pearson's r correlations, controlling for age group and NART Errors, were performed to test hypotheses **three** and **four** that predicted significant differential associations between ES probe responses, and behavioral and neuropsychological outcomes, respectively. For hypothesis **five**, parallel mediation models were conducted to evaluate age group and mind-wandering (unintentional and intentional) effects, and the relative role of putative mediators, derived from theoretical models. Variables representing cognitive function, task demand, affective, and motivational factors were included as mediators. For all mediation analyses, 95% Bootstrap confidence intervals (using 10,000 bootstrapped samples) were used for statistical inference, providing credible intervals for the specific indirect effects.

SPSS Version 24 (IBM; Chicago, IL, United States), SPSS Process Macro v3.3 model 4 (Hayes, 2013), and JASP software (JASP Team, 2019) were used to run the frequentist, mediation, and Bayesian analyses, respectively. Prism 8 (GraphPad) was used for graphical representations.

Results

Sample Characteristics

The final sample comprised 34 older adults (20 female) with a mean age of 70.97 years ($SD = 3.54$, range 65-78 years) and 34 younger adults (16 female) with a mean age of 21.71 years ($SD = 4.59$, range 18-35 years). The groups did not significantly differ on gender, $\chi^2(1, N = 68) = .94, p = .331, \Phi = -.12, BF_{10} = .47$, or years of education, $t(60.99) = 1.47, p = .148$ (two-tailed), $d = .36, BF_{10} = .62$ (see Table S2 sociodemographic characteristics, online supplement).

Group Comparisons on the Background Neuropsychological Measures

Descriptive statistics for group comparisons on key neuropsychological variables are summarized in Table S3 (online supplement). A suite of independent samples t -tests demonstrated statistically significant between-group differences on *cognitive function*. Older adults were slower to detect TEA Telephone Search targets, $t(60.68) = -6.31, p < .0005$, 95% CI [-1.55, -.80], $d = 1.53, BF_{10} = 370837.20$, and demonstrated longer search times when weighted for tone-counting accuracy, $t(32.61) = -6.32, p < .0005$, 95% CI [-4.03, -2.07], $d = 1.51, BF_{10} = 187696.93$, and a larger dual-task decrement, $t(35.86) = -4.23, p < .0005$, 95% CI [-2.19, -.77], $d = 1.04, BF_{10} = 283.19$. There was no support for group differences in Visual Elevator accuracy, $t(65) = -.11, p = .916$, 95% CI [-.82, .73], $d = .03, BF_{10} = .25$, or Stroop Word trial duration, $t(66) = -1.48, p = .144$, 95% CI [-7.32, 1.09], $d = .36, BF_{10} = .6$. Older adults did, however, take significantly longer to complete the Stroop Color, $t(66) = -4.14, p < .0005$, 95% CI [-20.51, -7.16], $d = 1.00, BF_{10} = 218.88$, and Color-Word, $t(66) = -6.00, p < .0005$, 95% CI [-51.74, -25.91], $d = 1.46, BF_{10} = 121177.62$, trials. Correspondingly, there was strong evidence that older adults were more susceptible to Stroop Interference, $t(44) = 3.15, p = .003$, 95% CI [3.17, 14.44], $d = 1.06, BF_{10} = 12.80$. Moreover, older adults produced fewer words on Categorical Verbal Fluency, $t(66) = 3.27, p = .002$, 95% CI [2.67,

11.03], $d = .79$, $BF_{10} = 19.66$, but were not significantly different from younger adults on the Phonemic condition, $t(57.41) = -.99$, $p = .325$, 95% CI $[-7.81, 2.63]$, $d = .24$, $BF_{10} = .38$. All statistically significant results were indicative of poorer cognitive performance by older adults, apart from the NART, where older adults produced fewer errors, $t(66) = 2.94$, $p = .005$, 95% CI $[1.77, 9.29]$, $d = .71$, $BF_{10} = 8.66$. This latter finding remained when data from non-native English speakers were removed and re-analysed; hence, results from the total sample are reported.

Despite poorer cognitive performance, older adults experienced less *negative affect*, reporting lower levels of HADS Anxiety, $t(59.91) = 3.96$, $p < .0005$, 95% CI $[1.55, 4.74]$, $d = .96$, $BF_{10} = 127.51$, and depression, $U = 403.50$, $Z = -2.16$, $p = .031$, $d = .54$, $BF_{10} = 1.96$. Further, there were significant group differences on CAARS *daily life attentional difficulties*; older adults expressed fewer issues with self-perceived inattention and memory, $t(45.75) = 3.09$, $p = .003$, 95% CI $[.74, 3.50]$, $d = .74$, $BF_{10} = 9.41$, reduced hyperactivity/restlessness, $t(56.79) = 6.34$, $p < .0005$, 95% CI $[2.68, 5.15]$, $d = 1.54$, $BF_{10} = 421009.79$, as well as fewer problems with self-concept, $t(59.06) = 3.51$, $p = .001$, 95% CI $[1.27, 4.63]$, $d = .85$, $BF_{10} = 37.03$. The groups did not significantly differ, however, with respect to their perceived impulsivity or emotional lability, $t(66) = 1.53$, $p = .130$, 95% CI $[-.23, 1.76]$, $d = .37$, $BF_{10} = .67$. Overall, there was strong evidence for a group difference in subjective experience of ADHD-related symptoms, with older adults reporting fewer difficulties, $t(60.73) = 4.55$, $p < .0005$, 95% CI $[2.79, 7.17]$, $d = 1.10$, $BF_{10} = 785.65$. Only one younger adult reported a formal ADHD diagnosis and t-scores for all participants fell below the threshold for clinically-elevated symptoms (Robertson et al., 1996).

Finally, the *task-related motivation* measures revealed older adults reported greater SSS alertness pre-task than their younger counterparts, $U = 315.00$, $Z = -3.44$, $p = .001$, $d = .85$, $BF_{10} = 8.71$. DSSQ group comparisons showed older adults found the task more

engaging; that is, they experienced less task-induced motivation losses relative to younger adults, $t(66) = -2.89, p = .005, 95\% \text{ CI } [-6.52, -1.19], d = .69, BF_{10} = 7.73$. There was no significant between-group difference regarding task-induced distress, $t(65) = 1.46, p = .149, 95\% \text{ CI } [-.75, 4.88], d = .36, BF_{10} = .62$, but weak evidence for increased task-induced worry in younger adults, $t(66) = 2.32, p = .024, 95\% \text{ CI } [.41, 5.48], d = .56, BF_{10} = 2.35$.

Hypothesis One: There will be no Marked Age-Related Decrements in Performance on the GradCCD-ES Task

Independent t -test and Mann-Whitney U analyses demonstrated relative group parity in GradCCD-ES task performance (see Table 1). There were no significant between-groups differences observed in hit rate, $U = 432.50, Z = -1.07, p = .285, d = .27, BF_{10} = .37$, false alarms, $U = 383.50, Z = -1.55, p = .122, d = .39, BF_{10} = .67$, or mean RT, $t(61.79) = -.56, p = .580, 95\% \text{ CI } [-.11, .06], d = .12, BF_{10} = .28$, across the task. There was, however, moderate evidence in support of a group difference in RT CoV; namely, older adults demonstrated significantly less performance variability than younger adults, $t(64) = 2.64, p = .011, 95\% \text{ CI } [.72, 5.24], d = .65, BF_{10} = 4.45$ (see Figure 2).

Figure 2

Scatterplots of Individual Level Data Points for Between-Group Comparisons on Behavioral Performance Indices.

Note. Graphs for reaction time (RT) and RT coefficient of variance display mean (SEM); Hit Rate and False Alarms graphs display median (IQR).

* $p < .05$

Hypothesis Two: Older Adults will Report Fewer Incidences of Unintentional and Intentional Mind-Wandering Throughout the Task

Descriptive statistics for the group ES probe responses are displayed in Table 1 and Figure 3. Older participants reported greater levels of focus than younger participants, $t(66) = -3.42, p = .001, 95\% \text{ CI } [-4.12, -1.08], d = .83, BF_{10} = 28.74$. Younger and older adults reported mind-wandering for approximately 45% and 27% of the probes, respectively. There was strong evidence to support a group difference in total mind-wandering frequency, with older adults exhibiting a lower propensity to mind-wander overall, than their younger counterparts, $t(65) = 3.88, p < .0005, 95\% \text{ CI } [1.38, 4.30], d = .95, BF_{10} = 102.14$. Specifically, older adults experienced fewer incidences of unintentional, $t(66) = 2.43, p = .018, 95\% \text{ CI } [.24, 2.48], d = .59, BF_{10} = 2.93$, and intentional, $t(65) = 4.65, p < .0005, 95\% \text{ CI } [.86, 2.15], d = 1.13, BF_{10} = 1087.82$, mind-wandering than younger participants.

Table 1*Behavioral Performance Indices and Experience Sampling Probe Responses on the Gradual**Contrast Change Detection Task for Younger and Older Adult Participants (N = 68)*

Variable	Young (<i>n</i> = 34)	Old (<i>n</i> = 34)
	Mean (<i>SD</i>)	Mean (<i>SD</i>)
Behavioral Performance		
Hit Rate, median (IQR), Young: <i>n</i> = 32, Old: <i>n</i> = 32	.95 (.05)	.97 (.07)
Reaction Time	1.31 (.15)	1.33 (.19)
Reaction Time CoV, * Young: <i>n</i> = 34, Old: <i>n</i> = 32	24.29 (5.22)	21.32 (3.80)
False Alarms, median (IQR), Young: <i>n</i> = 32, Old: <i>n</i> = 31	2.06 (3.19)	1.13 (4.13)
Experience Sampling		
Focus**	8.88 (2.91) 55.47%	11.47 (3.34) 71.71%
Unintentional MW*	4.88 (2.27) 30.47%	3.51 (2.35) 21.94%
Intentional MW***, Old: <i>n</i> = 33	2.25 (1.51) 14.06%	.75 (1.10) 4.66%
Total MW***, Old: <i>n</i> = 33	7.13 (2.91) 44.53%	4.28 (3.08) 26.78%

Note. CoV, Coefficient of Variance; IQR, Interquartile range; MW, Mind-wandering; *n*,

Number of observations; SD, Standard deviation.

**p* < .05

***p* < .01

****p* < .001

Figure 3

Grouped Bar Chart Showing Differences on the Experience Sampling Probe Responses between Younger and Older Adult Participants.

Note. Graph displays mean (SEM).

MW, mind-wandering.

* $p < .05$

** $p < .01$

*** $p < .001$

Hypothesis Three: Unintentional and Intentional Mind-Wandering will Negatively Impact Concurrent Task Performance

Partial Pearson correlations were conducted to determine the relationship between probe responses and behavioral performance indices, controlling for age group and NART Errors (see Table 2). There was a statistically significant positive association between focus and hit rate, $r_{\text{partial}}(56) = .41, p = .001$, and a negative relationship between focus and false alarms, $r_{\text{partial}}(56) = -.28, p = .034$. Unintentional mind-wandering was associated with reduced hit rate, $r_{\text{partial}}(56) = -.42, p = .001$, while intentional mind-wandering was positively

related with false alarms, $r_{\text{partial}}(56) = .28, p = .035$. Repeated partial correlations controlling for age group only showed negligible differences to the reported results (see Table S4, online supplement).

Follow-up exploratory simple mediation models showed RT CoV, but not RT, mediated the intentional mind-wandering and false alarms relationship (mediated effect = .47, 95% CI .08 to .92). Namely, higher incidences of intentional mind-wandering were associated with more false alarms, linked in part to their more variable performance (higher RT CoV). Note, an additional analysis did not find a corresponding indirect effect of RT CoV mediating unintentional mind-wandering and false alarms. Further, neither RT nor RT CoV indirectly influenced the unintentional mind-wandering and hit rate relationship (see Figure 4).

Table 2

Partial Pearson's r Correlation Coefficients for the Relationships between Experience Sampling Probe Responses and Behavioral Performance Indices, Controlling for Age Group and NART Errors (N= 56).

Variable	1	2	3	4	5	6	7	8
1. Focus	-	-.91***	-.70***	-1.00***	.41**	-.12	-.22	-.28*
2. Unintentional MW		-	.34**	.91***	-.42**	.16	.18	.21
3. Intentional MW			-	.70***	-.21	.00	.18	.28*
4. Total MW				-	-.41**	.12	.22	.28*
5. Hit Rate					-	-.59***	-.18	-.45***
6. RT						-	-.39**	-.05
7. RT CoV							-	.79***
8. False Alarms								-

Note. CoV, Coefficient of Variance; MW, Mind-wandering; n, number of observations; NART, National Adult Reading Test; RT, Reaction Time.

* $p < .05$

** $p < .01$

*** $p < .001$

Figure 4

Statistical Diagrams of Exploratory Simple Mediation Models Testing the Effects of Mind-Wandering (Unintentional and Intentional) on Behavioural Performance Outcomes (Hit Rate and False Alarms) as Mediated by Reaction Time and Reaction Time Coefficient of Variance

Note. CI, Confidence Interval; CoV, Coefficient of Variance; MW, Mind-Wandering; N= Number of observations; RT, Reaction Time.

The mediation parameters show that the effect of unintentional mind-wandering on hit rate was not mediated by either RT (a) or RT CoV (b). Further, the effect of intentional mind-wandering on the number of false alarms was not mediated by RT (c) but was significantly mediated by RT CoV (d).

Hypothesis Four: Unintentional and Intentional Mind-Wandering Will be Differentially Associated with Key Neuropsychological Outcomes

Partial Pearson's r correlations, adjusted for age group and NART Errors, found focus to be negatively associated with HADS Anxiety, $r_{\text{partial}}(60) = -.40, p = .001$, and CAARS ADHD Index, $r_{\text{partial}}(60) = -.25, p = .047$, and positively associated with DSSQ Engagement Difference, $r_{\text{partial}}(60) = .27, p = .037$. After controlling for covariates, unintentional mind-wandering was significantly positively correlated with greater anxiety, $r_{\text{partial}}(60) = .47, p < .0005$, and more ADHD symptoms, $r_{\text{partial}}(60) = .32, p = .012$. Intentional mind-wandering, conversely, was not associated with the key neuropsychological variables. See Table 3 for correlational coefficients. There were no major differences when partial correlations controlled for age group only (see Table S5, online supplement).

Table 3

Partial Pearson's r Correlation Coefficients for the Relationships Between Experience Sampling Probe Responses and Key Neuropsychological

Variable	1	2	3	4	5	6	7	8	9	10	11
1. Focus	-	-.89***	-.72***	-1.00***	-.17	-.07	-.19	.09	-.40**	-.25*	.27*
2. Unintentional MW		-	.34**	.89***	.08	.06	.19	-.05	.47***	.32*	-.23
3. Intentional MW			-	.72***	.23	.05	.11	-.13	.12	.04	-.20
4. Total MW				-	.17	.07	.19	-.09	.40**	.25*	-.27*
5. TEA Tel Search Time per Target					-	-.01	.14	-.35**	.19	.13	-.33**
6. TEA Visual Elevator number correct						-	-.11	.15	.27	.19	-.08
7. TEA Tel Search Dual task decrement							-	-.10	.02	-.01	-.08
8. COWAT Categorical Total								-	-.08	-.05	.05
9. HADS Anxiety									-	.50***	.11
10. CAARS ADHD Index										-	.18
11. DSSQ Engagement Difference											-

Measures, Controlling for Age Group and NART Errors ($N = 60$).

Note. ADHD, Attention-Deficit Hyperactivity Disorder; CAARS, Conners' Adult ADHD Rating Scale; COWAT, Controlled Oral Word Association Test; DSSQ, Dundee Stress State Questionnaire; HADS, Hospital Anxiety and Depression Scale; MW, Mind-wandering; TEA, Tests of Everyday Attention; Tel, Telephone.

* $p < .05$

** $p < .01$

*** $p < .001$

Hypothesis Five: Distinct Neuropsychological Factors Will Mediate the Age Effect for Unintentional and Intentional Mind-Wandering

Bootstrap confidence intervals were used to explore the role of six parallel mediators, derived from four competing theories (cognitive function, task demands, negative affect, and motivation), in mediating the age and mind-wandering effect. Separate parallel mediation analyses were conducted for unintentional and intentional mind-wandering outcomes. For *unintentional* mind-wandering, the total effect ($c = -1.17$, $t(62) = -2.15$, $p = .035$) showed age group to be a significant predictor, ignoring the mediators. Controlling for the mediators, the direct effect of group on unintentional mind-wandering was not significant; there was no evidence that unintentional mind-wandering differed as a function of age when the mediators were statistically controlled, $c' = .07$, $t(56) = .11$, $p = .915$. This indicated an indirect only effect through HADS Anxiety (mediated effect = $-.98$, 95% CI -1.61 to $-.41$) and DSSQ Engagement Difference (mediated effect = $-.47$, 95% CI -1.08 to $-.08$). Older adults reported fewer incidences of unintentional mind-wandering related to their lower level of anxiety and greater task engagement. No other indirect effects were significant. This is consistent with hypothesized frameworks suggesting the roles of affective and motivational factors. The specific indirect effect contrast did not show a significant difference in the strength of these mediators (effect = $-.51$, 95% CI -1.31 to $.33$). The overall model accounted for approximately 40% of the variance explained in unintentional mind-wandering ($r^2 = .3968$, $p < .0005$), see Figure 5.

For *intentional* mind-wandering, both the total ($c = -1.51$, $t(61) = -4.42$, $p < .0005$) and direct ($c' = -1.51$, $t(55) = -2.89$, $p = .006$) effects were significant. The direct effect showed age group was related to intentional mind-wandering independent of any mediators. Further, there were no significant indirect effects mediating this relationship, see Figure 6.

Figure 5

A Statistical Diagram of the Parallel Mediation Model Testing the Effect of Age Group on Unintentional Mind-Wandering with 6 Mediators (N = 64).

Note. M₁ Divided Attention (TEA Telephone Search Dual task decrement); M₂ Executive Function (COWA Category total); M₃ General Intelligence (NART Errors); M₄ Task Demands (RT CoV); M₅ Anxiety (HADS Anxiety); M₆ Task Engagement (DSSQ Engagement difference).

MW, Mind-wandering.

c = Total effect; c' = Direct effect

* $p < .05$

** $p < .01$

*** $p < .001$

Figure 6

A Statistical Diagram of the Parallel Mediation Model Testing the Effect of Age Group on Intentional Mind-Wandering with 6 Mediators (N = 63).

Note. M₁ Divided Attention (TEA Telephone Search Dual task decrement); M₂ Executive Function (COWA Category total); M₃ General Intelligence (NART Errors); M₄ Task Demands (RT CoV); M₅ Anxiety (HADS Anxiety); M₆ Task Engagement (DSSQ Engagement difference).

MW, Mind-wandering.

c = Total effect; c' = Direct effect

* $p < .05$

** $p < .01$

*** $p < .001$

Discussion

The present study investigated whether the frequency and phenomenology of mind-wandering changed as a function of age and examined the neuropsychological mechanisms mediating age-related differences in unintentional and intentional mind-wandering. In addition to replicating the consistently observed age-related decrease in unintentional and intentional mind-wandering, our research offers three novel findings. Firstly, we show that only unintentional, but not intentional, mind-wandering is predicted by affective and motivational models of age-related mind-wandering. Secondly, we demonstrate that intentional mind-wandering may reflect an adaptive exploratory state that younger adults engage in more frequently than older adults, without incurring a relative cost to task performance. Thirdly, our study is the first, to our knowledge, to concurrently contrast competing theories of mind-wandering to directly compare the relative contributions of dominant models in the field. These contributions are based on a multi-faceted methodological approach, assaying mind-wandering during a non-demanding task that presented targets as gradually unfolding contrast changes in a single perceptual feature, rather than fast sudden-onset discrete stimuli that demand rapid information processing and exogenous attention capture.

Despite a natural tendency for both groups to frequently engage in mind-wandering during a simple sustained attention task, older adults exhibited less unintentional and intentional mind-wandering than their younger counterparts. The larger effect size observed for the intentional group difference underscored a proclivity in younger adults to deliberately disengage from the task. This corroborates previous studies evincing an age-accompanied decrease in unspecified mind-wandering (Frank et al., 2015; Giambra, 1989; Jackson & Balota, 2012; Jordao et al., 2019; Krawietz et al., 2012; Maillet & Schacter, 2016; Maillet et al., 2020; Seli et al., 2020; Shake et al., 2016) and adds to the growing body of research

demonstrating age-related reductions in unintentional and intentional mind-wandering (Grotsky & Giambra, 1990; Seli, Maillet, et al., 2017).

There was relative group equivalence in behavioral performance, with the exception of a moderate age-related decrease in RTV. The Exploitation/Exploration oscillation strategy suggests that temporal fluctuations between goal-directed thinking and mind-wandering are modulated by an inner drive (Sripada, 2018). High RTV has been propounded as an index of exploratory mind-wandering, capturing the dynamic, and perhaps impulsive, alternation between task and competing intentions. Thus, our observed age-related reduction in between-trial RTV suggests steadier attentional engagement by older adults.

This finding replicated an effect originally reported by McGovern et al. (2018) who employed a variant of the present task and considered the possible roles of engagement and fluctuating attention in driving the age RTV discrepancy. They indirectly substantiated this claim through an analysis of neurophysiological signals relating to sensory evidence accumulation (Centro-Parietal Positivity or CPP; O'Connell et al., 2012) and endogenous attentional engagement (posterior alpha band activity; Dockree et al., 2017; Hanslmayr et al., 2007; Kelly & O'Connell, 2013; O'Connell et al., 2009). Specifically, McGovern et al. (2018) reported greater variability in CPP build-up coupled with more variable posterior alpha band activity in younger adults relative to older adults, indicative of a higher degree of attention fluctuation. Given higher variability in younger adults was demonstrated in studies that did (the present study) and did not (McGovern et al., 2018) include ES procedures, this finding does not appear to be a by-product of interrupting performance through probes, but rather a marker of oscillating attention. Indeed, previous research has proposed a pronounced exploration bias in younger adults (Mata et al., 2013) and demonstrated more marked RTV in individuals with ADHD compared to controls (e.g. Castellanos et al., 2005; Tamm et al., 2012). Taken together, our results suggest older adults exploited greater task focus and

procured a relative behavioral advantage, via more stable attentional performance. If there is a trade-off between goal-directed thinking and more explorative mind-wandering, as proffered by the oscillation strategy, then it appears older adults are less inclined to intentionally disengage and explore the mind-wandering space.

Our partial correlations, controlling for age group and IQ, showed focused states were associated with greater hit rate and fewer false alarms. Unintentional mind-wandering related to reduced hit rate, while intentional mind-wandering related to false alarms. This latter relationship was mediated by RTV; namely, intentional mind-wandering was associated with more false alarms accounted, in part, by increased performance instability. The probes were differentially but meaningfully related to behavioral concomitants, and showed mind-wandering to incur a negative effect on performance, in accordance with previous studies (e.g. Allan Cheyne et al., 2009; McVay & Kane, 2009; Mooneyham & Schooler, 2013; Smallwood, McSpadden, Luus, & Schooler, 2008). This corroborates a functional divergence in mind-wandering intentionality (Seli et al., 2016) and demonstrates the benefit of distinguishing heterogeneous mind-wandering experiences.

What can we understand about mind-wandering dynamics from their relationships with task performance? We submit that these differential associations are in line with the exploit/explore strategic theory of mind-wandering (Sripada, 2018); namely, frequent unintended involuntary disruptions to evidence accumulation, through unintentional mind-wandering, led to performance decrements (missed targets). Intentional mind-wandering, conversely, may have allowed for dual-tasking, wherein some resources were exploited toward the task and others marshalled in favor of mind-wandering. Given the easy nature of the task, participants may have modulated their intentional mind-wandering relative to task demands without reducing their accuracy. However, this deliberate dropping in and out of an exploratory state, especially by younger adults, may have increased the variability of their

responding (indexed by high RTV), and led to more false alarms. Given that the higher variability in younger adults did not incur a substantial performance cost, they may have more resources available to implement an optimal oscillation strategy, enabling greater exploration through mind-wandering.

Our neuropsychological assessments verified an age-related decline across various cognitive domains, in line with research showing reduced cognitive resources with advancing age (Braver & West, 2008; Foster et al., 2007). Conversely, older adults reported less anxiety and depression, as well as fewer daily-life attentional difficulties, than younger adults. Moreover, older adults were more alert ahead of the task and reported less task-induced motivation depreciation. This supports reports of greater positive affect and increased task interest in older adults (Jackson & Balota, 2012; Krawietz et al., 2012; Parks et al., 1989). Notably, our cognitive measures were not associated with mind-wandering after controlling for age group and IQ. Similarly, Shake et al. (2016) found working memory capacity to be unrelated to mind-wandering after covarying age and text interest. Correspondingly, our partial correlations revealed focus to be associated with less anxiety, fewer ADHD symptoms and less task-induced motivation loss. Conversely, unintentional mind-wandering was associated with increased anxiety and ADHD symptoms. Interestingly, intentional mind-wandering was not correlated with the neuropsychological outcomes. This highlights how conflation of mind-wandering types may mask unique associations.

What factors influence the inclination to mind-wander in younger but not older adults? Our parallel mediation analyses found anxiety and task engagement mediated the age group and unintentional mind-wandering relationship, whereas no indirect effects by the posited mediators were observed for intentional mind-wandering. Older adults curbed their unintentional mind-wandering, influenced, at least partially, by less negative affect and greater motivation than younger adults. Neither the cognitive nor task demand factors

influenced this relationship which is striking given the widely hypothesized mind-wandering accounts implicating executive resources (McVay & Kane, 2010; Smallwood & Schooler, 2006). Instead, our results elucidate the roles of dispositional factors, supporting affective (e.g. Frank et al., 2015; Klinger, 1971) and motivational (e.g. Jackson & Balota, 2012) accounts, in contributing to age-differences in unintentional mind-wandering.

Although intentional mind-wandering was also reduced in the older group, this effect was not similarly mediated by dispositional factors. This is in accordance with Seli, Maillet, et al. (2017), who reported a negative correlation for both age groups between motivation and unintentional mind-wandering, but not for motivation and intentional mind-wandering. We advance that older adults marshal their more limited executive resources toward the primary task to avoid risking a more balanced ‘exploit/explore’ oscillation strategy. In support, we showed a lack of indirect effects influencing intentional mind-wandering, a sustained direct effect of age group, and a key RTV group difference; together this favours a more restricted oscillation strategy with age. The reported mediations simultaneously tested the roles of multiple putative mechanisms in integrated models, but these models neither account for all possible intervening variables nor facilitate explicit causal claims. Other factors not currently investigated, such as cognitive fatigue, may also partially account for these observed findings. Although related to motivation, cognitive fatigue coupled with tedium may have led participants, particularly younger adults, to deliberately disengage from the task. Indeed, one of the espoused benefits of mind-wandering is relief from boredom (Mooneyham & Schooler, 2013). Further, given the low-task demands and lack of novelty employed by the current task, any moderating impact of older adults’ reduced capacity for rule-switching, or poorer memory for response requirements, may have been minimised.

Previous research has shown that after controlling for affect (Frank et al., 2015) and interest/motivation (Frank et al., 2015; Krawietz et al., 2012; Seli et al., 2020; Shake et al.,

2016), age differences in mind-wandering decreased. Our study extended previous designs that analysed motivation captured pre-task (Seli et al., 2020) or retrospectively (Frank et al., 2015; Krawietz et al., 2012; Shake et al., 2016), by analysing pre-to-post change scores to index task-induced motivation differences. Moreover, by including multiple mediators in our intentionality models, we dissociated several prominent theories and showed the additive value of affective and motivation factors; thereby providing further insights into the factors that influence unintentional mind-wandering. Overall, our findings show how distinguishing between the presence, or absence, of intentionality yields deeper insights into the impact of age on mind-wandering.

Despite current developments, we acknowledge several methodological limitations with recommendations for future research. Firstly, natural environments may provide broader scope for investigating mind-wandering compared to circumscribed lab environments, where individuals have stronger demand characteristics placed on them to perform. If the oscillation strategy is seen as an optimal approach to balance two modes of thought: exploring self-generated thoughts during mind-wandering versus focusing on current opportunities, then this might be best captured in open-ended, unstructured natural environments, with more freedom to explore. Within the quotidian, individuals engage in self- or other-imposed tasks, but also in situations where no explicit goal/task is defined (Murray, Krasich, Schooler, & Seli, 2020). Preliminary field research by Maillet et al. (2018), has demonstrated age-attenuated mind-wandering and a positive association between negative affect and mind-wandering during daily activities. Moreover, a recent study with students, found that despite broadly similar patterns of off-task thought content and neural architecture across lab and daily life contexts, lab-sampled thoughts were more oriented toward other people than those from daily life (Ho et al., 2020). Future approaches should investigate if everyday mind-wandering propensity changes with age, contextualised by the richness of everyday experience, to pinpoint the

mechanisms underlying such changes within a real-world environment. Incorporating field ES (Ho et al., 2020; Kane et al., 2017; Maillet et al., 2018; McVay et al., 2009) and non-invasive lifelogging technology (e.g. Gurrin, Smeaton, & Doherty, 2014) may augment our mechanistic understanding of fluctuating attention and its consequences across ecologically valid activities.

Secondly, despite the instrumental utility of ES for advancing the exploration of mind-wandering, there are associated challenges. It may be that content, rather than process, is more consciously penetrable for self-reports (Nisbett & Wilson, 1977), or that the very act of introspection may alter the quality of the experience being assessed (Schooler, 2002). The value of phenomenological reports, i.e. what it feels like to be in a particular experience/state, however, is not dependent on a conscious understanding of the higher order cognitive processes. Participants may, through reflective recovery of the process (which is subjective and first-personal), make a judgment as to whether their thoughts were deliberately intended. Indeed, the dissociable correlations between unintentional and intentional mind-wandering and external outcomes (Corbetta & Shulman, 2002; Golchert et al., 2017; Seli, Ralph, et al., 2017; Seli, Risko, et al., 2017; Seli et al., 2016; Seli, Smallwood, et al., 2015) demonstrates the validity of intentionality judgments and the inherent value of first-person responses.

Moreover, self-reported mind-wandering may be influenced by how it is defined or perceived. Although varying response options and social desirability bias represent possible moderating factors, age-related differences in mind-wandering remain even when a) thoughts concerning performance, namely task-related interference, are measured separately (Maillet & Schacter, 2016), b) variations in probe framing are included (Jordao et al., 2019), or c) incentives for reporting mind-wandering are provided (Zedelius, Broadway, & Schooler, 2015). This suggests that other factors are driving the age-reduction in mind-wandering. Additionally, prior-training on probe categories ahead of the task may have primed

participants to ascribe greater importance to monitoring their mental states (Smallwood & Schooler, 2006). However, age-differences in mind-wandering have persisted across probe- (Frank et al., 2015) and self-caught (Grodsky & Giambra, 1990) procedures, and the validity of mind-wandering self-reports has been established against behavioral concomitants (McVay et al., 2013), eye-movements (Frank et al., 2015), and neural correlates (Golchert et al., 2017). In the present study, the probes were used to circumvent potential meta-cognitive limitations in older adults (Maillet & Schacter, 2016). Metacognitive processes, however, warrant further investigation as a possible source of age-related changes in mind-wandering.

Thirdly, the HADS was employed to better understand the role of affect in age-related mind-wandering. This measure, however, does not fully capture the conceptually related ‘current concerns’ construct, which indexes the quantity and content of non-trivial concerns/active personal goals. It is challenging to distinguish affective from non-affective concerns in order to investigate the relative explanatory power of both current concerns and affective accounts. More research is needed with a diverse younger population to disentangle the impact of current concerns on mind-wandering and determine if it is the number of concerns, the content of concerns, or the affective saliency of concerns that contribute to increased mind-wandering in younger adults.

Finally, our older adults ranged in age from 65 to 78 (‘young-old’) and were highly educated. Cognitive decline is particularly pronounced in those of more advanced age (i.e. older adults on the older end of the continuum, (Borella, Carretti, & De Beni, 2008)) and with poorer education (Stern, Alexander, Prohovnik, & Mayeux, 1992). Clustering older adult age groups may mask the precise impact of executive resources or task demands on age-related mind-wandering (Gyurkovics, Balota, & Jackson, 2018; Jordao et al., 2019; Zavagnin et al., 2014). A recent meta-analysis observed a moderating effect of the mean age of the older group on the age-reduction in mind-wandering (Jordao et al., 2019). Moreover, mind-

wandering rates were comparatively lower in mild cognitive impairment (Niedźwieńska & Kvavilashvili, 2018), early stage Alzheimer's disease (Gyurkovics et al., 2018; although see O'Callaghan, Shine, Hodges, Andrews-Hanna, & Irish, 2019), frontotemporal dementia (O'Callaghan et al., 2019) and Parkinson's (Geffen et al., 2017) diseases compared to healthy older adults. Therefore, our surprising absence of executive deficits contributing to mind-wandering in healthy older adults raises the question as to whether, or at what timepoint, cognitive resources begin to degrade the propensity for, or content of, spontaneous thought in mild cognitive impairment and Alzheimer's disease. The ability to preserve these states for longer is an important facet of self-awareness and one's humanity and identity in the face of dementia (O'Callaghan et al., 2019). Longitudinal approaches may capture mind-wandering changes across a broader age continuum and with progressive degeneration.

Considering the documented global trend of population aging, clarifying the extent to which aging influences key mental processes is paramount. Accordingly, the complex relationship between mind-wandering and aging has garnered research attention. Despite its ubiquity, it remains an under-examined phenomenon because of its inherent ephemeral and covert phenomenology. Although, a robust and perhaps, paradoxical, age-accompanied decrease in mind-wandering has been reported, the crucial dynamics and factors involved have been largely precluded from the cognitive aging literature. Our study enabled consideration of different mind-wandering dimensions by providing additional insights into how unintentional and intentional mind-wandering change with age. We adjudicated between prominent theories, providing positive support for affective and motivational accounts as influencing the age-related diminution in unintentional mind-wandering, with reasons to be less persuaded by executive resource theories. Additionally, we propound a more exploitative oscillation strategy in older adults as mitigating the effects of their reduced cognitive resources to explain their decreased tendency to intentionally mind-wander. Consideration of

dispositional and strategic factors in future examinations may shed light on the impact of aging on unintentional and intentional mind-wandering.

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Online Supplement

Table S1

Details on the Neuropsychological Measures

	Cognitive Function
National Adult Reading Test (NART; Nelson & Willison, 1991)	The NART is a word reading test used to estimate premorbid IQ. Participants read aloud 50 irregular words, of increasing difficulty, scored for pronunciation accuracy. The number of pronunciation errors committed was recorded.
Tests of Everyday Attention (TEA; Robertson et al., 1996)	The TEA is a battery of tests assessing aspects of attentional functioning. Participants completed three TEA subtests: a) Visual Elevator (attentional switching), b) Telephone Search (visual selective attention), and c) Telephone Search while Counting (sustained and divided attention). In the Visual Elevator task, participants counted a series of visually presented elevator floors, in upward and downward directions, to identify the number of the final floor. The total number of correct trials was noted. For the Telephone Search, participants scanned a sample telephone directory sheet for pairs of matching symbols. The average time per correctly identified target was recorded. In the Telephone Search while Counting task, participants performed an alternate version of the previous subtest, identifying matching symbol pairs in a simulated telephone directory, concurrently to counting strings of audio tones played from a CD player. The average time per target weighted for tone counting accuracy (sustained attention) was calculated and then subtracted from the time per target from the previous trial to devise a dual-task decrement score (divided attention).
STROOP Color and Word test (Golden & Freshwater, 2002).	The Stroop test was incorporated as a measure of selective attention, processing speed and susceptibility to cognitive interference. Participants performed two congruous conditions (the Word and Color trials) and one incongruous condition (the Color-Word trial). In each condition, participants read aloud a stimulus sheet, comprising 100 items, as quickly as possible. In the Word trial (W), participants read a list of color words items ('Blue', 'Green', or 'Red') printed in black ink. The color trial (C) consisted of the letters 'XXXX' printed in blue, green or red ink. Here, participants were tasked with naming the color ink. In

Controlled Oral Word Association Test (COWAT; Benton et al., 1994; Spreen & Strauss, 1998)	<p>the Color-Word trial (CW), the color words were printed in incongruent ink colors (e.g. the word ‘Red’ was printed in blue ink). Participants were required to identify the color ink the word was printed in and suppress their instinct to read the word. The time taken to complete the 100 items in each condition was recorded. A further measure of ‘Interference’ was derived by subtracting the predicted color-word score from the raw colour-word score</p> <p>Participants were tasked with generating as many words as possible, within 60-second timeframes, from given phonemic (‘F’, ‘A’, ‘S’ letter fluency) or semantic (‘animals’ and ‘boys’ names’ category fluency) criteria to assess executive function. Summed acceptable words across phonemic and semantic trials were calculated.</p>
Hospital Anxiety and Depression Scale (HADS; Zigmond & Snaith, 1983)	<p>Negative Affect</p> <p>The HADS is a 14-item self-report scale measuring psychological distress symptoms occurring over the previous week and comprises two subscales with 7 items relating to anxiety (HADS Anxiety), and 7 items on depression (HADS Depression). Participants rated each item on a four-point response scale (0-3). Item responses were summed to create subscale totals, each with a maximum score of 21.</p>
Daily Life Attentional Difficulties	
Conners’ Adult ADHD Rating Scale (CAARS; Conners et al., 1999)	<p>The CAARS is a measure of the presence and severity of Attention-Deficit/ Hyperactivity Disorder (ADHD) related symptoms. Participants completed the short self-report form, a 26-item symptom rating scale comprising statements referring to recent behaviours and problems, rated on a four-point Likert scale, ranging from 0 “Not at all, never” to 3 “Very much, very frequently”. Four domain scores were derived from the scale items, including a) inattention/memory problems, b) hyperactivity/restlessness, c) impulsivity/emotional lability and d) problems with self-concept, with an additional e) 12-item ADHD index.</p>
Task-Related Motivation	
Stanford Sleepiness Scale (SSS; Hoddes et al., 1973)	<p>The SSS is a single-item question on current subjective level of sleepiness with a seven-point Likert response range, from 1 “Feeling active, vital, alert, wide awake” to 7 “No longer fighting sleep, sleep onset soon, having dream like thoughts”.</p>

The Dundee Stress State Questionnaire (DSSQ; Matthews et al., 1999)	The short-version of the DSSQ is a 30-item multidimensional self-report scale assessing task-related engagement, distress, and worry. Prior to the target detection task, participants were asked to rate each item on a five-point scale, from 0 “Definitely false” to 4 “Definitely true”, based on how they were feeling in that moment. Participants repeated the scale following completion of the task; this time, assessing how they felt while performing the task. DSSQ difference scores between the two time-points (post-task minus pre-task) were calculated to measure state changes induced by the task. Negative scores indicated task-induced decline, whereas positive scores indicated task-induced increase.
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Note. The neuropsychological test battery was administered to all participants by well-trained Research Assistants using a standardized protocol in a quiet well-lit testing room, lasting approximately 45-60 minutes. Descriptive statistics of their performance are provided in Table S3. The number of observations for the Stroop ‘Interference’ measure was reduced as the 45-second time limit used in the calculation of its component raw and predicted color-word scores, was introduced midway into the data collection period. Specific key neuropsychological variables used for hypothesis testing analyses included TEA Telephone Search Time per target, TEA Visual Elevator number correct, TEA Telephone Search dual-task decrement, COWAT Categorical total, HADS Anxiety, CAARS ADHD Index and DSSQ Engagement Difference.

Table S2*Baseline Socio-Demographic Characteristics for Younger and Older Adult Participants (N = 68)*

Variable	Young (<i>n</i> = 34)	Old (<i>n</i> = 34)
	Mean (SD)	Mean (SD)
Age, years	21.71 (4.59)	70.97 (3.54)
Age range, years	18-35	65-78
Gender, <i>n</i>	20 Female, 14 Male	16 Female, 18 Male
Marital status, <i>n</i> (%)		
Co-habiting	0	1 (2.90%)
Engaged	0	2 (5.90%)
Married	0	23 (67.60%)
Separated/divorced	0	2 (5.90%)
Single/Never married	34 (100%)	4 (11.80%)
Widowed	0	2 (5.90%)
Full-time education, years	16.21 (2.41)	15.19 (3.24)
Highest qualification, <i>n</i> (%)		
PhD	1 (2.90%)	1 (2.90%)
Masters	1 (2.90%)	6 (17.60%)
Undergraduate	4 (11.80%)	12 (35.30%)
Diploma/Certificate	3 (8.80%)	6 (17.60%)
Leaving Certificate	25 (73.50%)	7 (20.60%)
Junior Certificate	0	1 (2.90%)
Primary	0	1 (2.90%)
Employment status, <i>n</i> (%)		
Paid/self-employed	1 (2.90%)	2 (5.9%)
Retired	0	29 (85.30%)
Semi-retired	0	3 (8.80%)
Student	33 (97.10%)	0
Living situation, <i>n</i> (%)		
Alone	2 (5.90%)	8 (23.50%)
Alone with children	0	1 (2.90%)
With family	11 (32.40%)	0
With friends	11 (32.40%)	0
With partner and/or children	1 (2.90%)	24 (70.60%)
With unrelated persons	9 (26.50%)	1 (2.90%)

MoCA Total Score	N/A	27.47 (1.52)
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Note. MoCA, Montreal Cognitive Assessment; n, Number of observations; N/A, Not applicable; SD, Standard deviation.

Table S3*Descriptive Statistics on Key Neuropsychological Variables for Younger and Older Adult**Participants (N = 68).*

Variable	Young (n = 34)	Old (n = 34)
	Mean (SD)	Mean (SD)
Cognitive Function		
NART Errors**	16.94 (6.03)	11.41 (9.18)
TEA Visual Elevator Correct, Old: n = 33	8.35 (1.59)	8.39 (1.58)
TEA Telephone Search Time per Target***	2.86 (.65)	4.04 (.88)
TEA Telephone Search while Counting Time per Target Weighted, *** Young: n = 32	2.96 (.59)	6.01 (2.75)
TEA Telephone Search Dual Task Decrement, *** Young: n = 33, Old: n = 33	.24 (.48)	1.73 (1.96)
Stroop Word Total Time	48.37 (7.92)	51.49 (9.38)
Stroop Color Total Time***	64.65 (10.48)	78.48 (16.44)
Stroop Color-Word Total Time***	97.59 (21.08)	136.42 (31.26)
Stroop Interference, ** Old: n = 12	7.78 (8.48)	-1.03 (7.82)
COWAT Phonemic Total	41.21 (8.41)	43.79 (12.65)
COWAT Categorical Total**	45.03 (7.38)	38.18 (9.73)
Negative Affect		
HADS Anxiety***	6.53 (3.77)	3.38 (2.71)
HADS Depression, median (IQR)*	5.00 (8.00)	2.00 (4.00)
Daily Life Attentional Difficulties		
CAARS A Inattention/ Memory Problems** Old: n = 30	6.35 (3.63)	4.23 (1.55)
CAARS B Hyperactivity/ Restlessness***	6.79 (3.01)	2.88 (1.97)
CAARS C Impulsivity/ Emotional Lability	3.47 (2.36)	2.71 (1.69)

CAARS D Problems with Self-Concept**	7.15 (4.01)	4.21 (2.80)
CAARS E ADHD Index***	12.88 (5.14)	7.90 (3.79)
Task-Related Motivation		
SSS, median (IQR)**	2.00 (1.00)	2.00 (1.00)
DSSQ Engagement Difference**	-6.97 (4.99)	-3.12 (5.97)
DSSQ Distress Difference Young: $n = 33$	3.09 (5.82)	1.03 (5.72)
DSSQ Worry Difference*	4.71 (4.58)	1.76 (5.82)

Note. CAARS, Connor's Adult ADHD Rating Scale; COWAT, Controlled Oral Word Association

Test, DSSQ, Dundee Stress State Questionnaire; HADS, Hospital Anxiety and Depression Scale;

IQR, Interquartile range; NART, National Adult Reading Test; n , Number of observations; SD,

Standard deviation; SSS, Stanford Sleepiness Scale; TEA, Tests of Everyday Attention.

* $p < .05$

** $p < .01$

*** $p < .001$

Table S4

Partial Pearson's r Correlation Coefficients for the Relationships between Experience Sampling Probe Responses and Behavioral Performance Indices, Controlling for Age Group (N= 57).

Variable	1	2	3	4	5	6	7	8
1. Focus	-	-.90***	-.69***	-1.00***	.41**	-.12	-.21	-.28*
2. Unintentional MW		-	.32*	.90***	-.42**	.17	.18	.21
3. Intentional MW			-	.69***	-.21	-.01	.16	.26*
4. Total MW				-	-.41**	.12	.21	.28*
5. Hit Rate					-	-.59***	-.18	-.44***
6. RT						-	-.38**	-.04
7. RT CoV							-	.79***
8. False Alarms								-

Note. CoV, Coefficient of Variance; MW, Mind-wandering; N, number of observations; RT, Reaction Time.

* $p < .05$

** $p < .01$

*** $p < .001$

Table S5

Partial Pearson's r Correlation Coefficients for the Relationships Between Experience Sampling Probe Responses and Key Neuropsychological Measures, Controlling for Age Group ($N = 61$).

[illegible]

Note. ADHD, Attention-Deficit Hyperactivity Disorder; CAARS, Conners' Adult ADHD Rating Scale; COWAT, Controlled Oral Word Association Test; DSSQ, Dundee Stress State Questionnaire; HADS, Hospital Anxiety and Depression Scale; MW, Mind-wandering; NART, National Adult Reading Test; N, number of observations; TEA, Tests of Everyday Attention; Tel, Telephone.

$*p < .05$

$**p < .01$

$***p < .001$

Figure S1*Participant Consort Flow Diagram.* *Note.* OA: Older adults; YA: Younger adults.