

Pre-trial Gaze Stability Predicts Momentary Slips of Attention

Pre-trial Gaze Stability and Task focus

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Our ability to maintain focus on a task waxes and wanes. Recent research suggests that eye-tracking may be a useful tool to capture the momentary slips of attention. In this paper, we show that pre-trial gaze stability predicted momentary slips of attention on the upcoming trial. In two visual search tasks, we asked participants to stabilize their gaze on a fixation cross before the search array appeared. We recorded participants' manual responses and eye movements as they searched for the target. We also occasionally presented thought probes to examine whether participants were mind-wandering on a subset of trials. Results from the two tasks revealed a converging pattern: lower pre-trial gaze stability predicted worse performance in the upcoming trial. Specifically, participants had longer response times, were more influenced by distractors, and inspected the target for a longer duration. Participants also reported greater mind-wandering at the end of the trial if they had low pre-trial gaze stability. Overall, these findings suggest that pre-trial gaze stability is a simple and objective measure that can predict moments of inattention, which may be used to proactively curb its negative effects before the actual task starts.

CCS CONCEPTS • Human-centered computing • Human computer interaction (HCI) • HCI design and evaluation methods

Additional Keywords and Phrases: Eye-tracking, attention, mind-wandering, visual search

1 INTRODUCTION

It is notoriously difficult to sustain attention for a long period of time. In a typical cognitive task, participants are repeatedly exposed to a similar set of trials, and each time they must respond based on a certain task goal (e.g., find the target). Situations like this are conducive to mind-wandering, an attentional state in which one engages in thoughts unrelated to the current task [1]. Studies such as [2], [3] have reported that mind-wandering is ubiquitous in both laboratory and real-life settings and is often associated with compromised task performance.

Mind-wandering is traditionally measured via thought-sampling techniques. That is, participants are occasionally presented with a thought probe asking about their current thoughts and focus [4]. The method has been used extensively in the literature, but some noteworthy drawbacks including the reliance on self-reports and being too obtrusive to the primary task [5], [6]. These drawbacks have prompted calls for new measures of mind-wandering beyond self-reports [7].

Recently, eye-tracking has begun to gain traction as an alternative measure of one's attentional state. Compared to thought-sampling, eye-tracking is objective, unobtrusive, and provides a continuous measurement. Studies have found that episodes of self-reported mind-wandering are correlated with changes in certain eye-tracking parameters, such as reduced fixation count and increased fixation durations [8], [9]. There is also some limited but encouraging success in using machine learning algorithms to predict mind-wandering based on eye-tracking measures [10], [11]. However, the findings from this work are not entirely consistent across studies [12]–[14]. Moreover, the measured eye movement patterns were obtained while participants completed the actual task (i.e., viewing a picture or reading a sentence). If mind-wandering can be detected before the start of the task, we may have the opportunity to proactively mitigate its negative consequences to the primary task.

In this paper, we show that pre-trial gaze stability could signal momentary slips of attention in the upcoming trial in two visual search tasks. When participants were asked to fixate on a cross before the start of a trial, having unstable gaze positions predicted worse performance and greater mind-wandering in the upcoming trial. Previous research has shown that mind-wandering is associated with motor restlessness (e.g., fidgeting) and poor inhibition of behavior [15]–[16]. Here we sought to extend those findings to oculomotor control. The idea that gaze stability could signal mind-wandering also receives theoretical support. In particular, the attentional resources account proposes that during mind-wandering, few attentional resources will be directed to support the primary task [17]. To the extent that stabilizing the gaze also requires attentional resources, participants would be less able to do it during mind-wandering.

2 METHODS

2.1 Participants

Thirty-two undergraduate students from the authors' institution participated in Study 1 for course credits. Data from 7 participants were excluded¹. The final sample consisted of 25 participants (Mean Age = 19.12, SD Age = 1.11, 48% female). An independent sample of 49 undergraduate students from the author's institution participated in Study 2 for course credits. Data from 9 participants were excluded. The final sample consisted of 40 participants (Mean Age = 18.95, SD Age = 1.04, 60% female).

2.2 Apparatus and Tasks

Participants completed each task in a quiet room with dimmed lighting. The tasks were presented on a desktop computer with a 20.1-inch screen at a distance of approximately 80 centimeters from the participants. Monocular eye movements were recorded by an EyeLink 1000 System at a 500 Hz sampling rate. Head movements were controlled by tracking a sticker placed on the participants' forehead in Study 1 and by using a chin rest in Study 2.

Study 1's task was adapted from the additional singleton paradigm [18]. During the pre-trial interval, participants had to maintain their gaze within a 2° radius of a fixation cross (.86°*.86°) presented at the center of the screen for a total of 1000 ms to trigger the search array. The search array consisted of 10 unfilled shapes distributed equally on an imaginary circle with a radius of 9.15°. Items consisted of unfilled diamonds (1.71° diagonal) and circles (1.50° diameter), with the outline drawn in either red or green. Inside each item, there was a line segment (.63°*.11°) drawn in grey. The task was to identify the oddly shaped item and indicate whether the

¹ Study 1: (1) pre-existing medical conditions (n = 1), (2) incomplete data (n = 3), (3) technical errors during the experiment (n = 1), (4) or not following instructions (n = 2). Study 2: (1) pre-existing medical conditions (n = 3), and (2) incomplete data (n = 6).

line inside the item was vertical or horizontal. In half of the trials, one randomly selected non-target was drawn in a different color from the rest. Participants were told to ignore the distractor and respond as quickly and as accurately as possible. Participants first completed a practice block of 20 trials before 5 experimental blocks of 160 trials each. The eye-tracker was calibrated at the beginning of each block. Study 2's task was a variation of the additional singleton paradigm in which participants searched for a specific shape among heterogeneous items [19]. All aspects of the task were identical to Study 1 except for the following: Participants had to maintain their gaze within a 1.5° radius of a fixation cross ($.63^\circ \times .57^\circ$) for a total of 2000 ms to trigger the search array. The search array consisted of 6 filled shapes distributed equally on an imaginary circle with a radius of 4.5° . The target was always a diamond (1.13° diagonal) or a circle (0.9° diameter), counterbalanced across participants. Non-target items consisted of squares, hexagons, and the unselected target item (i.e., circle for the diamond group, diamond for the circle group). The line segment ($.19^\circ \times .05^\circ$) inside each item was drawn in black. Participants first completed a practice block of 80 trials, followed by 6 experimental blocks of 80 trials each.

2.3 Thought Probes

In Study 1, thought probes occurred after a haphazard 10% of the trials asking participants whether during the previous trial they were on-task (focusing on completing the task and not thinking about things unrelated to the task) or off-task (thinking about something completely unrelated to the task). In Study 2, thought probes also occurred after 10% of the trials asking participants whether during the previous trial they were on-task (focusing on completing the task and not thinking about things unrelated to the task), unintentionally mind-wandering (thinking about something completely unrelated to the task despite your best intention to stay on task), or intentionally mind-wandering (decided to think about things completely unrelated to the task) [20].

2.4 Data Preprocessing and Analysis

Fixations and saccades were detected using Eyelink's proprietary algorithm. Fixations and saccades with landing positions outside of the screen center ($> 4.5^\circ$ of visual angle in S1 and $> 2.5^\circ$ of visual angle in S2) were assigned to be on the target, the distractor, and other items based on the nearest item. Pre-trial gaze stability was defined as the root mean square of the Euclidean distance from each gaze sample's position to the average position of all gaze samples during the pre-trial interval. For each participant, we created deciles that divided each participant's gaze stability distribution into ten equal parts. We examined the following measures: (1) response times (correct trials only), (2) the number of fixations, (3) mean duration of fixations, (4) probability of capture (% of trials with the first saccade on the distractor; distractor-present trials only), (5) target looking time (the sum of fixations on the target), and (6) mind-wandering rate (the percentage of thought probes with a mind-wandering response, regardless of whether it was intentional or unintentional; probed trials only). Data analysis was performed in R using linear mixed models [18]. Random intercepts and slopes for each participant were included in all models.

3 RESULTS

Results of the two studies revealed a converging pattern (see Figure 1): Lower pre-trial gaze stability predicted worse performance and greater mind-wandering on the upcoming trial. Specifically, participants took longer time to respond, appeared to be more influenced by the distractor, and inspected the target for a longer duration. In Figure 1, the mind-wandering rate was the proportion of mind-wandering responses within each gaze stability decile. To further evaluate the prediction performance of gaze stability, we refitted a generalized logistic regression

model with mind-wandering as a binary outcome variable (whether participants indicated mind-wandering on a particular trial). We then set the cut-off value of .5 and obtained a confusion matrix of the model. For Study 1, we obtained a hit rate of 50.63%, a specificity of 82.7%, a precision of 62.87%, and a d' of .96. For Study 2, we obtained a hit rate of 52.58%, a specificity of 83.23%, a precision of 66.02%, and a d' of 1.03.

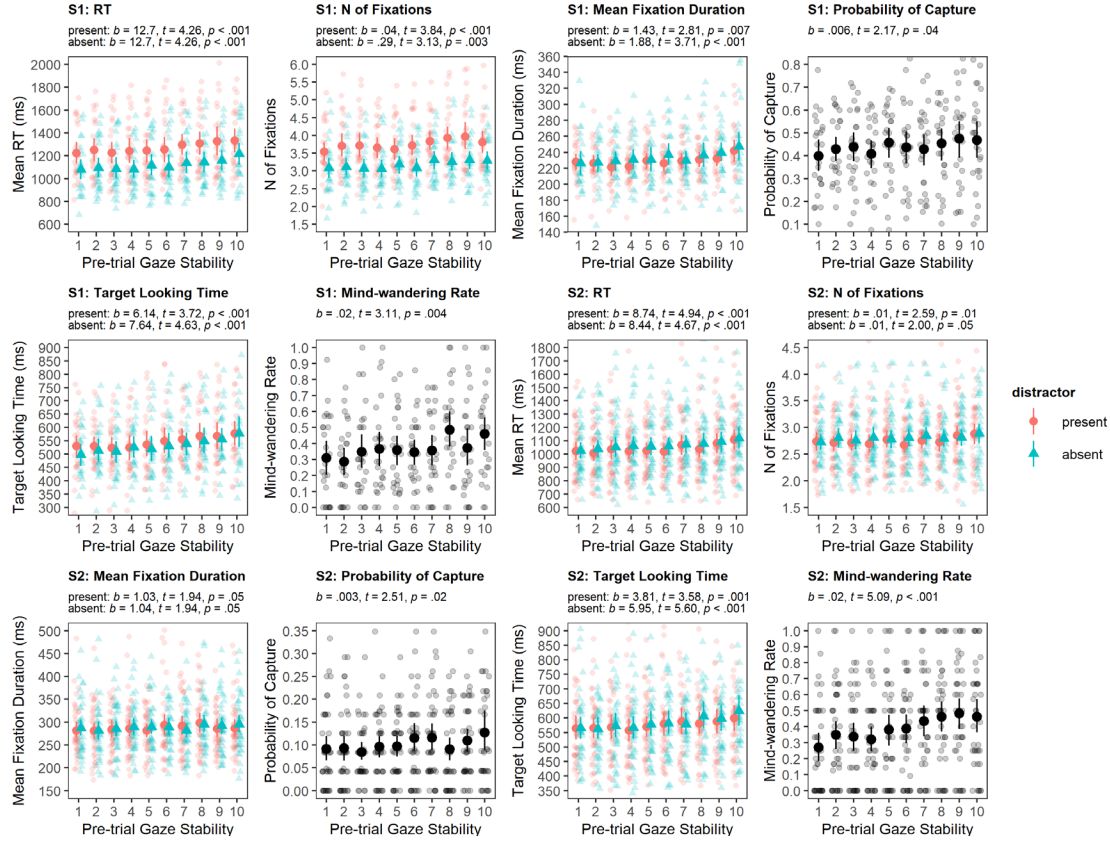


Figure 1. Pre-trial gaze stability deciles (1: the most stable, 10: the most unstable) predicting various measures of Study 1 and 2's visual search tasks. Error bars show 95% confidence intervals around the mean. Estimated linear trends are shown above each plot.

4 DISCUSSION

The results revealed that pre-trial gaze stability, as measured by the dispersion of pre-trial gaze locations, could signal participants' attentional state. Across two visual search tasks, lower pre-trial gaze stability consistently predicted worse performance on the upcoming trial and greater self-reported mind-wandering. The calculation of gaze stability is easy and can be integrated with many cognitive tasks. Also, because the measure is taken before rather than during the actual task, it allows us to proactively address the impact of inattention rather than reacting to it once it has caused damage to the task. Note that there are still miles to run before we can detect inattention in real-time. For one thing, it is unclear whether linear mixed model is the optimal algorithm to deploy in a wearable device for real-time detection. We also do not yet know whether the results are robust to new data. But we do hope that the current study will pique interest for more thorough investigations on this topic in the near future.

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