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Individual differences in state and trait mind-wandering influence episodic memory encoding and retrieval dynamics[☆,☆☆]

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ABSTRACT

Mind-wandering is a cognitive state in which attention shifts away from a primary task to unrelated thoughts, often occurring without the individual's awareness, and there may be both a state and trait component of mind-wandering such that some people may have a higher propensity to mind wander. In the present study, we investigated the relationship between mind-wandering and episodic memory, distinguishing between mind-wandering as a transient state versus a trait, individual differences characteristic. Specifically, through two individual differences experiments involving word list learning tasks, we explored how both state and trait mind-wandering affect overall memory performance and the dynamics of retrieval. Results indicated that state mind-wandering negatively correlated with recall and uniquely predicted memory outcomes. Additionally, participants prone to state mind-wandering showed a decreased likelihood of initiating recall with the first word studied. In contrast, while both state and trait mind-wandering were negatively associated with recall performance, trait mind-wandering did not uniquely influence memory performance. Moreover, evidence suggested that high trait mind-wandering may impair the lag-recency effect, indicating challenges in leveraging temporal contextual cues for memory retrieval. These findings suggest that while in-the-moment mind-wandering can disrupt memory formation, a predisposition towards mind-wandering does not necessarily impair memory ability but may impact the dynamics of retrieval.

Mind-wandering is a pervasive cognitive phenomenon that occurs when our attention strays from the demands of the current task to unrelated matters (Christoff et al., 2016; Seli et al., 2018a, 2018b; Smallwood & Schooler, 2015; Welhaf et al., 2024). When attempting to learn some information, instances of mind-wandering can lead to lapses in attentional control (McVay & Kane, 2010) and reduce the availability of executive and attentional resources for the learner (Smallwood & Schooler, 2006), thereby impacting memory encoding (Smallwood, 2010). As such, mind-wandering during encoding often results in impaired memory performance because mind-wandering competes for cognitive resources needed for effective information processing (Whitehead et al., 2021). Consistent with this trend, some studies have indicated that certain interventions aimed at reducing mind-wandering may enhance cognitive and academic performance (Mrazek et al., 2013; Peterson & Wissman, 2020; see also Smallwood et al., 2007).

To measure mind-wandering, researchers employ various assessment methods (see Kane et al., 2021). One common approach involves the use of thought probes where participants are asked to report their conscious experiences during an ongoing task (e.g., Weinstein, 2018). These thought probes are typically interspersed within a subset of primary task trials and researchers can adjust the frequency and interval between probes (Robison et al., 2019). Again, higher rates of self-reported mind-wandering in response to these thought probes are often associated with poorer performance on the primary task (McVay & Kane, 2009; Miller & Castel, 2024; Unsworth & McMillan, 2014). Thus, mind-wandering is generally detrimental to cognitive performance.

Prior research has applied thought probes and other techniques to measure mind-wandering during the learning of verbal materials (see

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Blondé et al., 2022 for a review). For example, Smallwood et al. (2003) measured mind-wandering via thought probes where participants were asked to report exactly what was passing through their mind upon hearing a buzzer sound, classifying their thoughts as task-related thought, task-related interference, and task-unrelated thought. Similarly, Peterson and Wissman (2020) had one categorical thought probe after each list of studied words. Furthermore, Xu and Metcalfe (2016) periodically asked participants throughout their study sessions whether they were focused on the task or if their minds were wandering. Importantly, in these studies using verbal memory paradigms, a negative association is consistently shown between mind-wandering and memory performance (the number of words a participant can recall). Despite these insights, Blondé et al. (2022) indicate that most of the previous research on mind-wandering and memory has focused primarily on average recall performance, leaving room for further exploration into the complexities of recall dynamics and how mind-wandering influences both encoding and retrieval processes in more nuanced ways. Additionally, this prior work has some limitations such as small sample sizes, a lack of focus on individual differences, and primarily examining state mind-wandering rather than differentiating between state and trait mind-wandering.

State and trait are terms commonly used in psychology to describe different aspects of an individual's moment-to-moment fluctuations versus stable characteristics, respectively. Specifically, state refers to a temporary or transient mental or emotional condition—states can be influenced by various factors such as the environment, mood, specific circumstances, or immediate experiences. For example, feeling anxious before an important presentation or being happy after receiving good news are both examples of states. Trait, on the other hand, refers to a stable and enduring characteristic that remains relatively constant over time and across situations. For instance, someone who is consistently optimistic or introverted across various contexts is exhibiting traits. The distinction between states and traits can be conceptualized within classical test theory, and psychometric advancements have been made in estimating momentary intraindividual variability in an individual's trait-based behaviors (Steyer et al., 1999, 2015).

In the context of mind-wandering and learning, "state mind-wandering" refers to the frequency with which a participant experiences the temporary and momentary occurrences of the mind drifting away from encoding the to-be-remembered information. Thought probes during the study phase can capture real-time mind-wandering (e.g., Feng et al., 2013), allowing for an examination of how the state of mind of a learner during encoding relates to memory performance. On the other hand, to quantitatively measure trait levels of mind-wandering, Mrazek et al. (2013) developed the Mind-Wandering Questionnaire (MWQ). This five-question scale assesses an individual's tendency to mind-wander in daily life, offering a standardized method for investigating trait-level mind-wandering.

Prior work has investigated the relationship between state and trait mind wandering. For example, Seli et al. (2016) assessed whether individual propensities for trait mind wandering (measured via self-reports) correspond to state-level occurrences recorded using thought probes. Results revealed that individuals' self-reported habitual mind-wandering tendencies (trait) often reflect their immediate mind-wandering behavior (state). Similarly, Da Silva et al. (2020) investigated the relationship between state and trait levels of mind wandering during a tracing task. They demonstrated that people who generally mind-wander more frequently tended to experience more diverse thoughts and perform differently, but these trait differences did not predict perceptual decoupling (the degree of disengagement from the external environment) or mental navigation (the movement of thoughts across time and space) during the task. Thus, while general mind-wandering tendencies (trait) can influence momentary experiences (state), different dimensions of mind-wandering may have distinct correlates and effects on cognitive performance. While certainly associated, prior work has shown that trait and state measures of other psychological constructs show convergent and discriminant validity and we expect similar findings with trait and state estimates of mind wandering (Zuckerman, 1983).

Although similar, state and trait mind-wandering are separate constructs, each influencing cognitive processes in distinct ways. For example, someone with a low propensity for mind-wandering may experience episodes of mind-wandering under certain conditions such as high stress or fatigue. Conversely, an individual characterized as a high trait mind-wanderer may not always be mind-wandering, especially in contexts that capture their interest or require focused attention. Additionally, the mechanisms through which state and trait mind-wandering affect learning could differ. Specifically, trait mind-wandering might influence memory via a general tendency towards less effective encoding strategies or poorer maintenance of goal-directed activity. On the other hand, state mind-wandering might impact memory through more immediate mechanisms such as momentary lapses in attention that lead to gaps in encoding (which would be reflected in retrieval patterns such as lag-conditional response probabilities). Thus, even though a higher frequency of mind-wandering instances is associated with the trait, the specific impact of each instance (state mind-wandering) and how this accumulates or interacts with an individual's baseline propensity can provide deeper insights into the relationship between mind-wandering and memory.

Another reason mind-wandering may be detrimental to episodic memory processes is a reduction in the consistency and intensity of attention, each representing separable components that reflect distinct aspects of cognitive engagement and regulation (Unsworth & Miller, 2021). *Consistency* involves how regularly attention is maintained across repeated trials of a task, reflecting the ability to avoid attentional lapses. On the other hand, *intensity* represents the amount of attentional effort directed toward a specific task. Better learners not only deploy greater attentional effort but also maintain this focus consistently throughout encoding, thereby avoiding frequent shifts in attention during the learning process (Miller & Unsworth, 2020, 2021; Unsworth & Miller, 2021). These components of attention are associated with state mind-wandering (Robison & Brewer, 2022), likely impacting overall memory performance and potentially retrieval dynamics as well.

Individuals prone to mind-wandering (trait) may exhibit poorer attentional consistency, experiencing more frequent lapses in attention during encoding. Additionally, when the mind wanders during encoding (state), the temporary reduction in the intensity of attention likely impairs subsequent memory performance. Specifically, when the mind is wandering, attention is diverted to task-unrelated thoughts rather than engaging in encoding strategies such as generating mental images of the items of creating sentences to link the words together in a meaningful way. Thus, trait mind-wanderers may be "inconsistent" with their attention, leading to more frequent states of mind-wandering and poorer memory performance due to a reduction in the intensity of attention. This cost of mind-wandering may particularly impair a learner's ability to bind temporal-contextual information that can later be used as a cue to benefit retrieval.

Most prior work on mind-wandering and learning has focused primarily on overall memory performance—demonstrating worse recall when participants mind-wandered—without delving into the dynamics of how items are retrieved (Blondé et al., 2022). A key aspect of memory retrieval is the use of internal context such as temporal, semantic, and source elements that guide the sequence of retrieval (Polyn et al., 2009). One specific measure that captures this process is the lag-recency effect which refers to the tendency to recall items that were encoded in close temporal proximity together. Specifically, the lag-recency effect illustrates how temporal context can serve as a cue during recall, often leading to the retrieval of items in the order they were presented (e.g., Sederberg et al., 2010). There are important individual differences in the lag-recency effect such as learners with lower working memory capacity struggling to use the products of retrieval to aid their search (Spillers & Unsworth, 2011), and these differences may be partly attributable to the tendency of individuals with lower cognitive abilities to engage in mind-wandering more frequently. Examining the lag-recency effect in the context of mind-wandering can provide deeper insights into how state and trait mind-wandering influence memory processes. State mind-wandering may disrupt the encoding of temporal-contextual cues, thereby weakening the lag-recency effect. In contrast, trait mind-wandering might have a more pervasive impact on overall cognitive strategies and memory organization, potentially leading to different retrieval patterns.

Prior work has suggested that conditions involving incidental encoding or very long lists, which can be boring, reduce the contiguity effect (Hong et al., 2023; Mundorf et al., 2021). This is closely related to the idea that mind-wandering impairs attention to context cues (i.e., attentional lapses can disrupt the encoding of temporal-contextual information) thereby diminishing the lag-recency effect. Thus, variations in levels of attention at encoding may influence the effectiveness of temporal-contextual cues in guiding memory retrieval. When a learner's mind wanders, their attention may shift away from the sequential presentation of items, disrupting the encoding process. Consequently, the temporal context of a given item may not be adequately encoded or integrated into memory and learners may struggle to establish the necessary associations between adjacent items, weakening the forward-ordered recall pattern typical of the lag-recency effect.

While the order in which an item was presented often plays a crucial role in its successful recall, numerous other predictable patterns have been observed. Notably, in free recall paradigms, learners tend to initiate their output with either the first or last item from a list (measured by the probability of first recall, PFR; Howard & Kahana, 1999; Kahana et al., 2002). This tendency to initiate recall with the first or last item is particularly pronounced in immediate free recall tests where the last item presented is more likely to be recalled first. Conversely, during delayed free recall, when rehearsal opportunities are interrupted after the final word's presentation, the first studied word tends to be the first recalled. In the current study, we aim to better our understanding of how involuntary shifts in attention as well as the predisposition towards mind-wandering affect retrieval initiation and other memory retrieval dynamics.

The current study

In the current study, we explored the potential relations between mind-wandering tendencies and episodic memory performance in a multi-trial delayed free recall paradigm. Specifically, we investigated the impact of both state and trait mind-wandering on recall accuracy, the lag-recency effect, and the probability of first recall. We were particularly interested in understanding whether the occurrence of mind-wandering, both in the moment (state) and as a more stable characteristic (trait), could differentially influence the temporal binding of information during encoding and the subsequent memory retrieval dynamics. We employed mind-wandering probes throughout a word list learning task as well as a separate mind-wandering questionnaire (at the end of the task) to measure state and trait mind-wandering, respectively. We hypothesized that individuals more prone to mind-wandering would exhibit lower levels of average recall, a diminished ability to effectively utilize temporal-contextual cues, and differ in their recall initiation strategies.

Experiment 1

In Experiment 1, participants were presented with 30 lists, each containing 10 words shown for 2 s each. Participants then completed a 30-second distractor task before a 1-minute free recall test. Once per list, at pseudo-random serial positions, participants responded to mind-wandering probes. These probes were used to compute the proportion of the time that participants were mind-wandering (state mind-wandering). As an additional mind-wandering measure, at the end of the memory task, participants were asked to rate how often their minds wandered during the task on a scale of 0 (never) to 100 (very frequently)—we refer to this as retrospective mind-wandering. Finally, participants completed the Mind-Wandering Questionnaire (Mrazek et al., 2013) to assess trait-level mind-wandering tendencies. Since mind-wandering typically disrupts memory, we expected participants with a greater propensity to mind-wander to demonstrate impaired overall episodic memory performance and display different retrieval transition tendencies and recall initiation patterns.

Method

Participants. After exclusions, participants were 205 undergraduate students (M_{age} = 19.81, SD_{age} = 3.25; 117 female, 86 male, 1 other, 1 chose not to report) recruited from the Arizona State University (ASU) Human Subjects Pool. In each experiment, participants were tested online, received course credit for their participation, and were excluded from analysis if they admitted to cheating (e.g., writing down answers) in a post-task questionnaire (they were told they would still receive credit if they cheated). This exclusion process resulted in seven exclusions. Participants were also excluded if they did not attest to giving their best effort on the task. This exclusion criterion resulted in no exclusions. In the present experiments, we aimed for a sample size of 200 participants which approaches the threshold for stable estimates of correlations as indicated by Schönbrodt and Perugini (2013), ensuring reliable and accurate measurement of our variables.

Materials. The words on each list were randomly selected from a pool of 689 unrelated words (e.g., button, chart, twig) that were between 4 and 7 letters (M = 4.85, SD = .98). On the log-transformed Hyperspace Analogue to Language frequency scale (with lower values indicating lower frequency in the English language and higher values indicating higher frequency), words ranged from 4.73 to 14.35 (M = 9.48, SD = 1.57). In terms of concreteness (with lower values indicating lower concreteness and higher values indicating higher concreteness), words ranged from 1.19 to 5.00 (M = 4.16, SD = .84). Frequency and concreteness ratings were generated using the English Lexicon Project website (Balota et al., 2007). Words are available on OSF.

Procedure. At the beginning of the task, participants were asked to 1) be prepared to complete the study in a single, 60-minute session (i.e., no prolonged breaks), (2) complete this study in an environment with minimal distraction (i.e., put away extra devices, close unneeded tabs, and turn off any music or TV in the background), (3) complete the study on a laptop or desktop computer (i.e., do NOT use a mobile phone or a tablet), and (4) if in the presence of other people, try to move somewhere more secluded. Participants were then told: "Please give your full effort on this task! PLEASE do not use any external aides and thus use ONLY YOUR OWN memory to complete the study." Next, participants were told: "This task will be very difficult. We do not expect you to remember everything; you will likely only be able to remember some of the information. Please do not cheat by taking pictures of the screen, writing things down, or using any other aid to complete this task." Finally, we again asked participants that they do not cheat on this task by using any memory aids and that they give their full effort on this task. They then had to attest whether they would not cheat and whether they would give their best effort.

Participants were then presented with lists of 10 unrelated words to remember for a later test. Participants studied each word for 2 s and after the presentation of all words, participants completed a 30-second distraction task requiring them to rearrange the digits of several three-digit numbers in descending order (e.g., 123 would be rearranged to 321). Participants were given 3 s to view each of the 10 three-digit numbers and subsequently rearrange the digits. Following the distractor task, participants were asked to recall all the words they could remember from the just-studied list. Participants were given 1 min to recall the words and were asked to try to continue to recall words throughout the entire minute. Participants recalled words by typing them into an on-screen text box—recalled words remained on the screen. Responses were scored using a similarity-based algorithm that calculates the percentage match between participants' responses and the correct answers. To account for typographical errors, we applied a leniency criterion, setting the threshold for correctness at 75 % similarity. For example, a response such as 'aple' for 'apple' would meet the 75 % threshold and be counted as correct, while 'apl' would not. Full details are available on OSF. This was repeated for a total of 30 study-test cycles.

Once per list (occurring at pseudo-random serial positions), participants were asked about their level of attentiveness. Specifically, participants were asked to characterize their current conscious experience; participants indicated whether they were either a) totally focused on the current task (i.e., paying attention to the word pairs and trying to learn them), b) thinking about their performance on the task or how long it is taking (i.e., whether they will remember the information but also wondering whether the task will end soon), c) distracted by information present in the room (e.g., sights and sounds), d) zoning out/mind-wandering (i.e., their attention has shifted away from the task to self-generated thoughts unrelated to the task), or e) "Other" (taken from Unsworth & McMillan, 2014). Responses to the mind-wandering probes were self-paced.

At the end of the last list, participants were asked: "Please rate how often your mind wandered during this task (when your thoughts wander away from what you are doing and go somewhere else on their own) on a scale of 0 to 100 (0 = never, 100 = very frequently)"—these ratings formed the retrospective mind-wandering rate. Finally, participants completed the Mind-Wandering Questionnaire developed by Mrazek et al. (2013). Specifically, using a scale from 0 to 100 (0 = never, 100 = very frequently), participants responded to the following questions: 1) I have difficulty maintaining focus on simple or repetitive work, 2) While reading, I find I have not been thinking about the text and must therefore read it again, 3) I do things without paying full attention, 4) I find myself listening with one ear, thinking about something else at the same time, and 5) I mind-wander during lectures of presentations. Responses on this questionnaire were used to measure trait mind-wandering, which was computed as the average rating across the five questions.

Data Availability. The materials, data, and information needed to reproduce the analyses are available on OSF.

Reliabilities. To examine the reliability of participants' mind-wandering rates, we compared the mind-wandering rate for even and odd lists for each participant [Cronbach's α = .95]. Reliability cannot be computed for retrospective mind-wandering because there was only one response for each participant. To examine the reliability of the trait mind-wandering questionnaire, we compared participants' responses to each of the five questions [Cronbach's α = .81]. Finally, we examined the reliability of participants' recall across the 30 lists [Cronbach's α = .96].

Results

To examine mind-wandering rates, we first coded participants' responses to the mind-wandering probes as either mind-wandering (distracted by information present in the room (sights and sounds) and zoning out/mind-wandering) or not mind-wandering (totally focused on the current task and thinking about their performance on the task or how long it is taking); "Other" responses were not considered mind-wandering or not mind-wandering. We then computed the proportion of the time participants indicated that they were mind-wandering. An examination of the Pearson correlations between our measures of mind-wandering (see Fig. 1, top panel) revealed that the mind-wandering rate during the task (state mind-wandering) was related to retrospective mind-wandering ratings [$r = .60$, $p < .001$] as well as trait mind-wandering [$r = .35$, $p < .001$]; additionally, retrospective mind-wandering ratings were related to trait mind-wandering [$r = .51$, $p < .001$].

Next, we investigated the relationship between mind-wandering and recall performance (see Fig. 1, bottom panel). Pearson correlations revealed that recall was negatively related to the mind-wandering rate during the task [$r = -.49$, $p < .001$], retrospective mind-wandering ratings, [$r = -.45$, $p < .001$], and trait mind-wandering [$r = -.29$, $p < .001$]. Given that all measures of mind-wandering were related (negatively) to recall, we also examined whether each measure of mind-wandering uniquely predicts memory. A General Linear Model with mind-wandering rate during the task (state mind-wandering), retrospective mind-wandering ratings, and trait mind-wandering scores predicting average memory performance ($R^2 = .28$) revealed that mind-wandering rate [$\beta = -.35$, $t(201) = -4.67$, $p < .001$] and retrospective mind-wandering [$\beta = -.21$, $t(201) = -2.55$, $p = .012$] both uniquely predicted memory performance but trait mind-wandering did not [$\beta = -.07$, $t(201) = -.96$, $p = .338$].

We next examined how mind-wandering rate and recall changed as the task endured (see Fig. 2). A mixed multi-level model with list-level recall accuracy (the proportion of items recalled on a given list) modeled as a function of list (continuous variable nested within individual participants) revealed that recall decreased as the task endured [$t(5944) = -18.22$, $p < .001$]. A similar model with mind-wandering on each list revealed that mind-wandering increased as the task endured [$t(5836) = 28.66$, $p < .001$].

In addition to overall memory performance, we wanted to analyze the lag-recency effect to gain a deeper understanding of how mind-wandering influences the temporal dynamics of memory retrieval and the use of contextual cues during recall. Lag conditional-response probabilities (lag-CRPs) can be used to quantitatively measure the lag-recency effect (see Kahana, 1996). Specifically, lag-CRPs provide a means of assessing how individuals transition between recalling items during memory retrieval. Since items presented in close temporal proximity share more contextual features, the retrieval of one item can act as a cue to retrieve nearby items, thus increasing the likelihood of recalling items with shorter temporal lags (Sederberg et al., 2010; Spillers & Unsworth, 2011). As a result, participants tend to demonstrate increased CRPs for adjacent items compared to items that are more distantly separated in the encoding sequence.

The CRP for a recall transition is calculated by dividing the sum of the number of times a specific lag transition occurred by the total number of times that transition could have been made. Lag refers to the ordinal space between serial positions, such as the lag between serial positions 8 and 9 being 1. For instance, if an individual recalls an item presented in serial position 8, the CRP for a lag of 1 would represent the probability that the item in serial position 8 is recalled immediately after the item in serial position 7 or 9, rather than items further away like 6 or 10 (illustrating a lag of 2). Lag-CRPs not only provide valuable insights into participants' recall patterns, but they also show a positive relationship with elevated task performance (Sederberg et al., 2010; Spillers & Unsworth, 2011). This suggests that the effective use of temporal-contextual cues, derived from just-recalled words, facilitates the retrieval of additional words during memory recall, leading to enhanced performance in memory tasks.

The probability of recalling an item from serial position x followed by an item from serial position y for lags 1–5 (the most relevant for visualization) split into quartiles based on mind-wandering rate/state

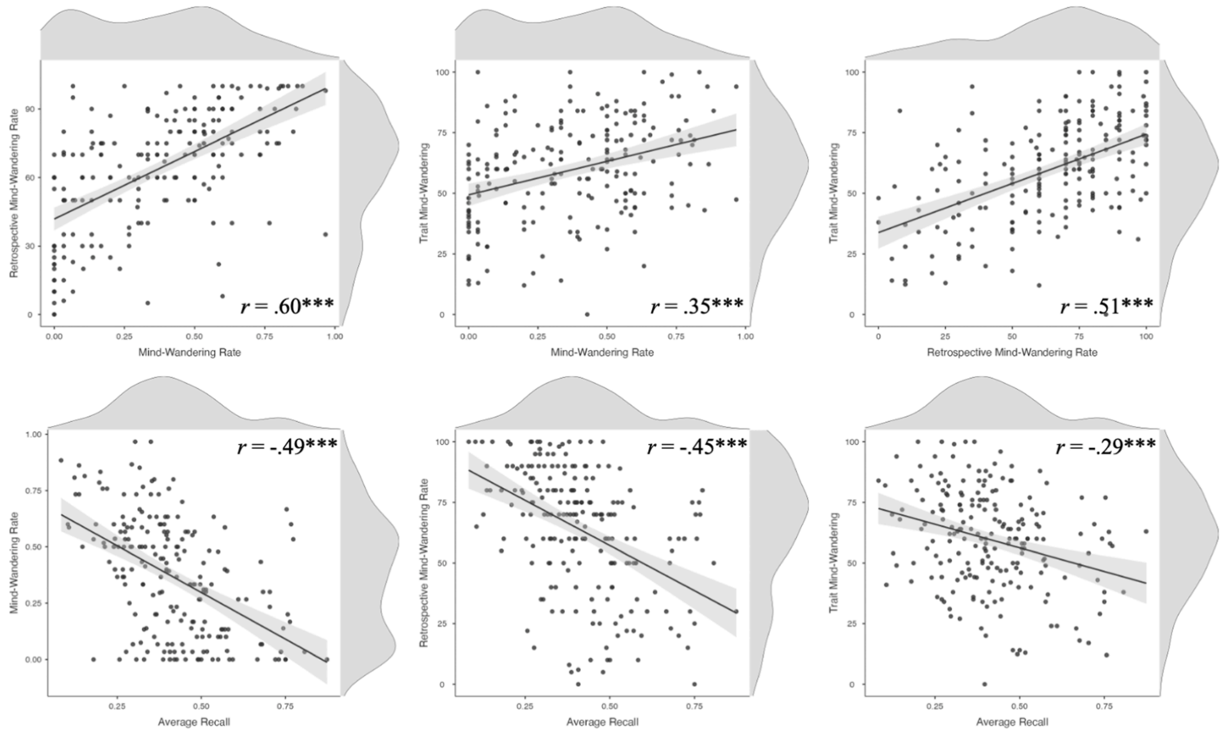

Fig. 1. Densities, correlations, and regression lines with standard error between our measures of mind-wandering as well as recall and our measures of mind-wandering in Experiment 1.

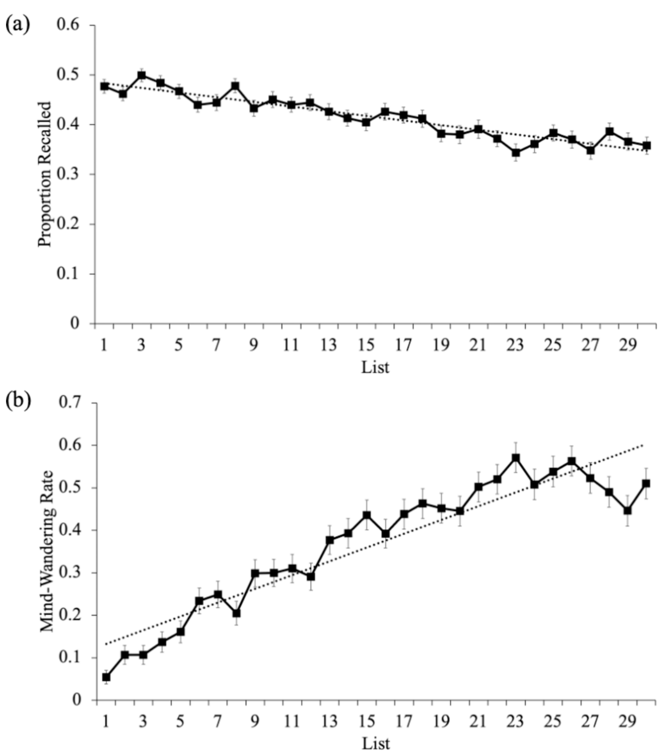

Fig. 2. Recall performance (a) and mind-wandering rates (b) on each list in Experiment 1. Error bars reflect the standard error of the mean. The dashed line represents the linear trend.

mind-wandering, retrospective mind-wandering ratings, and trait mind-wandering scores are shown in Fig. 3. We conducted a mixed multi-level model with direction (forward, backward), lag (1–9), mind-wandering rate/state mind-wandering, retrospective mind-wandering, and trait mind-wandering for each participant (predictors are nested within each participant) predicting CRPs—all mind-wandering measures were treated as continuous variables.[1] For simplicity, the results are reported in Table 1. As per Cohen et al. (2013), when there is a continuous variable interaction, researchers can use plots with quartiles for interpretation. Here, in terms of the critical three-way interactions, we only observed a significant three-way interaction between lag, direction, and mind-wandering when considering trait mind-wandering. Thus, the lag-recency effect appears to be particularly hindered in trait mind-wanderers such that their ability to recall adjacent items in the forward direction was impaired.[2]

We were also interested in how mind-wandering impacts the lag-recency effect as the task endures and mind-wandering becomes more prevalent (as shown in Fig. 2b). As such, we conducted a within-subject comparison of early- and late-list CRPs (see Fig. 4). The results of a mixed multi-level model with timing (first 10 lists, last 10 lists), direction (forward, backward), lag (1–9), mind-wandering rate/state mind-wandering, retrospective mind-wandering, and trait mind-wandering for each participant predicting CRPs are shown in Table 2—we note that as you increase the number of factors in an interaction, the model becomes exponentially more complex the complexity of this analysis

[1] We note that lag-CRPs are not statistically independent across lags, which may violate the independence assumptions of both ANOVA and mixed-effects models. For example, if a participant consistently makes transitions with a lag of +1, their lag-CRP for +1 will be 1.0, and the lag-CRPs for all other lags will necessarily be 0. This dependency between lag-CRPs can complicate statistical interpretations as higher values for one lag inherently reduce the values for others. While this limitation does not invalidate the use of these models, it serves as a caveat to the analyses and should be considered when interpreting the results.

[2] Given that lag-CRPs can be influenced by total recall, as a supplemental analysis, we employed a permutation method to control for the influence of overall recall differences on the shape of the lag-CRP (see Hong et al., 2023). The resulting temporal bias curves reflected similar patterns as the lag-CRP curves. This analysis is available as an online supplement on OSF.

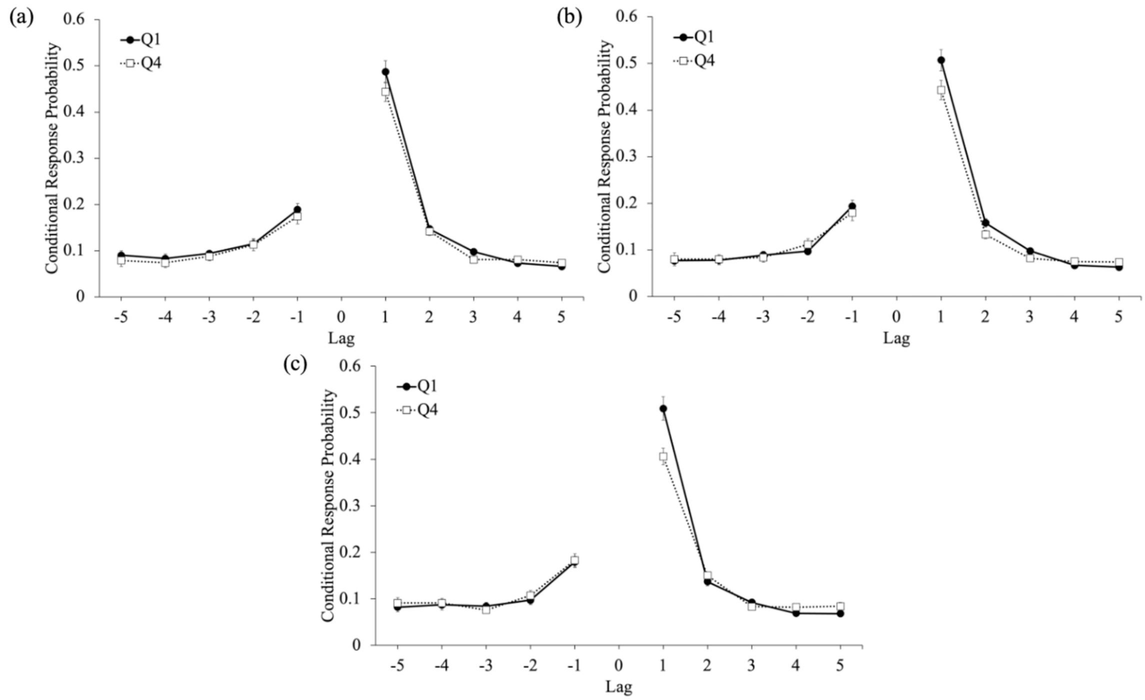

Fig. 3. Conditional-response probability (CRP) functions for forward and backward transitions as a function of lag split into quartiles based on mind-wandering rate/state mind-wandering (a), retrospective mind-wandering ratings (b), and trait mind-wandering scores (c) in Experiment 1. Error bars reflect the standard error of the mean.

Table 1
The results of a mixed multi-level model with direction, lag, mind-wandering rate/state mind-wandering, retrospective mind-wandering, and trait mind-wandering for each participant predicting CRPs in Experiment 1.

Fixed Effects Parameter Estimates							
Effect	**Estimate**	**SE**	**95 % CI: Lower**	**95 % CI: Upper**	**df**	***t***	***p***
(Intercept)	0.11	0	0.11	0.12	3674	56.1	<.001***
Direction	0	0	−0.01	0.01	3674	−0.42	0.674
Lag	−0.02	0	−0.02	−0.02	3674	–22.29	<.001***
Mind-Wandering Rate	−0.01	0.01	−0.03	0.01	3674	−0.8	0.426
State MW	0	0	0	0	3674	1.02	0.309
Trait MW	0	0	0	0	3674	−1.18	0.24
Direction * Lag	−0.03	0	−0.04	−0.03	3674	−21.84	<.001***
Direction * Mind-Wandering Rate	0.01	0.02	−0.02	0.05	3674	0.7	0.482
Lag * Mind-Wandering Rate	0	0	0	0.01	3674	0.66	0.509
Direction * State MW	0	0	0	0	3674	−1.42	0.156
Lag * State MW	0	0	0	0	3674	1.79	0.074
Direction * Trait MW	0	0	0	0	3674	0.63	0.53
Lag * Trait MW	0	0	0	0	3674	−1.14	0.253
Direction * Lag * Mind-Wandering Rate	0	0.01	−0.01	0.02	3674	0.12	0.907
Direction * Lag * State MW	0	0	0	0	3674	−0.6	0.548
Direction * Lag * Trait MW	0	0	0	0	3674	3.07	0.002**

Note: * = $p < .05$, ** = $p < .01$, *** = $p < .001$.

makes it difficult to estimate reliably. However, the visual interpretation of Fig. 4 suggests that the lag-recency effect decreases on later lists (when mind-wandering tends to increase) for learners reporting higher levels of mind-wandering rates (state mind-wanderers) and retrospective mind-wanderers, and trait mind-wanderers show an overall impairment that appears stable throughout the task.

We also examined memory as a function of participants' reported experience. Specifically, recall on lists where participants did not report mind-wandering (M = .45, SD = .15) was greater than recall on lists where participants reported mind-wandering (M = .34, SD = .16), [$t(181) = 10.58, p < .001, d = .78$]. We also analyzed CRPs as a function of participants' reported experience (see Fig. 5). The results of a mixed multi-level model with whether participants reported mind-wandering, direction (forward, backward), and lag (1–9) for each participant predicting CRPs are shown in Table 3. Critically, there was a three-way interaction between direction, lag, and whether participants were mind-wandering such that participants were more likely to transition adjacently in the backward direction when they mind-wandering.

Finally, we also examined the probability of first recall (PFR) which refers to the probability that items from a given serial position will be recalled first. Again, the PFR captures how participants initiate recall and in the present analysis, refers to the proportion of the time the word from a given serial position was the first word recalled (see Fig. 6). A repeated-measures ANOVA with 10 levels (serial position) and mind-wandering rate/state mind-wandering, retrospective mind-wandering, and trait mind-wandering as covariates (continuous variables) revealed an effect of serial position [$F(9, 1809) = 72.00, p < .001, \eta_p^2 = .26$] such that the first word presented was most likely to be the first

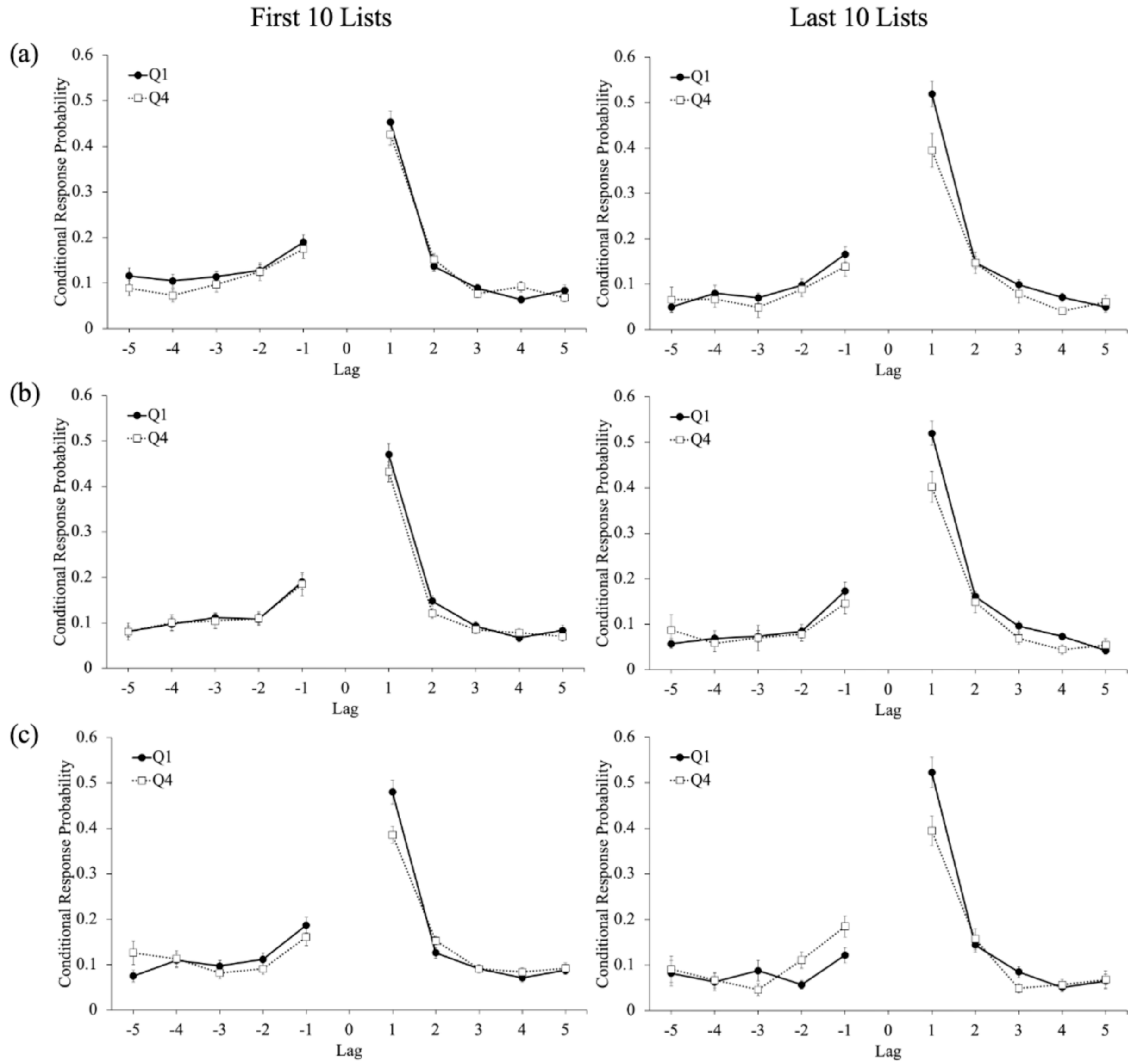

Fig. 4. Conditional-response probability (CRP) functions for the first 10 lists (left column) and last 10 lists (right column) for forward and backward transitions as a function of lag split into quartiles based on mind-wandering rate/state mind-wandering (a), retrospective mind-wandering ratings (b), and trait mind-wandering scores (c) in Experiment 1. Error bars reflect the standard error of the mean.

word recalled. Additionally, serial position interacted with mind-wandering rate/state mind-wandering [$F(9, 1809) = 3.92$, $p < .001$, $\eta_p^2 = .02$] and marginally interacted with retrospective mind-wandering [$F(9, 1809) = 1.85$, $p = .055$, $\eta_p^2 = .01$] such that individuals experiencing more state mind-wandering were less likely to initiate recall according to serial position. However, serial position did not interact with trait mind-wandering [$F(9, 1809) = .40$, $p = .935$, $\eta_p^2 < .01$] such that trait mind-wandering did not impact the recall initiation process.

Discussion

The results of Experiment 1 provided valuable insights into how mind-wandering impacts the dynamics of memory processes. Our measures of mind-wandering (state, retrospective state, and trait) were all positively correlated and as the task progressed, mind-wandering increased and there was a corresponding decrease in recall. As expected, recall was adversely affected by the rate of mind-wandering during the task/state mind-wandering, retrospective mind-wandering ratings, and, to a lesser extent, trait mind-wandering (trait mind-wandering was not a unique predictor of memory outcomes). Together, our findings suggest that being off task during encoding detrimentally impacts memory, as expected. However, having a predisposition to mind-wandering does not necessarily imply that the learner has a lower memory ability per se. Rather, trait mind-wandering reflects a higher likelihood of experiencing more frequent episodes of state mind-wandering, which in turn reduces the chances of effective encoding. This is supported by our results showing a correlation between trait and state mind-wandering. It is important to note that even individuals who do not identify as trait mind-wanderers can still experience state mind-wandering episodes during a task, and it is these episodes that ultimately impair memory performance.

The lag-recency effect, or the tendency to recall items in sequence, was particularly diminished among those considered trait mind-wanderers. However, as seen in Fig. 4, the diminished lag-recency effect appears to be relatively stable throughout the task for trait mind-wanderers while participants reporting more mind-wandering (state mind-wanderers) or retroactively identifying as state mind-wanderers seemed to demonstrate a decreased lag-recency effect later in the memory task when average mind-wandering rates were increasing. Thus, mind-wandering may alter the way items are encoded and

Table 2
The results of a mixed multi-level model with timing, direction, lag, mind-wandering rate/state mind-wandering, retrospective mind-wandering, and trait mind-wandering for each participant predicting CRPs in Experiment 1.

Fixed Effects Parameter Estimates							
Effect	**Estimate**	**SE**	**95 % CI: Lower**	**95 % CI: Upper**	**df**	***t***	***p***
(Intercept)	0.11	0	0.1	0.11	7348	59.24	<.001***
Timing	−0.02	0	−0.03	−0.01	7348	−5.18	<.001***
Direction1	0.01	0	0	0.01	7348	2.14	0.033*
Lag	−0.02	0	−0.02	−0.02	7348	−27.63	<.001***
Mind-Wandering Rate	−0.02	0.01	−0.04	0	7348	−2.44	0.015*
State MW	0	0	0	0	7348	0.29	0.772
Trait MW	0	0	0	0	7348	−0.1	0.919
Timing * Direction1	0.03	0.01	0.01	0.04	7348	3.52	<.001***
Timing * Lag	0	0	0	0	7348	−1.51	0.131
Direction1 * Lag	−0.03	0	−0.03	−0.03	7348	−21.11	<.001***
Timing * Mind-Wandering Rate	−0.02	0.02	−0.06	0.01	7348	−1.32	0.186
Direction1 * Mind-Wandering Rate	0.02	0.02	−0.02	0.05	7348	0.97	0.33
Lag * Mind-Wandering Rate	0	0	0	0.01	7348	0.59	0.555
Timing * State MW	0	0	0	0	7348	0.12	0.903
Direction1 * State MW	0	0	0	0	7348	−0.96	0.336
Lag * State MW	0	0	0	0	7348	0.98	0.329
Timing * Trait MW	0	0	0	0	7348	0.39	0.697
Direction1 * Trait MW	0	0	0	0	7348	−0.33	0.744
Lag * Trait MW	0	0	0	0	7348	0.18	0.86
Timing * Direction1 * Lag	0	0	−0.01	0	7348	−0.74	0.462
Timing * Direction1 * Mind-Wandering Rate	−0.01	0.03	−0.08	0.06	7348	−0.21	0.832
Timing * Lag * Mind-Wandering Rate	0.01	0.01	−0.01	0.02	7348	0.85	0.396
Direction1 * Lag * Mind-Wandering Rate	0.01	0.01	−0.01	0.02	7348	0.88	0.376
Timing * Direction1 * State MW	0	0	0	0	7348	−0.03	0.973
Timing * Lag * State MW	0	0	0	0	7348	0.91	0.362
Direction1 * Lag * State MW	0	0	0	0	7348	−0.05	0.958
Timing * Direction1 * Trait MW	0	0	0	0	7348	−0.06	0.949
Timing * Lag * Trait MW	0	0	0	0	7348	−1.12	0.264
Direction1 * Lag * Trait MW	0	0	0	0	7348	2.13	0.033*
Timing * Direction1 * Lag * Mind-Wandering Rate	0.01	0.01	−0.01	0.04	7348	0.99	0.323
Timing * Direction1 * Lag * State MW	0	0	0	0	7348	−0.84	0.4
Timing * Direction1 * Lag * Trait MW	0	0	0	0	7348	2.26	0.024*

Note: * $= p < .05$, ** $= p < .01$, *** $= p < .001$.

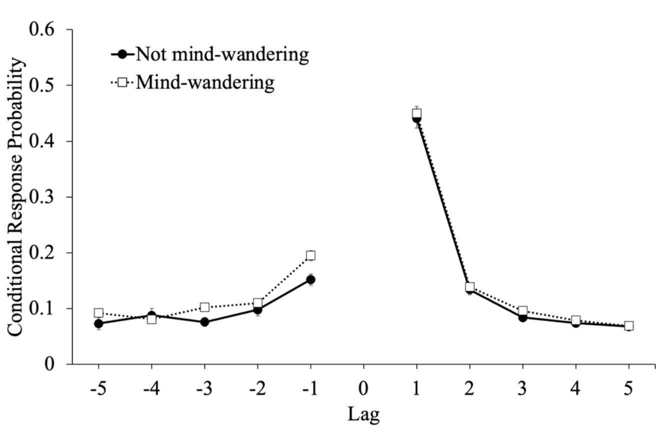

Fig. 5. Conditional-response probability (CRP) functions for lists where participants reported mind-wandering versus lists where they did not report mind-wandering in Experiment 1. Error bars reflect the standard error of the mean.

subsequently retrieved, and trait mind-wanderers may be less able to bind accompanying temporal-contextual cues of adjacent items in general. However, we note that the occurrence of mind-wandering on a given list did not significantly affect the lag-recency effect, and recall was higher on lists where mind-wandering was not reported.

Finally, while the first presented word was most likely to be recalled first regardless of mind-wandering status, learners who reported more state mind-wandering and identified as retrospective mind-wanderers showed a lesser tendency to initiate recall based on serial position. In contrast, trait mind-wandering did not impact this recall initiation pattern. This suggests that mind-wandering during a memory task impacts both the encoding and retrieval process but a predisposition towards mind-wandering does not impact how participants initiate the retrieval process.

Experiment 2

In Experiment 1, it is possible that the mind-wandering probes embedded in the list learning task impacted the encoding process (i.e., reactivity; see Double & Birney, 2019; Double et al., 2018; Murphy et al., 2023 for an example of metacognitive reactivity). For example, it is possible that the mind-wandering probes alert learners to their off-task thoughts while studying, and this immediate feedback could prompt them to refocus and intensify their efforts to stay "on task," potentially impacting encoding operations and subsequent memory performance. As such, in Experiment 2, we removed the mind-wandering probes during the study phase so that encoding was not disrupted. Thus, we examined retrospective evaluations of mind-wandering and trait mind-wandering without potentially biasing the encoding process. Similar to Experiment 1, we expected participants with a higher propensity to mind-wander, either as a retrospective judgment of their state (during the specific task) or trait (in general) level, to exhibit poorer total recall, a reduced lag-recency effect, and a lower likelihood of initiating retrieval according to serial position.

Method

Participants. After exclusions, participants were 204 undergraduate students (M_{age} = 18.79, SD_{age} = 1.43; 124 female, 78 male, 2 other) recruited from the ASU Human Subjects Pool. One participant was excluded for cheating and no participants were excluded for not attesting that they would give their full effort.

Table 3
The results of a mixed multi-level model with whether participants reported mind-wandering, direction, and lag for each participant predicting CRPs in Experiment 1.

Fixed Effects Parameter Estimates							
Effect	**Estimate**	**SE**	**95 % CI: Lower**	**95 % CI: Upper**	**df**	***t***	***p***
Mind-Wandering?	−0.01	0	−0.02	−0.01	6922	−3.87	<.001***
Direction	0.01	0	0	0.01	6922	2.07	0.039*
Lag	−0.02	0	−0.02	−0.02	6922	−26.02	<.001***
Mind-Wandering? * Direction	0.03	0.01	0.01	0.04	6922	3.65	<.001***
Mind-Wandering? * Lag	0	0	0	0	6922	−0.34	0.734
Direction * Lag	−0.03	0	−0.03	−0.03	6922	−20.58	<.001***
Mind-Wandering? * Direction * Lag	0.01	0	0	0.01	6922	2.17	0.03*

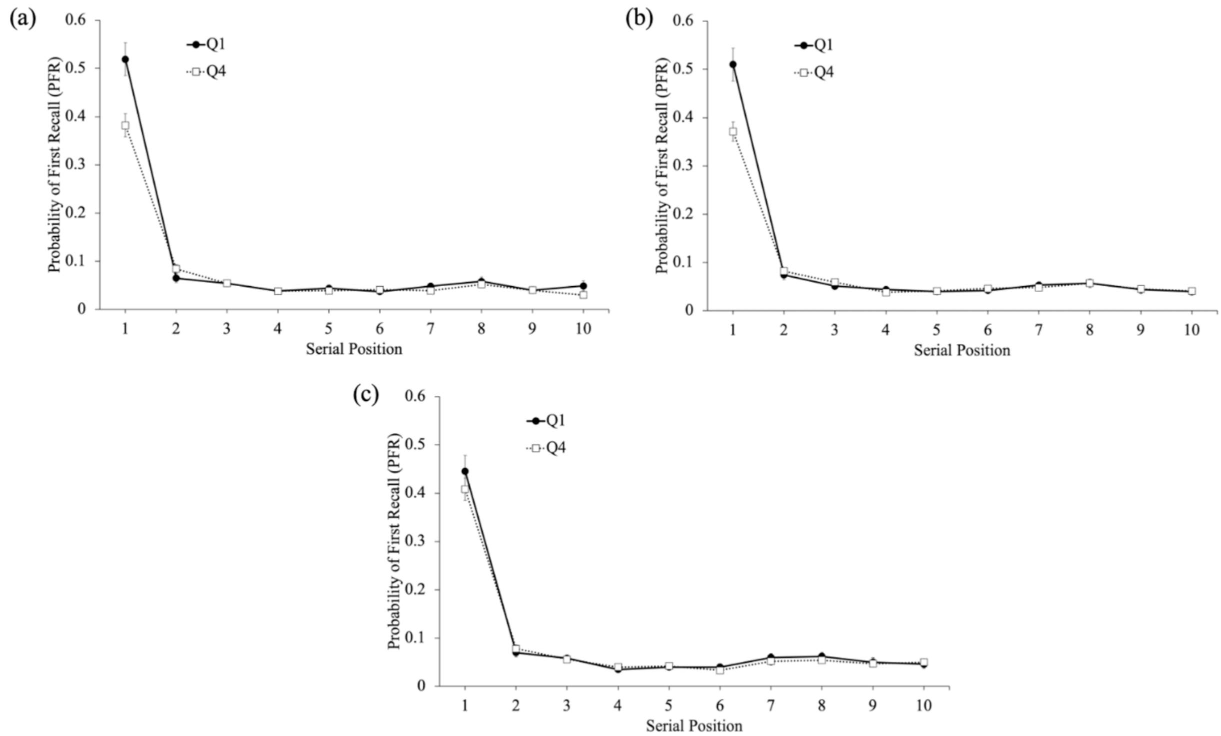

Fig. 6. The probability of first recall (PFR) functions as a function of serial position split into quartiles based on mind-wandering rate (a), retrospective mind-wandering ratings (b), and trait mind-wandering scores (c) in Experiment 1. Error bars reflect the standard error of the mean.

Materials and Procedure. The materials and procedure in Experiment 2 were nearly identical to Experiment 1. However, in Experiment 2, we removed the mind-wandering probes during the study phase so that encoding was not disrupted. Specifically, participants studied all 10 words on each list with no interruptions.

Reliabilities. To examine the reliability of the trait mind-wandering questionnaire, we compared participants' responses to each of the five questions [Cronbach's $\alpha = .81$]. We also examined the reliability of participants' recall across the 30 lists [Cronbach's $\alpha = .96$].

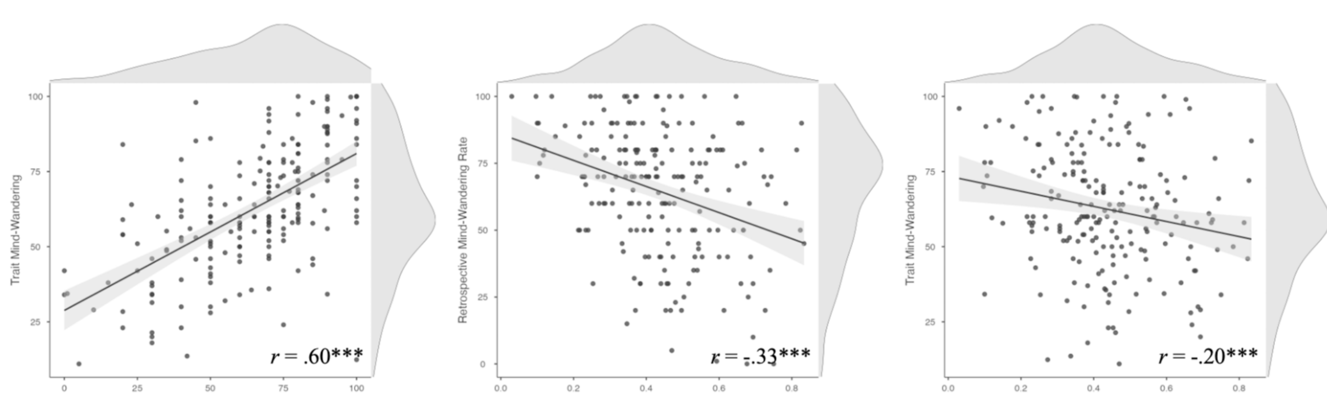

Fig. 7. Densities, correlations, and regression lines with standard error between recall and our measures of mind-wandering in Experiment 2.

Results

We first examined the relationship between retrospective mind-wandering ratings and trait mind-wandering (see Fig. 7). Pearson correlations revealed that retrospective mind-wandering ratings were related to trait mind-wandering [$r = .61$, $p < .001$]. Next, we investigated the relationship between mind-wandering and recall performance (see Fig. 7). Pearson correlations revealed that recall was negatively related to retrospective mind-wandering ratings [$r = -.33$, $p < .001$] and trait mind-wandering [$r = -.20$, $p < .001$]. A General Linear Model with retrospective mind-wandering ratings and trait mind-wandering scores predicting average memory performance ($R^2 = .11$) revealed that retrospective mind-wandering [$\beta = -.34$, $t(201) = -4.02$, $p < .001$] uniquely predicted memory performance but trait mind-wandering did not [$\beta = -.00$, $t(201) = -.05$, $p = .959$]. Similar to Experiment 1, we also examined how recall changed as the task endured. A mixed multi-level model with list-level recall accuracy modeled as a function of list (continuous variable nested within individual participants) revealed that recall decreased as the task endured [$t(5915) = -9.44$, $p < .001$].

CRPs split into quartiles based on retrospective mind-wandering ratings and trait mind-wandering scores are shown in Fig. 8. The results of a mixed multi-level model with direction (forward, backward), lag (1–9), retrospective mind-wandering, and trait mind-wandering for each participant predicting CRPs are shown in Table 4. Here, neither three-way interaction between lag, direction, and mind-wandering was significant. Thus, in contrast to Experiment 1, the lag-recency effect was not hindered in trait mind-wanderers (though we note that the patterns were similar to Experiment 1).

To examine early- and late-list CRPs (see Fig. 9), we conducted a mixed multi-level model with timing (first 10 lists, last 10 lists), direction (forward, backward), lag (1–9), retrospective mind-wandering, and trait mind-wandering for each participant predicting CRPs. The results are shown in Table 5. Although the four-way interactions did not reach significance, visual inspection of Fig. 9 suggests that the lag-recency effect may decrease on later lists for high retrospective mind-wanderers, but trait mind-wanderers' impairment appears to be similar on early and later lists.

Finally, we examined the PFR via a repeated-measures ANOVA with 10 levels (serial position) with retrospective and trait mind-wandering as covariates (continuous variables). Results revealed an effect of serial position [$F(9, 1809) = 41.21$, $p < .001$, $\eta_p^2 = .17$] such that the first word presented was most likely to be the first word recalled. However, serial position did not interact with retrospective mind-wandering [$F(9, 1809) = .86$, $p = .560$, $\eta_p^2 < .01$] or trait mind-wandering [$F(9, 1809) = 1.70$, $p = .083$, $\eta_p^2 = .01$] such that both retrospective judgments of state mind-wandering and trait mind-wandering did not impact the recall initiation process (see Fig. 10), contrasting Experiment 1 where retrospective state mind-wanderers showed a diminished PFR for the first studied item.

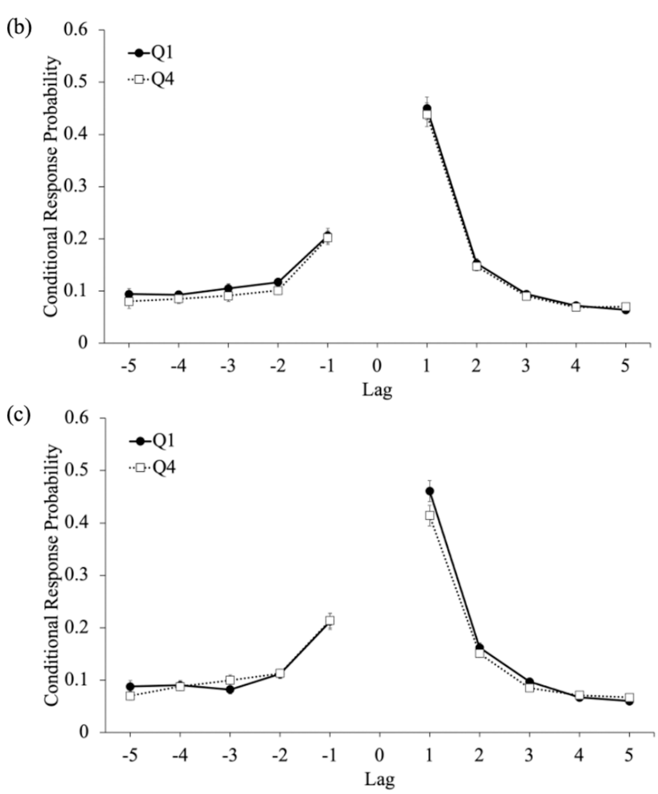

Fig. 8. Conditional-response probability (CRP) functions for forward and backward transitions as a function of lag split into quartiles based on retrospective mind-wandering ratings (b) and trait mind-wandering scores (c) in Experiment 2. Error bars reflect the standard error of the mean.

Discussion

The outcomes of Experiment 2 further illustrated mind-wandering's nuanced impact on memory processes, drawing some parallels with and also diverging from the findings of Experiment 1. As observed in Experiment 1, recall performance declined throughout the task and was inversely related to both retrospective mind-wandering ratings and trait mind-wandering (and our measures of mind-wandering were again related). Crucially, state mind-wandering emerged as a unique predictor of memory performance while trait mind-wandering did not, indicating that momentary lapses in attention have a more immediate effect on memory than a general predisposition to mind wander.

Unlike in Experiment 1, trait mind-wanderers did not exhibit a compromised lag-recency effect. However, trends again seemed to indicate that the lag-recency effect weakened on later lists for individuals with higher rates of retrospective mind-wandering whereas the patterns of trait mind-wanderers appeared relatively consistent across early and later lists, though this was not statistically significant. Finally, the tendency to recall the first-presented word as the first word in the recall sequence was unaffected by the level of retrospective mind-wandering or trait mind-wandering, also in contrast to Experiment 1. Given that the only difference between Experiments 1 and 2 was the presence of mind-wandering probes (a more sensitive measure of state mind-wandering compared with retrospective mind-wandering ratings), these probes might have influenced the encoding process. Thus, we conducted a cross-experiment comparison to determine whether the presence of though probes impacted the encoding and retrieval process.

Cross experiment comparison

To examine whether the presence of thought probes impacted overall recall performance, we conducted an independent samples *t*-test. Results revealed that recall in Experiment 1 with thought probes ($M = .42$, $SD = .16$) was similar to recall in Experiment 2 without thought probes ($M = .44$, $SD = .16$), [$t(407) = 1.24$, $p = .215$, $d = .12$]. In terms of CRPs, we conducted a mixed multi-level model with experiment (Experiment 1 vs Experiment 2), direction (forward, backward), and lag (1–9) for each participant predicting CRPs. However, there were no interactions with Experiment [all $ps > .133$], suggesting that the presence of probes did not impact the lag-recency effect. In terms of the PFR, we conducted a 2 (Experiment 1 vs Experiment 2) × 10 (serial position) ANOVA. Results revealed an effect of serial position [$F(9, 3663) = 827.67$, $p < .001$, $\eta_p^2 = .67$] such that the first word presented was most likely to be the first word recalled but serial position did not interact with Experiment [$F(9, 3663) = .78$, $p = .632$, $\eta_p^2 < .01$]. Thus, the presence of thought probes does not seem to affect overall memory performance or the dynamics of recall.

Next, given some of the disparate findings across experiments, we

Table 4
The results of a mixed multi-level model with direction, lag, retrospective mind-wandering, and trait mind-wandering for each participant predicting CRPs in Experiment 2.

Fixed Effects Parameter Estimates							
Effect	**Estimate**	**SE**	**95 % CI: Lower**	**95 % CI: Upper**	**df**	***t***	***p***
(Intercept)	0.12	0	0.11	0.12	3660	59.1	<.001***
Direction	0	0	−0.01	0	3660	−1.15	0.252
Lag	−0.02	0	−0.02	−0.02	3660	−22.68	<.001***
State MW	0	0	0	0	3660	−1.91	0.057
Trait MW	0	0	0	0	3660	0.61	0.543
Direction * Lag	−0.03	0	−0.03	−0.03	3660	−20.47	<.001***
Direction * State MW	0	0	0	0	3660	0.68	0.498
Lag * State MW	0	0	0	0	3660	−1.34	0.181
Direction * Trait MW	0	0	0	0	3660	0.19	0.848
Lag * Trait MW	0	0	0	0	3660	1	0.318
Direction * Lag * State MW	0	0	0	0	3660	0.17	0.866
Direction * Lag * Trait MW	0	0	0	0	3660	1.41	0.158

Note: * = $p < .05$, ** = $p < .01$, *** = $p < .001$.

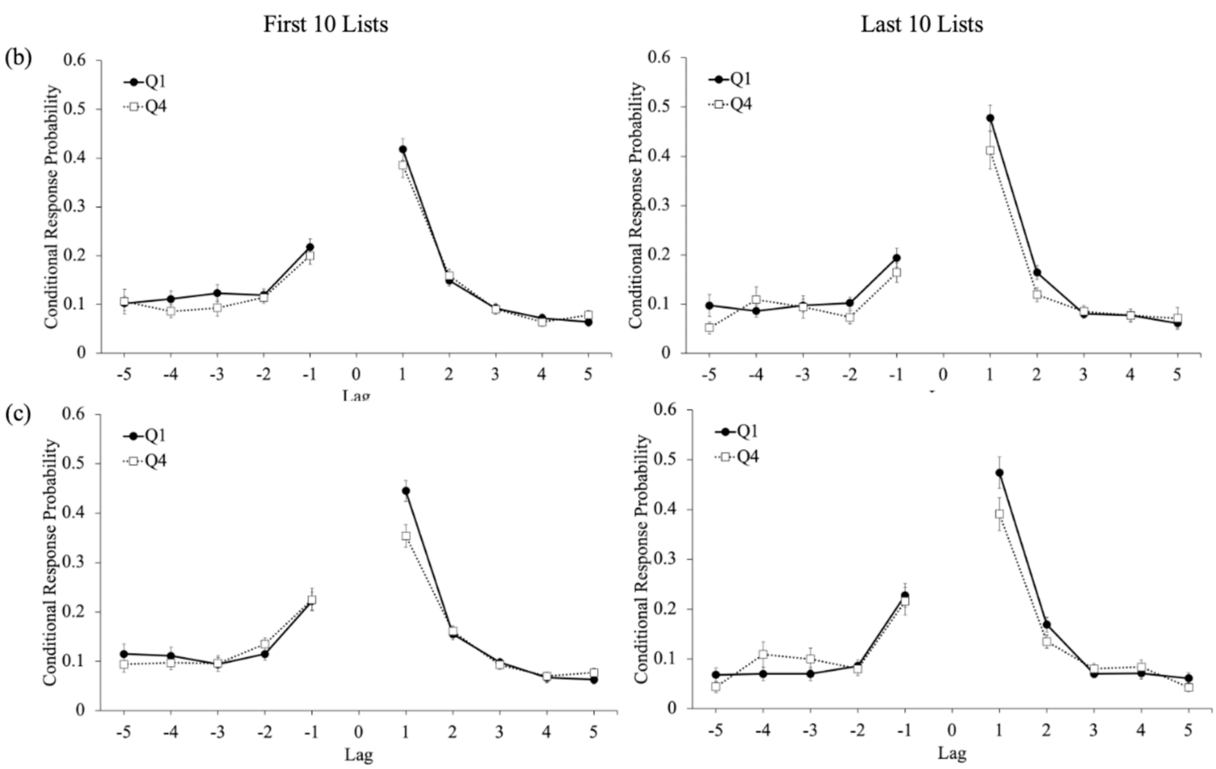

Fig. 9. Conditional-response probability (CRP) functions for the first 10 lists (left) and last 10 lists (right) for forward and backward transitions as a function of lag split into quartiles based on retrospective mind-wandering ratings (b) and trait mind-wandering scores (c) in Experiment 2. Error bars reflect the standard error of the mean.

combined the data from Experiments 1 and 2 to further examine the effect of mind-wandering on lag-CRPs. Specifically, as an exploratory analysis, we conducted a mixed multi-level model with direction (forward, backward), lag (1–9), retrospective mind-wandering, and trait mind-wandering for each participant predicting CRPs. Results revealed that the three-way interaction between direction, lag, and trait mind-wandering was significant [$p < .001$] but the three-way interaction between direction, lag, and retrospective mind-wandering was not significant [$p = .660$]. Thus, despite the differences between findings on lag-CRP across Experiments 1 and 2, a model combining these data still illustrates the effect.

Finally, we combined the data from Experiments 1 and 2 to further examine the effect of mind-wandering on the PFR. A repeated-measures ANOVA with 10 levels (serial position) with retrospective and trait mind-wandering as covariates (continuous variables) revealed an effect of serial position [$F(9, 3654) = 111.92, p < .001, \eta_p^2 = .22$] such that the first word presented was most likely to be the first word recalled. Additionally, serial position interacted with retrospective mind-wandering [$F(9, 3654) = 3.08$, $p = .001$, $\eta_p^2 = .01$] such that individuals reporting experiencing more state mind-wandering were less likely to initiate recall according to serial position. However, serial position did not interact with trait mind-wandering [$F(9, 3654) = .62, p = .783, \eta_p^2 < .01$] such that trait mind-wandering did not impact the recall initiation process. The full details of these cross-experiment analyses are available on OSF.

General discussion

Mind-wandering, characterized by the diversion of attention from a primary task to unrelated thoughts without the individual's conscious

Table 5
The results of a mixed multi-level model with timing, direction, lag, retrospective mind-wandering, and trait mind-wandering for each participant predicting CRPs in Experiment 2.

Fixed Effects Parameter Estimates

Effect	Estimate	SE	95 % CI: Lower	95 % CI: Upper	df	t	p
(Intercept)	0.11	0	0.11	0.11	7320	61.78	<.001***
Timing	−0.01	0	−0.02	−0.01	7320	−3.87	<.001***
Direction	0.01	0	0	0.01	7320	1.44	0.151
Lag	−0.02	0	−0.02	−0.02	7320	−27.3	<.001***
State MW	0	0	0	0	7320	−3.61	<.001***
Trait MW	0	0	0	0	7320	1.33	0.183
Timing * Direction	0.03	0.01	0.01	0.04	7320	3.79	<.001***
Timing * Lag	0	0	−0.01	0	7320	−1.83	0.067
Direction * Lag	−0.03	0	−0.03	−0.02	7320	−18.31	<.001***
Timing * State MW	0	0	0	0	7320	−1.23	0.219
Direction * State MW	0	0	0	0	7320	1.78	0.074
Lag * State MW	0	0	0	0	7320	−0.86	0.393
Timing * Trait MW	0	0	0	0	7320	0.53	0.597
Direction * Trait MW	0	0	0	0	7320	−0.86	0.389
Lag * Trait MW	0	0	0	0	7320	1.03	0.303
Timing * Direction * Lag	0	0	−0.01	0	7320	−1.09	0.275
Timing * Direction * State MW	0	0	0	0	7320	0.45	0.651
Timing * Lag * State MW	0	0	0	0	7320	0.36	0.722
Direction * Lag * State MW	0	0	0	0	7320	0.75	0.453
Timing * Direction * Trait MW	0	0	0	0	7320	−0.74	0.462
Timing * Lag * Trait MW	0	0	0	0	7320	−0.21	0.838
Direction * Lag * Trait MW	0	0	0	0	7320	1.65	0.1
Timing * Direction * Lag * State MW	0	0	0	0	7320	1.27	0.204
Timing * Direction * Lag * Trait MW	0	0	0	0	7320	−0.87	0.385

Note: * = $p < .05$, ** = $p < .01$, *** = $p < .001$.

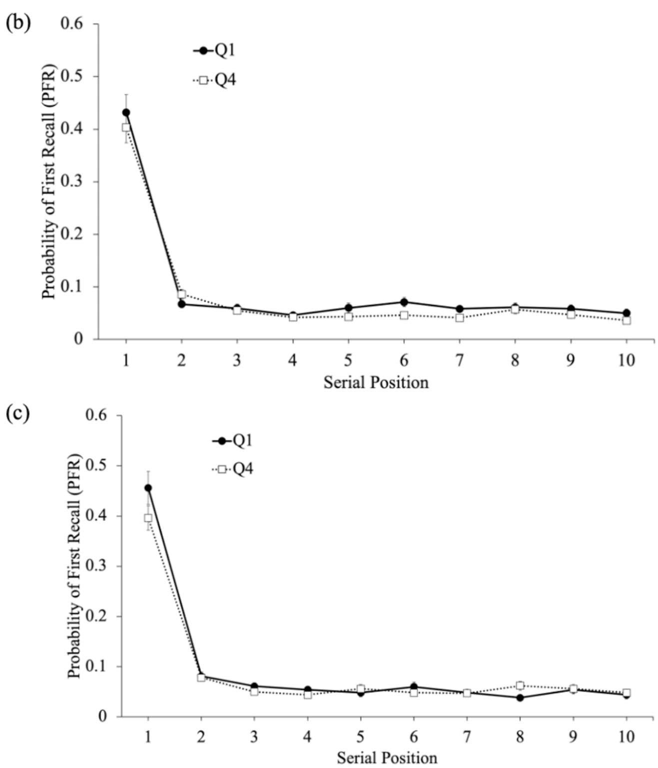

Fig. 10. The probability of first recall (PFR) functions as a function of serial position split into quartiles based on retrospective mind-wandering ratings (b) and trait mind-wandering scores (c) in Experiment 1. Error bars reflect the standard error of the mean.

realization, exhibits both state and trait dimensions, such that some individuals are more inclined to experience mind-wandering. In the present study, we examined how mind-wandering, both as a momentary occurrence and a consistent individual differences characteristic, influences episodic memory encoding and retrieval dynamics. Participants were presented with 30 lists of words to remember for recall tests, and through our analysis, we sought to gain insights into how the state of mind during encoding and the general propensity to mind wander impact the learning process. We hypothesized that individuals with a tendency towards mind-wandering would exhibit reduced efficiency in leveraging temporal-contextual cues, resulting in compromised overall recall performance (and potentially other retrieval dynamics as well, such as the probability of first recall).

In terms of our measures of mind-wandering, trait mind-wandering (as computed by the Mind-Wandering Questionnaire; Mrazek et al., 2013) predicted state mind-wandering such that an individual with a higher propensity to mind-wander was more likely to mind-wandering during the memory task. Moreover, all measures of mind-wandering were negatively related to memory performance such that mind-wandering hurt memory performance and we also found that recall was higher on lists for which participants did not report mind-wandering compared to lists where they reported experiencing mind-wandering. Additionally, we observed that mind-wandering increased as the task endured, and consequently, recall decreased on later lists. However, our analyses revealed that only state mind-wandering (not trait mind-wandering) uniquely predicted recall performance. This suggests that off-task thoughts during encoding can impact memory processes, but trait mind-wandering is not necessarily accompanied by a poor memory.

We also found some evidence that trait mind-wanderers were less likely to use a given item's accompanying temporal-contextual cues to recall additional items, known as the lag-regency effect (see Kahana, 1996). Additionally, trends indicated that the lag-recency effect diminishes on later lists (a time when mind-wandering is likely to rise) for participants who report elevated state mind-wandering rates and retrospectively reported mind-wandering. However, individuals with a trait predisposition to mind-wander generally displayed a consistent impairment in this effect across the task (i.e., the lag-recency effect is diminished for these individuals even on early lists).

Previous work has shown that the best learners are people who allocate greater attentional intensity to the to-be-remembered information and are also better able to prevent lapses of attention (Miller &

Unsworth, 2020, 2021; Unsworth & Miller, 2021). Theoretically, mind-wandering disrupts the intensity of attention by diverting attention and cognitive resources away from the task at hand, leading to inconsistent attention and diminished attentional intensity, which adversely affects cognitive engagement and regulation (e.g., Robison et al., 2022). As a result, disruptions in the intensity of attention due to mind-wandering may have weakened the lag-recency effect by impairing participants' ability to consistently regulate attention and maintain intense focus during encoding, thereby affecting the efficient temporal binding of items and reducing the likelihood of recalling items in close succession or at the beginning and end of lists. Together, prior work and the present results suggest that mind-wandering leads to a binding deficit, whether between items or between items and context, reflecting a potentially task-general impairment. We propose that this deficit arises because binding is inherently an attention-driven process, requiring both the intensity and consistency of attention for optimal effectiveness.

Surprisingly, our analysis of how participants initiated the recall process (i.e., probability of first recall, PFR; Howard & Kahana, 1999; Kahana et al., 2002) indicated that state mind-wandering can affect how individuals initiate recall, particularly reducing the tendency to start recall with the initially presented word. This suggests that momentary distractions or shifts in attention can disrupt the initial encoding of items, subsequently altering the preferential retrieval of information that was presented at the start of the list. However, increased trait mind-wandering was not accompanied by a reduction in PFR for the first studied item, highlighting that the effect of mind-wandering on retrieval dynamics is likely driven by lapses of attention during encoding for a given list, rather than the general propensity to mind-wander.

Mind-wandering's impact on attentional intensity could have led to a scattered or unfocused start to recall. This may result in a less strategic retrieval approach, potentially affecting the tendency to initiate recall with items from specific serial positions, such as the first or last items presented, which are typically favored in undisturbed memory recall processes (e.g., Kahana et al., 2002). Additionally, given the important role of internally maintained context in driving the selection of items for recall (see Polyn et al., 2009), mind-wandering could disrupt the initial focus or 'spotlight' on relevant contextual cues, leading to less efficient recall initiation. This might result in a reduced likelihood of starting recall sequences with items that were encoded in strong associative contexts—either temporal or semantic—and also affect the recall of subsequent items and overall recall performance.

We note that there were some important differences between Experiments 1 and 2. In Experiment 1, where thought probes were used, there was some evidence suggesting a compromised lag-recency effect among individuals with high trait mind-wandering. This indicated potential difficulties in leveraging temporal-contextual cues for memory retrieval. Conversely, Experiment 2, which omitted thought probes, did not show a significant hindrance in the lag-recency effect for trait mind-wanderers but the pattern of the effect was in the same direction as in Experiment 1 and the cross-experiment comparison still illustrated the effect. Similarly, Experiment 2 showed that the word most likely to be recalled first was not influenced by state or trait mind-wandering but state mind-wandering impacted PFR in Experiment 1 as well as in the cross-experiment analysis.

It is possible that the presence of thought probes in this list learning task reactively impacted performance. Experiment 1, which employed thought probes during the task, aimed to capture in-the-moment instances of mind-wandering whereas Experiment 2 omitted these probes to examine if their absence would influence encoding processes differently. However, a cross-experiment comparison revealed that overall recall did not significantly differ between the two experiments, suggesting that the immediate disruption caused by thought probes might not have a substantial impact on overall memory outcomes. Additionally, the presence of probes in Experiment 1 versus their absence in Experiment 2 did not yield statistically significant differences in CRPs or the PFR. Together, this suggests that the presence of thought probes within a memory experiment may not reactively impact memorial processes, consistent with some prior work showing no differences in cognitive tasks as a function of the presence of thought probes (e.g., Arnicane et al., 2021; Wiemers & Redick, 2019).

Another potential reason for slight differences between Experiments 1 and 2 is that state measures, such as thought probes, offer a more sensitive means of detecting actual mind-wandering during learning tasks compared to retrospective judgments. State measures tend to correlate more strongly with other state measures of the same construct on a given occasion than with trait measures of the construct (and the same applies to traits versus traits), indicating that both state and trait tests demonstrate convergent and divergent validity (Zuckerman, 1983). Thought probes, inserted at various points during the learning process, prompt immediate reflection on the current focus of attention, capturing mind-wandering episodes as they occur. This somewhat more real-time assessment minimizes memory biases and the inaccuracies inherent in post-task reflections where participants may forget, overlook, or misjudge periods of inattention—retrospective judgments rely on the individual's ability to accurately recall and assess their attentional state after the fact, a process susceptible to reconstruction errors and subjective interpretations of what constitutes mind-wandering. Consequently, thought probes provide a more direct and moment-to-moment account of mind-wandering, making them a superior tool for understanding how attention fluctuates during learning. Thus, the removal of these probes in Experiment 2 may have impacted our ability to recover some of the effects of transient periods of task-irrelevant thought.

In sum, the present study has replicated and extended prior work regarding the relationship between mind-wandering and episodic memory, elucidating both the detrimental and nuanced aspects of how different facets of individual differences in mind-wandering—state, retrospective judgment, and trait—impact episodic memory encoding and retrieval dynamics. This distinction underscores the complexity of mind-wandering phenomena and their variable impacts on learning and retrieval processes. By distinguishing how state and trait mind wandering differentially impact encoding and retrieval processes, researchers can better tailor interventions and strategies to mitigate the negative effects of mind wandering. For instance, state mind-wandering could be addressed by modifying task environments to enhance engagement and reduce boredom or fatigue while trait mind-wandering might require more comprehensive approaches such as training in mindfulness or attention management techniques. As we advance our understanding of these processes, this work not only contributes to the theoretical knowledge in cognitive psychology but also suggests practical implications for enhancing educational strategies and interventions aimed at improving memory performance in learning environments.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used chatGPT to edit the manuscript for clarity and concision. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

CRediT authorship contribution statement

Dillon H. Murphy: Writing – review & editing, Writing – original draft, Software, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation. **Gene A. Brewer:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The materials, data, and information needed to reproduce the analyses are available on OSF.

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