Wandering Mice, Wandering Minds: Using Computer Mouse Tracking to Predict Mind Wandering

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Abstract. Mind wandering is a state in which an individual's attention is not fully focused on the task at hand. Mind wandering affects performance in many tasks requiring focused attention, including (online) learning. Previous studies have examined eye tracking and self-report as a method to assess whether a person is mind wandering. Because the first method requires specialized technology and the second method may be susceptible to reporting biases, we here examine whether mouse tracking can be used to predict mind wandering in tasks involving classical computer interfaces. Assuming 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 could provide unique insight into a person's thoughts. In our experiment, a total of 183 students completed a mouse-based operation span task, during which their thoughts were probed and their mouse movements recorded. Mixed model analysis of the recordings indicated that speed errors, time to press start, initiation time, total distance, and average speed can be used as predictors of task-unrelated thoughts. The results show that mouse movements may be able to provide an objective measure of mind wandering in online tasks.

Keywords: Mouse tracking · mind wandering · working memory · arousal.

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1 Introduction

A unique part of the human existence involves the mind's ability to wander, i.e., to shift attention from the present task to internal thoughts. Studies indicate that people's minds wander between 30 to 50% of their waking moments [24, 49]. Although important for creating an integrated sense of identity [46] and fostering creativity [1], mind wandering (MW) is detrimental to performance on a wide variety of tasks, particularly tasks that require sustained attention and working memory [36, 39]. The negative association between MW and performance on these tasks warrants the need to develop technologies that are able to detect a wandering mind and return it to the task at hand [10]. In order to reduce the negative effects of MW, it is important to be able to identify when individuals are mind wandering. The challenge in studying MW, however, stems from the fact that it cannot easily be induced in laboratory settings. Moreover, its detection relies on self-reports, by means of experience sampling methods such as thought probes and retrospective measures, which are inherently subjective [49]. Compared to thought probes, retrospective measures are useful in that they do not interrupt the natural flow of the task. However, retrospective measures are only able to make general estimations about the total frequency of MW on a task, while thought probes are better at pinpointing specific instances of MW within a task. Past studies show that to a certain degree, both are subject to incorrect estimations from participants [42, 48]. Because of this, additional behavioral measures such as reaction times [28], reading speed [32], fidgeting [5, 43], and physiological responses such as brain activity and eye movements [10, 12, 33, 47], have been explored to distinguish periods of focus from periods of MW. These approaches, however, interfere with the natural performance on a primary task [17] in that they require additional measuring instruments, which introduce a certain level of discomfort for the participant. In this paper, we examined mouse movement behavior as a method that could be used to predict the occurrence of MW unobtrusively.

1.1 Mouse movements as a behavioral measure of mind wandering

It has been shown that in relation to various related domains, including decision making, attention, and learning [13, 17, 37], computer mouse tracking effectively traces the evolution of internal cognitive processes through action execution. As a natural and practiced visuo-motor response, various populations, from young children [18] to older adults [41] can easily perform mouse-based tasks. More importantly, mouse movements can map covert cognitive processes on a Cartesian coordinate space, making experimental manipulations straightforward and interpretations intuitively understandable [50]. Alternative choices can be represented in front of a participant, and the evolution of reach trajectories towards a target can be visualized as a representation of how competing cognitive states are resolved over time. Finally, measuring reach movements is affordable and widely accessible, and can be effectively run as a background processes during mouse-based tasks.

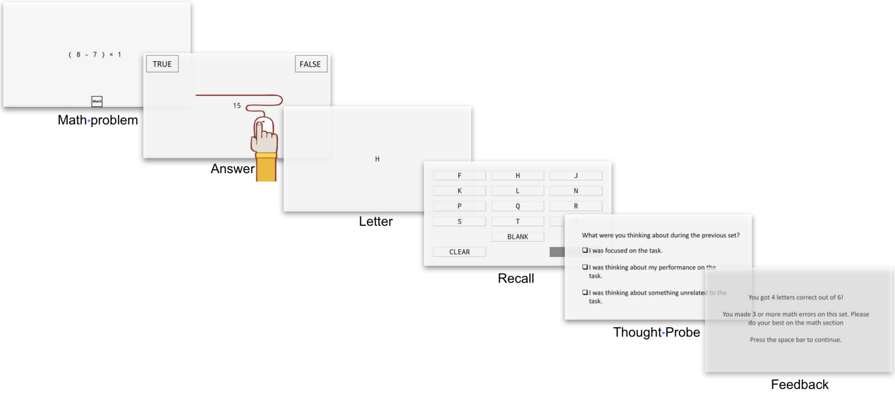
Can mouse movements predict the occurrence of MW? Interestingly, mouse movements have been associated with decreased fine motor control and increases in neuromotor noise during high arousal [16] and with automatism during low arousal [35]. Research on MW indicates that periods of off-task thought are associated with changes in arousal [55]. This can be explained by the tight link between attention and arousal, in that high or low levels of arousal are related to lower attentional control, more lapses in attention, and thus a greater susceptibility to MW, while moderate levels of arousal are associated with optimal task engagement and task performance [6, 22, 25, 34, 58]. Therefore, we could expect that MW episodes would be associated with changes in motor behavior necessary to move the computer mouse.

Two models address how arousal influences mouse movements: the stochastic optimized submovement (SOS) model and the response activation model. According to the SOS model [30, 31] mouse movements towards a target are described as having two parts an initial high-velocity phase, which although fast, tends to be imprecise, and a subsequent deceleration phase, which is corrective in nature, where speed decreases, but accuracy increases [15, 17]. As a target is approached, a tradeoff in speed is necessary to increase precision of movement, as there is limited information capacity for motor control [11, 45]. The mind attempts to minimize the total movement by optimizing the velocity and number of submovements towards the target, however, as neuromotor noise (i.e., from high arousal) is introduced into the model, there is less resources available for the intended corrective movements, leading to slower and less precise movements [30, 31, 4]. As individuals must choose between multiple response options, the cognitive effort necessary to evaluate the available choices leads to disruptions of fine motor control [20]. As more choices are presented, there is more information to process, leading to slower response times, which is due either to a search process towards the correct response or to uncertainty in selecting an appropriate response.

Complementary to the SOS model, the response activation model describes motor movements as representing an aggregation of all potential movements that could arise from all potentially actionable cognitions [56]. When competing cognitions are introduced, motor movements become less precise and response times are slower, as necessary cognitive resources are consumed. In line with both the SOS and the response activation model, increases in arousal, and consequently, the higher number of cognitions that arise from MW, increases the amount of noise and uncertainty during a task, leading to less precise, more complex and slower mouse movements [19, 57]. This falls in line with research indicating that increased levels of arousal are related to individual differences in MW [55], which in turn is also associated increased reaction times [26] as well as variability in reaction times [2, 29, 44] in tasks of sustained attention, suggesting an inconsistency in attention control during periods of MW.

1.2 Current Study

The primary goal of our research is to explore if MW during a complex cognitive task (a working memory test, i.e., an operation span task) can be detected from mouse movements. Due to their ability to capture cognitive processes in real time, computer mouse movements may actually provide valuable insight into the temporal cognitive dynamics underlying MW. During the task (Figure 1), participants need to shift between an unrelated processing task while updating contents of working memory [8, 9, 52, 54]. In particular, the evolution of mouse trajectories can be traced during the operation span task in order to predict incidences of MW. Consolidating previous research on MW and arousal, as well as mouse movements and arousal, we will explore whether various mouse movement features can be indicators of MW, namely, time-related, movement-related, and position-related variables.



What were you thinking about during the previous set?

☐ I was focused on the task.

☐ I was thinking about my performance on the task.

☐ I was thinking about something unrelated to the task.

You got 4 letters correct out of 6!

You made 3 or more math errors on this set. Please do your best on the math section

Press the space bar to continue.

Fig. 1. Operation Span Task

2 Methods

2.1 Participants and Procedure

In total, 183 participants between 17 and 37 years of age (M= 22.13), 59 male, performed an operation span task and received credit for their participation. The study was approved by the Tilburg University Institutional Ethics Committee, and informed consent was obtained from each participant at the beginning of the experimental session. After signing the consent form, participants filled out a questionnaire assessing their demographics and completed the Operation Span Task, which took on average 20 minutes to be completed. Standard procedure was followed for the Operation Span (OSPAN) task (see Fig. 1, [7]).

2.2 Material

The task required participants to maintain access to memory items (letters) while completing an unrelated processing task (math equations) with an individualized response deadline (M + 2.5 SDs), calculated during 15 processing-task-only items [53]. This allowed each one to set their own pace and ensured that they did not rehearse the to-be-recalled letters by limiting the amount of time they have to solve the math operations. Participants viewed a compound math equation on the computer screen, and once they had solved it, they had to click on the start button. If participants took longer than their average time to click on the start button, the trial was marked as an error. On the center of the next screen, they saw a number, as well as a True and False box on the top left corner and top right corner of the screen, respectively. If the number they saw corresponded to the correct answer to the math equation, participants were instructed to click on the True button, and if not, on the False button. A capital letter appeared for 1000 ms after the math operation. After 3-7 compound equations-letter pairs, all 12 letters appeared on the screen and subjects were required to identify (by clicking) on the letters that were presented in the trial in serial order. Each set length (3-7) was presented 3 times, randomly ordered for each subject, for a total of 75 trials (15 sets). MW was assessed by thought probes embedded throughout the task after each set [36] In order to prevent participants from devoting all their processing time to remembering the letters, they had to achieve an accuracy of at least 80% of the math operations. Task. The program calculated the sum of all correctly recalled set sizes (OSPAN score), the total number of letters recalled in the correct position, and the total number of math errors [53]. At the end of the task, participants received feedback concerning their performance.

2.3 Instrumentation

The Operation Span Task was programmed on Opensesame, [27], version 3.1.6, using a modified version of the script provided by Eoin Travers. The experiment was run in full screen mode on a P2210 Dell monitor, 22 inch (55.88cm), with a resolution of 1366 by 768 pixels on a Windows 7 operating system. The desktop computer was placed on a table so that enough space was available to move the mouse around without hitting the keyboard or the edge of the table. Mouse settings were left at their default values (acceleration on and medium speed). A Dell USB 3 Button Scrollwheel Optical Mouse was used to record cursor coordinates for the math verification portion of the experiment. There was enough space available for participants to move the mouse without hitting the keyboard or the edge of the table.

Mouse movements were recorded during the math verification part of the task towards one of two alternatives (True or False). Upon clicking on the start button, mouse movements began to be recorded, and participants were not informed of this. The dimensions of the True and False buttons were of 279 by 157 pixels, and dimensions of the start button were of 80 x 80 pixels. Cursor coordinates were recorded every 30 ms.

In the instructions, participants were informed that after each set, they would be asked a question about their thoughts during the previous set. They were also informed that it is normal for people's minds to wander off task or to thoughts about their performance on the task. After each set, participants were asked, What were you thinking about during the previous task?, and had to choose from 3 alternatives, namely, 1) I was focused on the task, 2) I was focused on my performance on the task, and 3) I was thinking about something unrelated to the task. Alternative 1 denoted all instances in which participants were focused on the task; alternative 2 denoted all instances in which participants experienced task-related interferences; and alternative 3 denoted all instances in which participants experienced task-unrelated thoughts [51].

2.4 Data Processing

Individual raw data files were merged and read into R version 3.4.1 [38]. Of the total number of participants, 3 participants did not achieve the 80% accuracy criterion on the math portion of the operation span task and were excluded from the analysis. Trials in which participants took longer than their average time to click on the start button were also excluded from analyses (305 trials). Mouse tracking data were then imported and processed using the library mousetrap [23] on R. Trajectories were measured from the moment the start button was pressed to the moment either the True or False response were clicked on. All trajectories aligned to a common starting position and were remapped onto one side, and various measures were computed for each trajectory. Before plotting aggregate trajectories, all trajectories were time-normalized to 101 equidistant time slices.

2.5 Results

Participants spent 68.3% of their time focused on the task, 22.7% having task-related interferences, and 9% of their time having task-unrelated thoughts. As task-related interferences represent an ambiguous category in between focus and task-unrelated thoughts, they were not analyzed further [28], leaving a total of 10,185 trials. Moreover, as thought probes retrospectively assessed a person's thoughts after each set, mouse movement features were aggregated per set for statistical analyses, yielding 15 observations per participant, for a total of 2093 sets. A first visual impression of the effect of MW on mouse movements is demonstrated by aggregate mouse trajectories (Fig. 2 and Fig. 3).

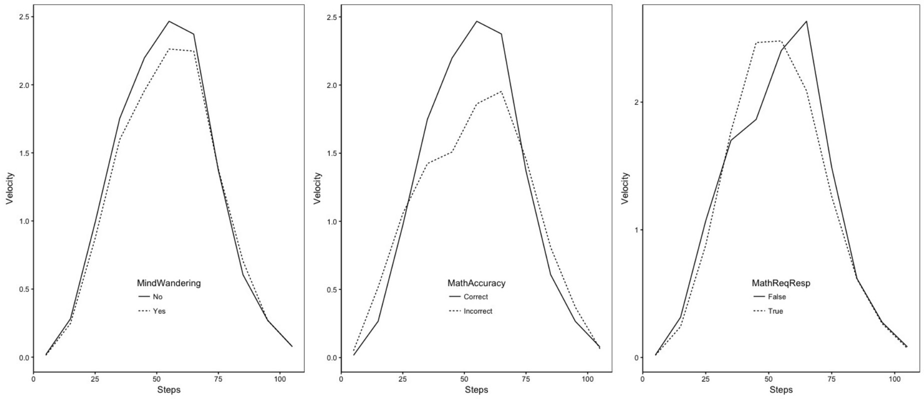


Fig. 2. Aggregate time-normalized mouse trajectories for task-unrelated thoughts (N=1207 versus focus, N=8978), math accuracy (correct, N=9749 or incorrect, N=436), and math condition (True, N=5156, or False, N=5029).

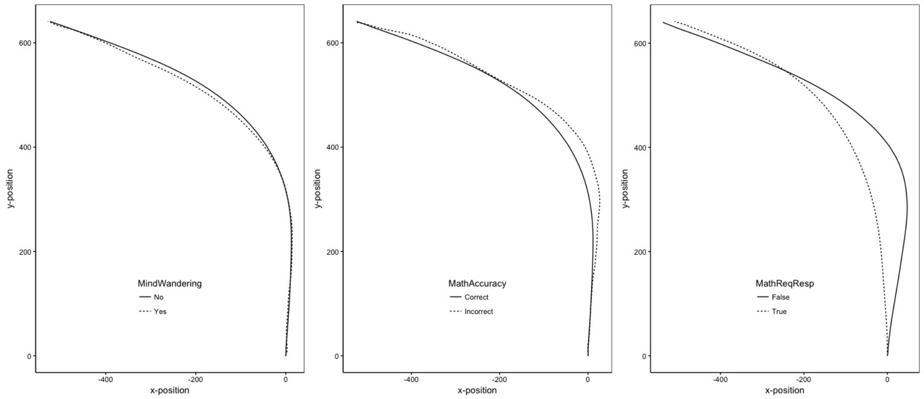


Fig. 3. Aggregate time-normalized velocities per binned time-steps for task-unrelated thoughts (versus focus), math accuracy (correct or incorrect), and math condition (True or False).

To examine the relationship between mouse movements and task-unrelated thoughts, we employed a mixed effects logistic regression and evaluated how well trajectory features could predict MW. We used the lme4 package [3] in R to perform the analysis. First, all mouse trajectory features were z-normalized, so that the mean and standard deviation of each variable were 0 and 1 respectively. As fixed effects, we entered time to press the start button, initiation time, total distance, average speed, and speed errors per set. As random effects, we included intercepts for subjects. The effect of the mouse tracking variables was tested by comparing models with and without the factors by means of a likelihood-ratio test. When the model fit of the full model was significantly better than that of the nested model according to the chi-square statistic, the mouse-tracking features were judged to contribute to the prediction in a significant way. A full model with mouse tracking variables performed significantly better than a model with only random effects, $\chi^2 = 96.46$, df = 5, $p < 0.001$ (Tab. 1).

Table 1. Coefficient estimates (β), standard errors SE(β), odds-ratios (Exp(β)), associated Wald's z-scores, degrees of freedom, chi-square statistics and associated significance levels for all predictors in the analysis.

Fixed effects:								
	β	SE(β)	Exp(β)(95% CI)	z-score	pz	df	χ^2	$p\chi^2$
(Intercept)	-3.19	0.23	0.04(0.02-0.06)	-13.76	<0.001			
Time to press start	0.25	0.11	1.28(1.02-1.63)	2.09	0.04	1	4.54	0.03
Initiation time	0.24	0.12	1.28(1.00-1.61)	2.04	0.04	1	4.05	<0.04
Total distance	0.27	0.11	1.30(1.05-1.62)	2.40	0.02	1	5.63	0.02
Average speed	-0.41	0.12	0.66(0.52-0.84)	-3.36	<0.001	1	11.57	<0.001
Speed Errors	0.53	0.07	1.71(1.49-1.96)	7.64	<0.001	1	59.70	<0.001
Random effects:								
	Variance	*SD*						
Participant	3.86	1.97						

The coefficients for time to press start (β = 0.25, SE(β) = 0.11, p = 0.04), initiation time (β = 0.24, SE(β) = 0.12, p = 0.04), total distance (β = 0.27, SE(β) = 0.11, p = 0.02), average speed (β = -0.41, SE(β) = 0.12, $p < 0.001$), and speed errors per set (β = 0.53, SE(β) = 0.07, $p < 0.001$) were significant, indicating that task-unrelated thoughts are more likely to occur when participants take longer to press the start button, take a longer time to begin moving the mouse towards the response, travel a greater total distance with the cursor, have slower cursor movements, and make more speed errors.

3 Discussion

This study provides initial evidence that mouse tracking can be used to predict MW. Specifically, longer initiation times reflect a delay in the decision making process, which may be indicative of a decoupling of attention which occurs during task-unrelated MW. Moreover, greater total distance and slower speeds during periods of task-unrelated MW may be indicative of increased neuromotor noise as a result of increased arousal [16]. Such increases in neuromotor noise lead to an increase in complexity of trajectories [17], which may reflect increased uncertainty triggered by internal fluctuations in attentiveness (i.e. MW) and may initiate the involvement of prefrontal cognitive control mechanisms to help disambiguate sensory information and determine the correct response [14].

It is important to note that the amount of time participants spent having task-unrelated thoughts was very low (9%), leading to a large class imbalance. Although this would be expected considering the demanding nature of the task and the pressure to perform well above the 80% accuracy rate on the math verification, this percentage falls below other studies that also investigate MW under demanding tasks, which report a proportion between 15-30% of task-unrelated thoughts (e.g. [21, 40]). Paradoxically, in order to obtain a reliable objective measure of MW through mouse tracking, we still rely on thought probes, which are prone to being subjective and inherently cannot capture moment by moment fluctuations in attention. As such, we cannot pinpoint the exact moment in time in which participants were having task-unrelated thoughts within each set. Therefore, we can only generalize about the overall effect of MW on mouse movement behavior. It may be that future studies can identify a greater leak into action execution caused by task-unrelated thoughts by narrowing down the actual trials during which participants were MW by including random probes throughout the task, which ask participants what they were thinking about immediately before the probe rather than retrospectively for an entire set. However, this may require using a different task, since random probes would disrupt the measure of working memory capacity during the operation span task. An alternative solution would be to instead of using a categorical response variable for MW, to instead use a continuous response variable, in order to capture the more graded aspects of the phenomenon.

4 Conclusion

This study examined whether mouse movements can predict mind wandering during a complex span task. The results show that mouse movement response dynamics can predict mind wandering, and more specifically, task-unrelated thoughts. Understanding how mind wandering can leak into action execution may help us better understand the complexity of self-generated cognition. Taken together, mouse movement features are promising behavioral measures of mind wandering, however, further investigation of mind wandering and mouse movements is warranted for different types of tasks.

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