Employing a Wearable Eye-tracker to Observe Mind-wandering in Dynamic Stimuli

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***Abstract*— As a natural brain process, mind-wandering happens spontaneously and is usually linked with outcomes that affect students' performance in educational settings. In addition to capturing pupil and gaze coordinates in high resolution and with accuracy, wearable eye-trackers were used in this pilot study to infer student attention during an online lecture. While gaze is a good indicator for measuring visual attention, the need for more substantial proof of internal and covert attention is essential. In this work, we used advanced eye-tracking glasses to measure the mind-wandering level in students. The data collection was carried out with 15 students in two different settings for self-caught (8 students) and probe-caught (7 students) conditions. The data was later analysed to confirm the relationship between variables. Correlating the mind-wandering with engagement level (self-caught $r = .37$, probe-caught $r = -.59$) shows a significant relationship in both conditions (*P-value* $< .001$) . Our results show that using eye-trackers for mind-wandering measurements moves us toward the greater goal of building a customised teaching environment by detecting the actual data from students and teachers in the learning environment.**

***Keywords*— Wearable device, Eye-tracking, Mind-wandering, Engineering Education.**

I. Introduction

In a world surrounded by infinite fast and attention-capturing stimulation, the ongoing struggle to maintain focus is comprehensible. Although educational organisations are doing their best to provide students with stimulating learning material, the inattentiveness and detachment from learning material are still pervasive. Such mental episodes of an engaged mind with thoughts unrelated to the ongoing task are introduced as Mind-wandering (MW).

MW is closely related to learning and various studies have explored the effect of mind wandering during lectures [1], [2]. In the literature, the two most commonly recognised methods for collecting MW-related data involve the “self-report” and “probe-caught” techniques, which were also implemented in this study. In the “probe-caught” method, participants will be interrupted and asked about their state of mind at that moment, whereas in the “self-report”, participants are responsible for reporting back. Furthermore, adding a biological sensor to measure user vital signs can be an advanced way to improve the overall result of the experiment.

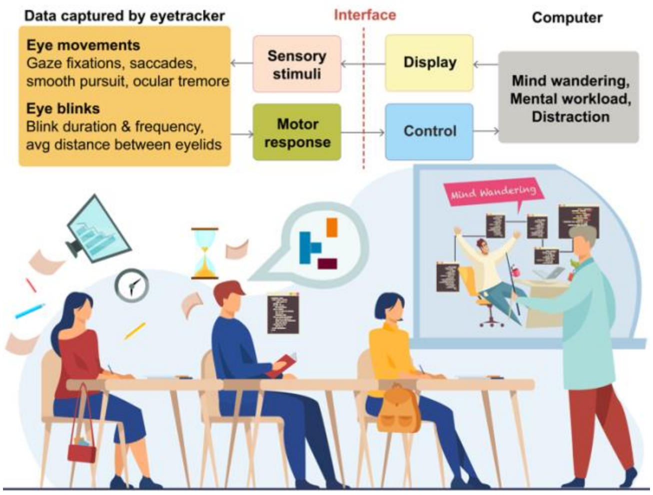

Fig 1. Mind-wandering in the learning environment and an envisioned block diagram for its measurements in students using eye-trackers.

In the past decade, engineers have become interested in designing and implementing new technologies to measure MW and subsequently enhance learning in educational environments. For example, collecting test responses using phones and tablets to measure MW using self-reporting by students. Other types of sensors that can detect biological markers such as temperature and pressure sensors could also be determined to find the explanations that lead us to identify the sources of distraction and MW in students. However, these techniques are not suitable for the participants and require a long time to analyse the data. New technologies such as eye-trackers combined with machine learning lead to an attractive solution for MW in the students, as shown in Fig. 1. Because of their lightweight and wearability the students feel comfortable using them and could be compatible with data analysis algorithm for a rapid and real-time data analysis.

We previously demonstrated how students respond to learning materials such as lecture slides by evaluating students' visual attention using eye-trackers [3]. Since visual attention is only a part of the focusing process or, in other words, paying attention, even though a person seemingly is on the task and their gaze is guided toward the designated subject, they can be thinking about an entirely different matter. The link between eye movement and cognitive processing is undeniable. Gaze behaviour has been used in monitoring cognitive load, attention, focus, and MW [4]. State-of-the-art wearable devices allow the measurement of visual eye movement on a specific part of the learning material to identify the exact source of distraction. In our preview work, we use a wearable eye-tracker to monitor students' visual attention in reading learning material and spot the different behaviours in the text vs graphic base visual representative [3]. Considering that visual attention does not define if the person is entirely focused on the task, we require another indicator that can confirm our result captured by a wearable eye-tracker.

For this study, dynamic stimuli such as video could offer more details of MW compared to static stimuli. In this regard, we follow the work by Zhang et al [5] in capturing MW in a video lecture. To advance the experiment and elevate the accuracy, we used the pupil core wearable eye-tracker that records the data at 200 Hz.

In our previous work, we hypothesised that the fixation duration is longer on the graphics in comparison with text; in this work, we want to see the effect of having the instructor image included in the video on the gaze behaviour.

II. Methodology

A. Technologies for MW-measurements

Different physiological biomarkers have been used to determine MW, which includes heart rate, skin conductance [6] and respiration. Pressure sensors [7], Electroencephalogram (EEG) and eye-trackers are the most promising technologies in terms of their accuracy. However, each technology has its own merits and drawbacks, as summarised in Table 1. The choice of adapting technologies depends on the space and situation.

Table 1. Pros and cons of the technologies that can be used in the measurement of mind-wandering.

Technology	Pros	Cons
Respiration/pressure sensors	Unique to its specific purpose	Lack of movement, discomfort
Heart rate sensors	Ease of access	Need for validation
Galvanic Skin Response sensor	Measuring the emotional state	Sensitive to movement
EEG	Provides data on cognitive state	Sensitive to environment
Eye-tracker	Can be used with moving target	Only collect visual data

B. Wearable vs Desktop Eye-trackers

Most desktop eye-trackers only rely on a webcam for measuring participant eye data. Affordability and ease of use are the main advantages of such technologies that caused their widespread use by researchers. However, desktop eye-rackers use a camera at a distance beyond 50 cm and can be interfered with background lights such as sunlight. On the other hand, wearable eye-trackers can precisely monitor pupil movement because of their close proximity to the eye. Furthermore, they provide the ability to monitor and collect the gaze point that happened outside of the monitor's frame and follow the participants' gaze map to identify the source of distraction. In this experiment, we recorded data using Pupil core eye tracking glasses at 200 HZ in a 400×400 pixel resolution [6]. Pupil core eye-trackers can measure eye movement in 2D and 3D formats. The 3D gaze collection uses pye3d for 3D pupil detection [7]. In addition, a confidence level is provided to set a threshold for proper pupil detection. The threshold is between 0, indicating no pupil detection, and 1, the highest possibility of pupil detection. To calculate fixations, the Pupil core employs a dispersion-based algorithm [8] with the ability to be implemented both online and offline. In this study, we used an online method for both pupils and gaze detection and calculated the fixation based on a dispersion level of 1.5 degrees in terms of degrees of visual angle with a minimum duration of 100 ms[9]. Data with a confidence value lower than ~0.6 were eliminated from the experiment.

C. Dynamic vs statics stimuli

The way that information is presented to the students can be the line between success and failure. Even presenting the information in text or graphic format makes a big difference. In our recent work, we used lecture slides to observe the differences in gaze behaviour on text vs graphic representations. In this study, we followed the experiment by Zhang et al.[5] and used a 19-minute video lecture on International Comparisons in Education. There were five questions before the video and 18 questions after the participant watched the video. The Areas of Interest (AOI) were defined to separate the slide and teacher window.

D. Internal and external measures

To better understand the occurrence of MW, internal and external information is required. MW can be evaluated directly by referring to the subject's state of mind or indirectly utilizing physiological measures[8]. The direct method includes the self-caught method, where participants are in charge of reporting their state of mind and the probe-caught method, where participants are asked to report where their attention was directed. Our past experiment concluded that we need to provide more validating measures to prove the relation between gaze data and attention. In this study, we used the eye-tracking data collected by our wearable eye-tracker and divided the experiment into two groups of probe-caught and self-caught to report their MW. In the probe-caught method, a question was presented to participants in the form of written text with the content of "were you MW?" at four fixed times during video lectures. Participants responded to the question by pressing the Y or N key to indicate Yes or No. In the self-caught experiment, participants were instructed to press any key every time they noticed they were MW.

E. Data Collection Process

All the experiment was made and executed in OpenSesame [8], including two questionnaires (pre and post-lecture) and the lecture video with probe-caught questions. The video was played on the desktop monitor with 1920×1080 resolution at approximately 60 cm distance. The participants' responses were used as triggers to send annotations to the eye-tracker. The collected annotations were timestamped on the gaze data automatically. The gaze data for the pop-up MW questions were excluded from the calculation to reduce the effect of response time on the results. The process of the data collection is shown in Fig 2.

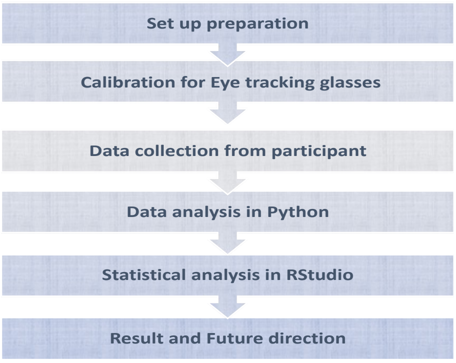

Fig 2. Data collection process from preparing the setup to presenting the result.

III. EXPERIMENT AND DATA ANALYSIS

A. Participants

The experiment was carried out in two different settings for self-caught and probe-caught. Our participants included 15 students from our research group that were randomly assigned to one of the tests. In the end, 8 students were in the probe-caught experiment and 7 in the self-caught experiment. All participants met the standard requirement for the level of eyesight.

B. Experiment

To identify what is considered MW, the concept was explained to participants prior to the start of the test. We ensured that the participant was in a suitable seating position that required the least amount of head movement and could read the screen perfectly. The eye tracking glasses were fitted on the participant's eyes, and we performed a 9-point calibration. The participant starts with the pre-test questions and immediately moves to the video. An instruction slide with the text appears before every step to give participants a clear idea of what they are expected to do. In the probe-caught test, the pop-up questions will interrupt the video at four pre-defined intervals to check their state of mind. The participant responds with a key press to confirm or dismiss, as shown in Fig 3(a). After the video lecture ends, the post-test questionnaire will appear to evaluate the learning outcome of the lecture video. At the end of the experiment, the participant rated their engagement level by answering two questions regarding their interest in the lecture material and their engagement level during the execution of the video lecture. The answers for the last part will be used to calculate participants' engagement levels based on their responses. The setup during the experiment can be seen in Fig 3(b).

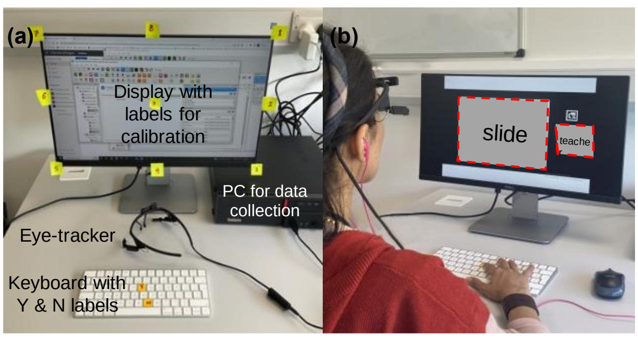

Fig 3. The experimental setup for the wearable eye-tracking device. (a) The calibration procedure and the Pupil Core headset, (b) a participant taking the test.

C. Data analysis

The fixation data for each AOI was extracted separately for both self-caught and probe-caught conditions. For the main calculation, only 50 seconds before the assumed moment of MW plus 15 seconds after were separated from all data and then divided into 13 bins (5-second per bin) to calculate the temporal changes that happen at the moment leading to MW. We correlated participants' levels of MW with their answers to validate the general relationship between them. We investigate the effect of including an image in the lecture video and inspect the gaze behaviour associated with MW. The fixation duration can be drastically different across AOIs depending on the presentation of stimuli. A longer fixation duration can be associated with MW [9], and to confirm that, we will analyse the fixation duration for participants in both self-caught and probe-caught conditions.

Table 2. the correlation between MW level, engagement and post-test result.

Report method	**MW level**	**SD**	**MW-engagement**[1]	**MW-post-test**	**MW-post-test -Pre-test**
Probe-caught	.62	.22	-.59(<.001)***	-.009(0.568)	-.04 (.003)**
Self-caught	138.89	87.77	.37(<.001)***	.06 (<.001)***	.07 (<.001)***

1. Pearson Correlation coefficient (P-value)
2. ***p < .001; **p < .01.

IV. RESULTS AND DISCUSSION

We calculated the correlation between MW and engagement to examine their relationship (Table 2). MW in the probe-caught conditions was measured using answers from participants to the pop-up questions, whereas in the self-caught method, we used the number of reports by participants. To calculate engagement level, we used the answers to rating scale questions. Correlating the MW level with engagement shows a significant relationship in both conditions of self-caught ($r = .37,\ P < .001$) and probe-caught ($r = -.59$, $P<.001$). Furthermore, we inspected the relation between MW and the scores from the post-test. There is a correlation between MW and post-test results in self-caught ($r = .06$, $P <.001$), but in the probe-caught, no correlation was found between the two. However, the relationship between both has kept true. In both conditions, the relationship becomes significant after considering the effect of the pre-test (*partial* $r = -.04$, $P = .003$ *and partial* $r = .07$, $P < .001$).

We analysed the data for both conditions to examine the moment of MW. Fig 4 shows temporal changes in eye movement patterns that lead to MW in both conditions. The x-axis shows the number of bins in 50 seconds leading to the key press by participants and 15 seconds after the key press. Bin number 10 represents the exact moment of MW.

In Fig 4(a) the red line represents the self-caught MW and the blue dotted line is for the on-task. The increase in fixation frequency before bin 10 shows that participants allocated their gaze to the teacher more often in moments leading to MW. In contrast, the on-task trend shows a sharp increase and decrease at the same bin. The probe-caught results are shown in Fig 4(b), the blue lines represent MW using the “yes” responses to the pop-up questions. The red dotted line represents the on-task behaviour or “no” answers. MW has an increasing trend at the beginning followed by a sudden decrease at bin 7 and in

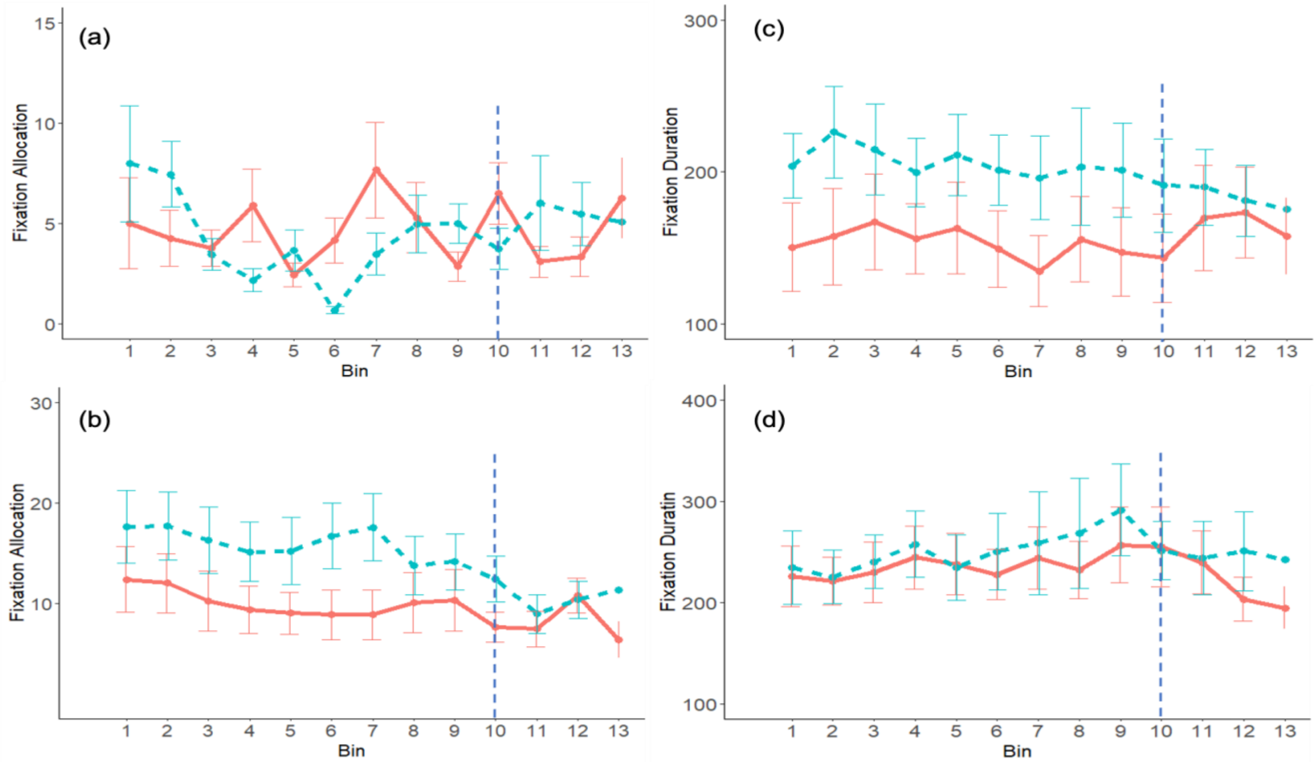

Fig 4. The time trend of fixation in the moments leading to MW. (a) and (b) the x-axis represents the time bins, and the y-axis represents the frequency of fixations. (c) and (d) the x-axis represents the time bins and the y-axis for the fixation duration on the slides. The blue dotted line in all the figures shows the MW, and the red line indicates the on-task behaviour. (Error bars show mean ± standard error)

comparison with the on-task trend that mostly follows a gradual decline.

We used the fixation duration on the slides to observe the relation between MW and fixation duration on written text through time. Fig 4(c) is the results of the self-caught experiment based on the duration of fixations on slides. The MW follows a gradual decrease to the end; on the other hand, the on-task shows an increasing trend from the same bin. Fig 4 (d) shows the results of the probe-caught condition based on the duration of fixations on slides. The fixation duration has the highest point of increase at bin 9 and decreases slowly from bin 10 but does not go as low as the on-task trend.

V. Conclusion and Future Work

Both probe-caught and self-caught experiments at some level confirm an increasing time trend in the frequency of fixation on the teacher window. The appearance of a person in the video can significantly change the distribution of gaze and can generate a distraction from the lecture material. On the other hand, the fixation duration seems to be increasing at the moments of MW in one experiment, but the other experiment shows a decreasing trend. Both allocations of fixation and duration seem to have a noticeable relationship with MW and can help us to customise the learning materials.

In our future studies, we will consider a bigger sample size to make a stronger case for our observations. To improve data accuracy and validation, we will include more sensors for measuring neurological and physiological data from participants.

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