View metadata, citation and similar papers at core.ac.uk

brought to you by CORE

provided by Tilburg University Repository

Tilburg University

Tracking the wandering mind

Dias Da Silva, Mariana; Postma, Marie

Published in:
Proceedings of the 41st Annual Conference of the Cognitive Science Society

Publication date:
2019

Document Version
Other version

Link to publication in Tilburg University Research Portal

Citation for published version (APA):
Dias Da Silva, M., & Postma, M. (2019). Tracking the wandering mind: Memory, mouse movements and decision making styles. In A. Goel, C. Seifert, & C. Freska (Eds.), *Proceedings of the 41st Annual Conference of the Cognitive Science Society* (Vol. 41, pp. 2592-2598).

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

Take down policy
If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Download date: 12. May. 2021

Tracking the wandering mind: Memory, mouse movements and decision making styles

Mariana Rachel Dias da Silva (m.r.diasdasilva@tilburguniversity.edu)

Marie Postma (marie.postma@tilburguniversity.edu)

Tilburg University Cognitive Science and Artificial Intelligence Department,
Warandelaan 2, 5037AB Tilburg, The Netherlands

Abstract

Mind wandering involves internally focused attention and is often conceptualized as the opposite of external attention that is oriented towards the task at hand. Individuals vary according to the amount they mind wander as well as with regards to the pattern of oscillations between mind wandering thoughts and externally directed, focused thought. Assuming that mind wandering is influenced by episodic contents, we explore the proposition that mind wandering frequency is related to the manner in which individuals deal with the contents of episodic memory, as reflected by a maximizing decision making style. Based on previous studies measuring cognitive processes, we assume that mouse trajectories towards a particular response on the screen are continuously updated by time-dependent and temporally-dynamic cognitive processes. As a behavioral methodology, mouse tracking provides potential cues to help predict mind wandering. In our experiment, a total of 274 students completed a decision making questionnaire, episodic and associative memory tests (during which mouse movements were recorded) and a working memory task, during which mind wandering thoughts were assessed. We found certain mouse movement characteristics to be significantly predictive of mind wandering. Also, a maximizing decision making style appeared to be related to a particular type of mind wandering, namely, task-related interference.

Keywords:

mind wandering; episodic memory; mouse-tracking; decision making; maximizing

Introduction

Conscious experience is fluid and dynamic. Mind wandering (MW) involves a flow of thoughts, often from one topic to another, back and forth between the outside external world and internal thoughts and feelings. Where do these thoughts come from? Why do our thoughts wander elsewhere when we are trying to focus on a task? Can we detect whenever a person is mind wandering from their behavior? Over the last two decades, researchers have been investigating these questions empirically in hopes of understanding how we navigate our stream of consciousness and the world around us. In this paper, we aim to shed additional light upon these questions by focusing on behavioral cues to MW and the link between MW and different decision making styles.

Factors influencing MW

During MW, thoughts frequently focus on events that occur in distinct periods in time, either in the past or future, which suggests self-generated mental content to be largely a product of the episodic memory system (Smallwood & Schooler, 2015). Neural accounts of MW demonstrate increased activation in the medial temporal lobe subsystem (Andrews-Hanna, Reidler, Huang, & Buckner, 2010; Ellamil, Dobson, Beeman, & Christoff, 2012), which is associated with episodic retrieval (Klinger, 2013; Mittner, Hawkins, Boekel, & Forstmann, 2016). In addition to being a part of veridical episodic events, details from past experiences can also be recombined in order to construe episodic mental simulations and other mental states that become part of the stream of thought. During MW there is also increased activation in the dorsal medial subsystem, which is associated with social processes, scenarios, meaning and comprehension. The *default variability hypothesis* (Mills, Herrera-Bennett, Faber, & Christoff, 2018) proposes that thoughts ceaselessly move from one topic to the next, with heightened variability over time. The ceaseless flow serves to distinguish different memories while the variability of content serves to provide a time buffer between memories, improving episodic memory efficiency. In addition, heightened variability enables the extraction of commonalities and differences between memories and the eventual development of categorization and category boundaries. Commonalities allow for the creation of meaning while dissimilarities prevent the overlearning of categories. Thus, the default content variability in MW increases the opportunities for interleaved episodic to semantic transformations.

Regular oscillations between engagement with the external environment and engagement in internal thoughts are normative to the human brain functioning (Mills et al., 2018). However, patterns of oscillations are subject to a wide range of individual differences, which vary according to the context (Seli et al., 2018). In particular, low demand contexts (Smallwood & Andrews-Hanna, 2013), less task interest (Unsworth & Mcmillan, 2012) and greater fatigue (Walker & Trick, 2018) are related to more MW, to name a few possible factors. In addition to these factors, we are interested in how a person's episodic memory performance is related to this pattern of oscillations. Previous research has investigated mind wandering during episodic memory tests (Riby, Smallwood, & Gunn, 2008), finding that regardless of the amount of MW reported in a retrospective questionnaire, participants performed equally well on an episodic memory test. However, Event-Related Potentials (ERP) analyses indicated that low MW groups differed from high MW groups in their retrieval strategy. Those who did not mind wander a lot used a pure recollection strategy[1] for remembering words which they had previously seen before and words which were new. However, those who mind wandered frequently were unable to easily recollect stimuli; to compensate, they used additional monitoring and strategic processes[2] in order to aid episodic remembering.

Decision making styles as indicators of MW

Are there decision making styles that are related to mind wandering? Mind wandering content is dependent on what enters into episodic memory. At the same time, there is variability in the manner in which individuals select and sift through the contents of episodic memory. For example, some individuals tend to become more stuck on particular memories, while others have a greater tendency to quickly navigate from topic to topic. Similarly, there is variability in the manner in which individuals sift through information as they make decisions. When making decisions, individuals must select relevant information to attend to and create meaning out of in order to make a choice (Beach, 1993). Previous research has distinguished between two decision making styles, one which involves a tendency to find the best possible alternative, or *maximizing*, and one which involves a tendency to find the option that is good enough, or *satisficing*. *Maximizers* have more difficulty in making decisions and tend to be less satisfied with their choices, meanwhile *satisficers* tend to have an easier time making decisions and tend to be more satisfied with their choices (Schwartz et al., 2002). Yet, what is it about the nature of *maximizing* and *satisficing* that might be related to mind wandering? We postulate that the rigid quality of a *maximizing* decision making style may be related to greater rumination (Paivandy, Bullock, Reardon, & Kelly, 2008), and in turn manifest as type of MW which involves a tendency to worry about performance on the task at hand (Dias da Silva, Rusz, & Postma-Nilsenová, 2018), namely, task-related interference. We therefore would expect a tendency to *maximize* to be related to more interfering thoughts about performance on a task which inhibit actual performance of the task itself.

Computer mouse movements as indicators of MW

From an embodied cognition perspective, which assumes cognition is evidenced in our bodily behaviors (Barsalou, 2008), as our minds are decoupled from the sensory environment during MW, our minds seem to also disengage from controlling behavioral motor outputs. Consequently, motor performance becomes more automatic or degraded (Franklin, Smallwood, & Schooler, 2011). Initial evidence for this was found in a study by Kam et al. (2012), in which participants were instructed to track a moving ball on a screen with a joystick. Intermittently during the task, participants were asked whether or not they were MW. In trials during which participants were MW, they deviated further from the correct path than in times during which they were focused. Additionally, Arapakis, Lalmas, and Valkanas (2014) found that various mouse movement measures were able to predict engagement− which is often contrasted with MW − in an unsupervisied manner. It is thus plausible that MW in online tasks can be inferred by hand reach movements which are continuously updated by ongoing mental processes (Spivey & Dale, 2006) and become more degraded and automatic during MW (Kam et al., 2012), as attention decouples from the task at hand.

Current Study

The primary goal of the present study is to investigate if episodic memory, decision making style, mouse movements and task interest can predict MW. Previous research consistently indicates a strong negative relationship between MW and task interest. However, little has been done in terms of the relationship between performance on episodic memory tests, mouse movements and MW. To our knowledge, no research so far explored the relationship between mind wandering and decision making styles. Therefore, the guiding questions in this research are: 1) What is the relationship between episodic memory performance, motor output, and mind wandering? 2) How are task interest and decision making styles related to MW? As our aim is to explore the relationship between various measures, we do not propose directional hypotheses.

Methods

Participants and Procedure

In total, 274 participants between 17 and 41 years of age $M = 22.09$), 180 female, performed this experiment and received course credit for their participation. Three participants were excluded due to a procedural error. The study was approved by the university's Institutional Review Board. Before beginning the experiment, participants signed a consent form. Participants then answered questions about their demographics and choice making orientation. Next, they performed episodic and associative memory tests, a working memory test during which mind wandering was measured, and finally, they filled out a questionnaire about their interest in the task (see Figure 1). Note some of the data has been reported in Dias da Silva and Postma-Nilsenová (2019)[3] and, thus, the current data and that data are not from independent samples. Specifically, the MW responses from the current participants are shared with Dias da Silva and Postma-Nilsenová (2019). The purpose of that study was to examine relations between mouse movements and MW probes during an operation span task. In this study, we rather explore relationships between various additional measures from episodic memory tests and decision making styles with the overall MW frequency reported during the OSPAN task.

Materials

Decision Making Decision-making orientation (Schwartz et al., 2002) is an individual difference variable that differ-

[1] as indicated by a larger magnitude of the left-parietal ERP component.

[2] as indicated by larger central negativity effects.

[3] submitted for publication.

entiates people according to how they make decisions. At one extreme, *maximizing* involves a tendency to find the best possible alternative, while at the other extreme, satisficing involves a tendency to find the option that is good enough. Decision-making orientation was assessed by the Maximization Scale (Cronbach $\alpha = .64$), consisting of 13 items assessed on a 7-point Likert scale (1 = completely disagree to 7 = completely agree). Higher scores on the scale reflect a general tendency to *maximize*, while lower scores on the scale reflect a general tendency to *satisfice*.

Episodic Memory: 15-Word List Learning (WLLT) and Recognition Tests (WRT) THE WLLT consisted of free recall of 15 semantically unrelated words (concrete, imaginable nouns), in three trials. Words were selected from SUBTLEX-NL, a database of Dutch word frequencies based on 44 million words from film and television subtitles (Keuleers, Brysbaert, & New, 2010). All words were bisyllabic, had 6 letters, and had a medium frequency ($Range = 2.25 - 3.45$, $M = 2.56$, $Mdn = 2.46$) and a prevalence of above 98%. Each word was presented on the screen for 2 seconds, in a random sequence. Between each set of words, participants performed a 20-second Brown-Peterson distraction task[4], which required them to count backwards from a 3-digit number presented on the screen. During the recall phase, participants were asked to write down the words they could recall. The score was the total number of words reproduced over three trials (0-45). Immediately after the WLLT, participants were shown 30 words (15 distractor words were presented in addition to the ones previously seen) in a random order on a computer screen and were instructed to explicitly recognize whether or not they had seen the word by clicking on yes or no with the computer mouse on the screen. This part was WRT. The score was the sum of true positive and true negative answers (0-30).

Associative Memory: Paired-Associate Learning (PALT) and Recognition Tests (PART) The PALT consisted of cued recall of 12 semantically related word pairs, and 12 semantically unrelated word pairs, constructed in the same format of the 15-word list learning test, with three trials, and a Brown-Peterson distraction task. Words were selected from SUBTLEX-NL (Keuleers et al., 2010). Word length varied from 3 to 8. All words had a prevalence of above 98% and had a medium frequency ($Range : 1.56 - 4.56$, $M = 3.04$, $Mdn = 3.03$). Semantic associations were made according to De Deyne and Storms (2008)'s word association norms, and semantic distance was additionally checked with Snaut (Mandera, Keuleers, & Brysbaert, 2017). Each pair was presented on the screen for 2 seconds. Between each set of 24 pairs, participants performed a 20-second Brown-Peterson distraction task. During the recall phase, participants were asked to write down the target word in response to each cue word which was randomly presented on the screen. The score was the sum of pairs reproduced over three trials (0-72). The PALT was followed immediately by a recognition test (PART), which involved forced choice of the target words of the PALT in response to the presented cue words. In each trial, three distractor words were simultaneously presented on the screen together with the target and cue[5]. Each cue was always presented with 2 semantically related words, and 2 semantically unrelated words. The score was the sum of correct answers (0-24).

Mind Wandering Intermittent thought probes assessing participant's state of mind were presented during a working memory task (Operation Span task, (Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Mrazek et al., 2012)). MW was calculated as the percentage of thought probes during which participants responded that they were either having task-unrelated thought (TUT) or task-related interference (TRI) (Stawarczyk, Majerus, & D'Argembeau, 2013). Focused attention (FA) was calculated as the percentage of thought probes during which participants were focused on the task.

Task-interest As a last part of the experiment, task interest (TI) was assessed using a 5-point Likert scale with 4 questions (Cronbach $\alpha = .82$): (a) Did you enjoy performing this task? (b) Did you take interest in this task?; (c) Are you interested in performing tasks like this?; and (d) Did you feel pleasant while performing the task? The response categories vary from 1 (not at all) to 5 (very much) (Van Yperen, 2003).

Instrumentation All questionnaires were presented online via Qualtrics. The episodic and associative memory tasks were programmed on OpenSesame 3.1.6 (Mathôt, Schreij, & Theeuwes, 2012). The experiment was run on full screen mode, with a resolution of 1024 by 768 pixels on a Windows 7 operating system. The desktop computer was placed on the table so that participants had enough room to move the mouse without running out of space. Mouse settings were left at their default values (medium acceleration and medium speed). A Dell USB3 Button Scrollwheel Optical Mouse was used to record cursor coordinates during the memory tests. Mouse movements were recorded both in the Recognition parts of the Word List and Paired-Associates tests. In the WRT (Fig. 1a), once participants click on the start button (341 by 85 pixels), two words (a target and a distractor) were displayed to them on the extreme top right and left corners of the screen (192 by 128 pixels). Once participants determined which of the words they had learned in the previous portion of the task, they made a selection with the computer mouse. During the PART (Fig. 1b), once the participants clicked the start button (341 by 85 pixels), they viewed a cue at the center of

[4]The Brown-Peterson distraction task was administered in order to prevent the confounding of episodic memory with short-term memory (as a result of recency effects which occur during learning tests) (Spaan, 2016).

[5]There were always 2 semantically related and two non-semantically related words presented on the screen (i.e.: If the target was semantically related to the cue, one distractor would also be semantically related to the cue and the other two would not).

the screen, along with 1 target and 3 distractors (192 by 128 pixels) distributed along the 4 extreme corners of the screen. Once they determined which word was associated with the cue, they made a selection with the computer mouse.

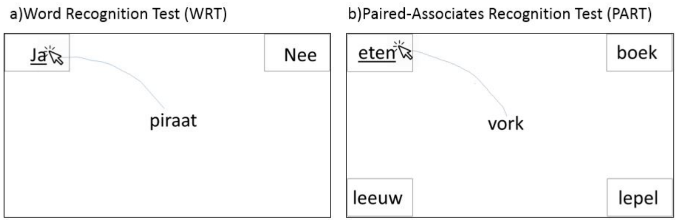

Figure 1: Illustration of the a)WRT and b)PART tests.

Data processing Participants' individual raw data files were merged and read into R version 3.4.1(R Core Team, n.d.). Mouse tracking data were imported and processed using the library mousetrap (Kieslich & Henninger, 2017). Trajectories were recorded from the moment the start button was clicked on, to the moment a target or distractor was selected in both the WRT and the PART tests. All trajectories aligned to a common starting position and were remapped onto one side. Various features such as total distance and maximum velocity[6] were calculated based on the mouse trajectories and aggregated per participant (see Supplementary Information).

Results

Data were analyzed for 271 participants. Descriptives for the WLLT, WRT, PALT, PART memory measures, decision making and task interest questionnaires can be found in Table 1. Ceiling effects were observed in the Word Learning Recognition Test (WRT) and in the Paired Associates Recognition Test (PART), as a majority participants had either perfect or near perfect scores on these tests. Therefore, they were not used further for statistical testing. As mouse movement coordinates were recorded during the tests, they were used for statistical testing instead.

Memory, computer mouse movements, and MW

Correlations In order to examine how both memory recall measures and mouse movements during the recognition tests[7] predict MW during a subsequent task, we first examined which variables were correlated with TUT, TRI, and FA. TUT frequency was found to be significantly correlated with mouse measures in the WRT, namely; maximum x-position ($r(269) = 0.17$, $p = .01$) and total distance travelled ($r(269) = 0.13$, $p = .04$). TRI frequency was positively correlated with various measures in the PART, namely; reaction time ($r(269) = 0.21$, $p < .000$), idle time ($r(269) = 0.18$, $p < .000$), time to maximum deviation towards the alternative response ($r(269) = 0.16$, $p = .01$), time to maximum deviation below the ideal path towards the selected response ($r(269) = 0.13$, $p = .03$), time to maximum deviation from the ideal path overall ($r(269) = 0.15$, $p = .01$), time to maximum acceleration ($r(269) = 0.19$, $p < .000$), time to maximum velocity ($r(269) = 0.18$, $p < .000$), and time to minimum acceleration ($r(269) = 0.19$, $p < .000$). In addition, TRI was negatively correlated with performance on non-semantic items in the paired recall test ($r(269) = -0.13$, $p = .03$). Lastly, FA was inversely correlated with the same measures that were positively correlated with TRI.

Table 1: Descriptives of Task Interest (TI), Maximizing, Word List Learning Test (WLT), Word Recognition Test (WRT), Paired Associates Learning Test (PALT), Paied Associates Recognition Test (PART), frequency of Task-unrelated Thoughts (TUT%), Task-Related Interference (TRI%), and Focused Attention (FA%).

Measure	Mean	SD	95% CI
TI (1-5)	3.31	0.84	3.21 - 3.41
Age	22.07	3.26	21.68 - 22.46
Maximizing (1-7)	4.38	0.70	4.30 - 4.46
WLLT	0.60	0.14	0.59 - 0.62
WRT	0.99	0.03	0.98 - 0.99
PALT	0.75	0.15	0.73 - 0.76
PALT s.	0.86	0.13	0.84 - 0.87
PALT n.s.	0.63	0.20	0.61 - 0.66
PART	0.97	0.09	0.96 - 0.98
PART s.	0.98	0.05	0.98 - 0.99
PART n.s	0.95	0.14	0.93 - 0.97
TUT(%)	8.51	13.46	6.91 - 10.11
TRI(%)	22.58	21.48	20.03 - 25.14
FA(%)	68.91	26.27	65.78 - 72.03

Note: s. = semantic; n.s. = nonsemantic

Dimensionality reduction Pearson's correlations between the mouse-tracking features indicate that some features may be measuring nearly identical underlying constructs (e.g.: *time to reach maximum velocity (WRT)* and *time to reach minimum acceleration (WRT)*, $r = 0.98$). Therefore, PCA (with oblimin rotation) was used to reduce the dimensionality of the data separately for the WRT and PART features, removing any multicollinearity. We used Kaiser's Criterion in order to determine the number of principal components in the WRT and in the PART separately. Five components were used that cumulatively accounted for 29% 57% 70% 77% and 85% of the variance in the mouse-tracking data in the WRT test, respectively. For the PART, 4 components were used that cumulatively accounted for 33% 61% 76% and 86% of the variance in the mouse-tracking data.

Regressions Subsequently, we performed two separate regressions, one with TRI percentage as the dependent variable and one with FA percentage as the dependent variable. As

[6]28 mouse features for the WRT and 28 for the PART.
[7]Mouse movements were recorded during the WRT and PART.

input for the regressions, we included the PCA components which significantly correlated with MW frequency. Note that no PCA components were significantly correlated with TUT. The second component (temporal) from the PART was significantly correlated with TRI and FA frequency ($r = 0.18$ for TRI and $r = -0.17$ for FA).

Results of the regression indicate that percentage of TRI was significantly predicted by the temporal principal component ($R = .18$, adjusted-$R^2 = 0.03$, $F(1,269) = 8.56$, $p = .004$). Regression coefficients are shown in Table 2.

Table 2: Temporal Principal Component as a predictor of Task-related Interference.

	B	*SE(B)*	*t*	*p*
(Intercept)	22.68	1.29	17.57	$< .000$
PART TC2 (temporal)	3.78	1.29	2.93	.004

Adjusted $R^2 = 0.03$, $p = .004$

Similarly, percentage of FA was also significantly predicted by the temporal principal component ($R = -.17$, adjusted-$R^2 = 0.03$, $F(1,269) = 8.23$, $p = .004$). Regression coefficients are shown in Table 3.

Table 3: Temporal Principal Component as a predictor of Focused Attention.

	B	*SE(B)*	*t*	*p*
(Intercept)	68.81	1.58	43.55	$< .000$
PART TC2 (temporal)	-4.54	1.58	-2.87	.004

Adjusted $R^2 = 0.03$, $p = .004$

Task Interest, Decision Making Style, and MW

In order to investigate the relationship between task interest, decision making style, and MW, we observed correlations between the variables. In line with previous findings (Unsworth & Mcmillan, 2012), task interest was positively correlated with FA ($r = 0.18$) and negatively correlated with TUT ($r = -0.24$). Interestingly, and novel to this research, we found that maximizing was positively related to TRI ($r = 0.12$) and negatively correlated to FA ($r = -0.12$). 2).

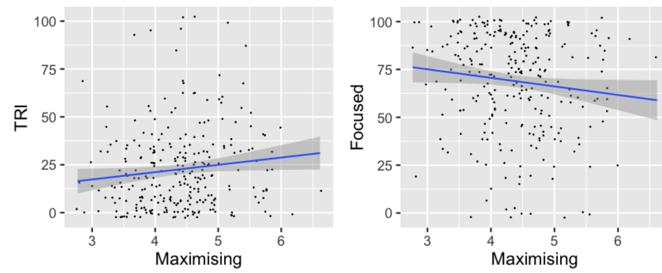

Figure 2: Relationship between TRI and Maximizing ($r = 0.12$) and FA and Maximizing ($r = -0.12$)

Discussion

In accordance with previous literature (Unsworth & Mcmillan, 2012), we found that MW is negatively correlated with task interest. Interestingly, we found a *maximizing* decision-making style to be be positively related to TRI and negatively related to FA. Novel to our research, we discovered that TRI percentage is related to more *maximizing*, while FA percentage is related to more *satisficing*. That is, the need to select the best possible option is reflected in the amount of TRI in a task, while satisfaction with selecting the good enough alternative is more related to FA during a task. This relationship has important implications, as it may be that a *maximizing* trait could potentially influence, through rumination, a tendency for having task-related interference, leading to poorer performance in tasks. Although this relationship was not directly tested in this study, future research could investigate the relationship between *maximizing*, rumination, and task-related interference further.

Moreover, we found a negative correlation between performance on non-semantic items in the Paired Recall task and TRI; however, we found no effect of any of the other memory tests on the proportion of TUT or TRI. This may be explained by two reasons. First, it may be that the tests were too easy, as reflected by the particularly high scores on the recognition tests. Second, it is likely that the scores on the episodic and associative memory tests do not accurately represent the aspects of episodic memory that are related to MW, i.e., aspects that are most likely contextually dependent and vary from individual to individual. Finally, if we observe the distribution of MW scores, over half of the participants never reported having TUT during the working memory task. This indicates that the OSPAN task was too engaging and demanding, leaving little room for TUT.

According to the *default variability hypothesis* (Mills et al., 2018), mind wandering serves the purpose of (episodic) memory consolidation. The results found by Riby et al. (2008) demonstrate that performance on episodic memory tests is unaffected by the proportion of mind wandering. However, low mind wanderers used a pure recollection strategy while high mind wanderers used additional monitoring strategies. Thus, it may be that mind wandering about the items in the episodic memory task helped consolidate memories of high mind wanderers during the task. However, something that neither Riby et al. (2008) nor our study did was assess the content of MW thoughts during the task. In order for us to verify the *default variability hypothesis* in the short term, as measured by episodic memory tests, it is also necessary that we consider the contents of mind wandering thoughts. For instance, MW about the items in the episodic memory task versus MW about something completely unrelated would likely have differential effects on memory consolidation.

Despite the ceiling effects we found in the recognition tests, we did find that mouse movements recorded during both episodic and associative forced choice recognition tests are related (albeit weakly) to MW in a subsequent working memory task. Therefore, it may be that a greater proportion of MW during a task is related to a general tendency to mind wander and, thereby, be detectable in specific overall motor behaviors beyond the task during which a person is mind wandering. In this study, mouse movements during episodic and associative memory tasks served to predict task-related interference (albeit weakly) and focused attention during a subsequent task. The most important feature in predicting task-related interference and focused attention was a temporal principal component, which contains information about the evolution of trajectories over time. This is consistent with the highly significant correlations that emerged between TRI and the various time-related mouse measures (*RT, idle time, time to reach maximum deviation, time to reach maximum velocity, etc.*) Such features characterize the degree of commitment towards a response during mind wandering, such that negative correlations (with FA) represent quicker and more automatic decisions, while positive correlations (with TRI) represent a delay in the commitment towards a response.

Returning to Riby et al. (2008)'s findings, high mind wanderers differed from low mind wanderers in their use of additional monitoring and strategic processing to compensate for mind wandering. Linking their findings to ours, it may be that monitoring and strategic processing are indicated differently by general mouse movement features according to the type of MW thought. Our findings indicate that some mouse movement features correlated with TUT in one task, and other mouse movements correlated with and predicted TRI and FA in another task. This may be explained by the differences in the two tasks (WRT & PART). The WRT only had 2 alternatives, while the PART had 4 alternatives. Moreover, the tests recruited different parts of memory differentially - the WRT only involved recognition of previously seen words during the WLLT, while the PART required the recruitment of associative memory[8] for remembering associations between words.

Finally, in order to better understand how MW may be related to decision making as well as performance on episodic memory tasks and overall motor behaviors, it would be relevant to assess trait differences in MW in addition to state differences. Moreover, it would be interesting to see if the relationship between trait MW and motor movements generalize to different types of computer mouse-based tasks.

Conclusion

The relationship between episodic memory and MW is a complex one, and it is likely that the episodic and associative memory tests which we used were unable to capture this relationship fully. This may be either due to the tests demands being too low and hence not able to capture individual differences in terms of accuracy, or because the tests did not capture the aspects of episodic memory that vary according to the context and to the individual. Interestingly though, we have found evidence for a relationship between specific computer mouse movements and MW, which warrant further investigation. In particular, future research should see if our findings generalize to unseen data. Lastly, we have found a novel relationship between MW and *maximizing*, in that *maximizing* was related to an increased frequency of TRI and less FA. Our aim in this study was to explore an encompassing model of mind wandering starting from its inputs, determined by what enters into episodic memory and ending with behavioral outputs, which are visible in mouse movement patterns. We believe we have taken a small step for a better understanding of how our minds wander and navigate this world.

[8] In addition, the PART requires inhibition of previously learned semantic associations learned in different contexts.

Supplementary Information

Experiment Materials All materials used in the task are available at https://osf.io/dse3k/

References

Andrews-Hanna, J. R., Reidler, J. S., Huang, C., & Buckner, R. L. (2010). Evidence for the Default Network's Role in Spontaneous Cognition. *J Neuro-physiol*, *104*, 322–335. doi: 10.1152/jn.00830.2009

Arapakis, I., Lalmas, M., & Valkanas, G. (2014). Understanding Within-Content Engagement through Pattern Analysis of Mouse Gestures. In *Cikm.* Shanghai, China.. doi: 10.1145/2661829.2661909

Barsalou, L. W. (2008, 1). Grounded Cognition. *Annual Review of Psychology*, *59*(1), 617–645. doi: 10.1146/annurev.psych.59.103006.093639

Beach, L. R. (1993, 7). Broadening the Definition of Decision Making: The Role of Prechoice Screening of Options. *Psychological Science*, *4*(4), 215–220. doi: 10.1111/j.1467-9280.1993.tb00264.x

Conway, A. R., Cowan, N., Bunting, M. F., Therriault, D. J., & Minkoff, S. R. (2002, 3). A latent variable analysis of working memory capacity, short-term memory capacity, processing speed, and general fluid intelligence. *Intelligence*, *30*(2), 163–183. doi: 10.1016/S0160-2896(01)00096-4

De Deyne, S., & Storms, G. (2008). Word associations: Norms for 1,424 Dutch words in a continuous task. *Behavior Research Methods*, *40*(1), 198–205. doi: 10.3758/BRM.40.1.198

Dias da Silva, M. R., & Postma-Nilsenová, M. (2019). *Mindering Mice, Wandering Minds: Using computer mouse tracking to predict mind wandering.*

Dias da Silva, M. R., Rusz, D., & Postma-Nilsenová, M. (2018, 11). Ruminative minds, wandering minds: Effects of rumination and mind wandering on lexical associations, pitch imitation and eye behaviour. *PLOS ONE*, *13*(11). doi: 10.1371/journal.pone.0207578

Ellamil, M., Dobson, C., Beeman, M., & Christoff, K. (2012, 1). Evaluative and generative modes of thought during the creative process. *NeuroImage*, *59*(2), 1783–1794. doi: 10.1016/j.neuroimage.2011.08.008

Franklin, M. S., Smallwood, J., & Schooler, J. W. (2011, 10). Catching the mind in flight: Using behavioral indices to detect mindless reading in real time. *Psychonomic Bulletin & Review*, *18*(5), 992–997. doi: 10.3758/s13423-011-0109-6

Kam, J. W. Y., Dao, E., Blinn, P., Krigolson, O. E., Boyd, L. A., & Handy, T. C. (2012). Mind wandering and motor control: off-task thinking disrupts the online adjustment of behavior. *Frontiers in Human Neuroscience*, *6*, 329. doi: 10.3389/fnhum.2012.00329

Keuleers, E., Brysbaert, M., & New, B. (2010, 8). SUBTLEX-NL: A new measure for Dutch word frequency based on film subtitles. *Behavior Research Methods*, *42*(3), 643–650. doi: 10.3758/BRM.42.3.643

Kieslich, P. J., & Henninger, F. (2017, 10). Mousetrap: An integrated, open-source mouse-tracking package. *Behavior Research Methods*, *49*(5), 1652–1667. doi: 10.3758/s13428-017-0900-z

Klinger, E. (2013). Goal commitments and the content of thoughts and dreams: Basic principles. *Frontiers in Psychology*, *4*(JUL), 1–17. doi: 10.3389/fpsyg.2013.00415

Mandera, P., Keuleers, E., & Brysbaert, M. (2017). Explaining human performance in psycholinguistic tasks with models of semantic similarity based on prediction and counting: A review and empirical validation. *Journal of Memory and Language*, *92*, 57–78. doi: 10.1016/j.jml.2016.04.001

Mathôt, S., Schreij, D., & Theeuwes, J. (2012, 6). OpenSesame: An open-source, graphical experiment builder for the social sciences. *Behavior Research Methods*, *44*(2), 314–324. doi: 10.3758/s13428-011-0168-7

Mills, C., Herrera-Bennett, A., Faber, M., & Christoff, K. (2018). Why the mind wanders: How spontaneous thought's default variability may support episodic efficiency and semantic optimization. In Kieran C.R. Fox & Kalina Christoff (Eds.), *The oxford handbook of spontaneous thought: Mind-wandering, creativity, and dreaming.* Oxford University Press.

Mittner, M., Hawkins, G. E., Boekel, W., & Forstmann, B. U. (2016, 8). A Neural Model of Mind Wandering. *Trends in cognitive sciences*, *20*(8), 570–8. doi: 10.1016/j.tics.2016.06.004

Mrazek, M. D., Smallwood, J., Franklin, M. S., Chin, J. M., Baird, B., & Schooler, J. W. (2012). The role of mind-wandering in measurements of general aptitude. *Journal of Experimental Psychology: General*, *141*(4), 788–798. doi: 10.1037/a0027968

Paivandy, S., Bullock, E. E., Reardon, R. C., & Kelly, F. D. (2008, 11). The Effects of Decision-Making Style and Cognitive Thought Patterns on Negative Career Thoughts. *Journal of Career Assessment*, *16*(4), 474–488. doi: 10.1177/1069072708318904

R Core Team. (n.d.). *R: A Language and Environment for Statistical Computing.* Vienna, Austria: R Foundation for Statistical Computing.

Riby, L. M., Smallwood, J., & Gunn, V. P. (2008, 6). Mind Wandering and Retrieval from Episodic Memory: A Pilot Event-Related Potential Study. *Psychological Reports*, *102*(3), 805–818. doi: 10.2466/pr0.102.3.805-818

Schwartz, B., Ward, A., Monterosso, J., Lyubomirsky, S., White, K., & Lehman, D. R. (2002). Maximizing Versus Satisficing: Happiness Is a Matter of Choice. *Journal of Personality and Social Psychology*, *83*(5), 1178–1197. doi: 10.1037/0022-3514.83.5.1178

Seli, P., Kane, M. J., Smallwood, J., Schacter, D. L., Maillet, D., Schooler, J. W., & Smilek, D. (2018, 6). Mind-Wandering as a Natural Kind: A Family-Resemblances View. *Trends in cognitive sciences*, *22*(6), 479–490. doi: 10.1016/j.tics.2018.03.010

Smallwood, J., & Andrews-Hanna, J. (2013). Not all minds that wander are lost: The importance of a balanced perspective on the mind-wandering state. *Frontiers in Psychology*, *4*(AUG), 1–6. doi: 10.3389/fpsyg.2013.00441

Smallwood, J., & Schooler, J. W. (2015). The Science of Mind Wandering: Empirically Navigating the Stream of Consciousness. *Annual Review of Psychology*, *66*(1), 487–518. doi: 10.1146/annurev-psych-010814-015331

Spaan, P. E. (2016). Episodic and semantic memory impairments in (very) early Alzheimers disease: The diagnostic accuracy of paired-associate learning formats. *Cogent Psychology*, *3*(1), 1–25. doi: 10.1080/23311908.2015.1125076

Spivey, M. J., & Dale, R. (2006). Continuous Dynamics in Real-Time Cognition. *Association for Psychological Science*, *15*(5), 207–211. doi: 10.1111/j.1467-8721.2006.00437.x

Stawarczyk, D., Majerus, S., & D'Argembeau, A. (2013). Concern-induced negative affect is associated with the occurrence and content of mind-wandering. *Consciousness and Cognition*, *22*(2), 442–448. doi: 10.1016/j.concog.2013.01.012

Unsworth, N., & Mcmillan, B. D. (2012). Mind Wandering and Reading Comprehension: Examining the Roles of Working Memory Capacity, Interest, Motivation, and Topic Experience. *Journal of Experimental Psychology: © 2012 American Psychological Association Learning, Memory, and Cognition*, *39*(3), 832–842. doi: 10.1037/a0029669

Van Yperen, N. W. (2003). Task Interest and Actual Performance: The Moderating Effects of Assigned and Adopted Purpose Goals. *J Pers Soc Psychol.*, *85*(6), 1006–15. doi: 10.1037/0022-3514.85.6.1006

Walker, H. E., & Trick, L. M. (2018, 11). Mind-wandering while driving: The impact of fatigue, task length, and sustained attention abilities. *Transportation Research Part F: Traffic Psychology and Behaviour*, *59*, 81–97. doi: 10.1016/J.TRF.2018.08.009