Detecting Mind Wandering Episodes in Virtual Realities Using Eye Tracking

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Abstract. Virtual Reality (VR) allows users to experience their environment differently and more immersively than traditional information systems (IS). Therefore, it is important to also study cognitive processes in VR settings. In this proposal, we focus on the concept of mind wandering, which is an emerging concept in IS research that can be studied using neurological measures such as eye tracking. Current literature suggests that mind wandering is a complex concept with different dimensions, namely deliberate and spontaneous mind wandering. While previous literature has provided initial evidence on the feasibility of eye tracking to approximate mind wandering, this study seeks to investigate how well eye tracking performs when it comes to a more nuanced perspective on mind wandering applied in an VR setting.

Keywords: Mind wandering · Deliberate · Spontaneous · Virtual reality · Eye tracking

1 Introduction

For decades, information systems (IS) researchers have acknowledged the importance of cognitive processes during technology use. Constructs such as cognitive absorption [1] or IT-mindfulness [2] have widely been applied and have uncovered significant effects in IS-related contexts. With the rise of NeuroIS, the importance of cognitive aspects in technology-related settings has again been emphasized.

This study focuses on mind wandering, which is a cognitive concept that has only recently gained significant attention in psychology and neuroscience [3]. Mind wandering refers to episodes where our mind shifts to internal thoughts. While mind wandering can have severe negative effects [4], there are also an increasing number of studies that have demonstrated positive aspects of mind wandering, including a higher degree of creativity [5, 6].

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Several studies have investigated the concept of mind wandering in different scenarios, with various measurement techniques. However, little is known about mind wandering episodes in virtual reality (VR). Since a major driver of VR technologies relates to the fact that they affect and potentially even enhance our cognition, investigating mind wandering episodes in VR promises to generate further insights. To stress this argument, Thornhill-Miller and Dupont [7] "highlight[s] virtual reality (VR) as perhaps the safest, most fully developed of the emerging technologies of cognitive enhancement and as an underused tool for the enhancement of creativity in particular" (p. 102).

To better understand the relationship between VR and the concept of mind wandering, this study proposes an experiment to further investigate mind wandering in VR. The remainder is structured as follows: First, we briefly review the concept of mind wandering and how it is measured (Sect. 2). In Sect. 3, we propose the experimental setting that allows us to investigate mind wandering in VR. We conclude by reflecting on potential insights and future directions of this research.

2 Related Work

2.1 Mind Wandering

IS research often assumes that technology users are continuously focused [1, 8, 9]. However, empirical evidence shows that peoples' thoughts frequently proceed in a seemingly haphazard manner and effortlessly jump from one topic to another [10–12]. For up to half of their waking time, minds are not tethered to the actual moment or task, but easefully disconnected from the external environment [13].

Mind wandering is commonly described as a shift of attention away from a primary task toward dynamic, unconstrained spontaneous thoughts [4, 14] and as the mind's capacity to move away aimlessly from external happenings [15]. According to Christoff et al. [10], mind wandering can be defined as: "a mental state, or a sequence of mental states, that arise relatively freely due to an absence of strong constraints on the contents of each state". While mind wandering has widely been considered a failure of attention and control [16–20], recent studies highlight its advantages, including more effective brain processing, pattern recognition, and creativity [5, 12, 21, 22]. Specifically, mind wandering can help consider future events, solve problems, and create new ideas, e.g., at the digital workplace. It predominantly occurs during a resting state, task-free activity, and non-demanding circumstance [10, 12, 23, 24].

Since mind wandering can be a decisive factor for how users process information when using technology, IS researchers have started to acknowledge its relevance [25–28]. Sullivan et al. [26] were first to show that mind wandering influences functional outcomes of interacting with technology (i.e., creativity). They developed a domain-specific definition for technology-related mind wandering, being "task-unrelated thought which occurs spontaneously and the content is related to the aspects of computer systems" [26]. Moreover, Oschinsky et al. [25] revealed a significant difference between hedonic system use and utilitarian system use when it comes to mind wandering. Their study showed that the design of a system influences mind wandering, which in turn is known to affect antecedents of IT behavior and thus actual IT use.

There is a potential relationship between mind wandering and cognitive load, which has been investigated in the IS discipline. Representations of goal-states can be cued by goal-related stimuli under high cognitive load [3]. On the contrary, episodes of spontaneous thought are connected to low-level attention and uncontrolled, automatic thinking. As long as mind wandering is taking place, we seem to lack the ability to terminate or suspend it – we are fully immersed and yet relaxed and calm. The important difference of focused thinking under high cognitive load and the potential trigger of mind wandering episodes under low cognitive load is not yet sufficiently explored in the domain of NeuroIS research, and it is possible that there is an inverse relationship between the two constructs.

Because the interest in mind wandering has significantly increased in psychological and neuroscientific as well as IS research [22], different measurement scales have been proposed. However, the operationalization of mind wandering in IS-related conditions is still immature and incomplete [25–27, 29]. For instance, only little research exists that investigates the neurophysiological measures (e.g., EEG) in the domain of IS research (i.e., NeuroIS). Since self-report measurement does not seem to be the most efficient and appropriate way to assess the appearance of mind wandering experiences, refining the corresponding measurement instruments continues to be an important goal for research in this area [12]. We seek to contribute to closing this gap and propose the inclusion of and triangulation with objective data through eye tracking.

2.2 Eye Tracking and Mind Wandering

We conducted a literature review to identify how previous studies have measured mind wandering. For this study, we focus on the underlying type of technology (computer vs. VR) as well as the measurement of mind wandering (self-reported and using eye tracking). An overview of previous studies is given in Table 1.

Table 1. Studies on mind wandering and eye tracking.

Technology		Measurement		Example references
Computer	Virtual reality	Self-report	Eye tracking	
✓		✓		[25, 26]
	✓	✓		[30]
✓		✓	✓	[31–48]
	✓	✓	✓	(this study)

Table 1 highlights a variety of mind wandering findings which were collected by using self-reports and eye tracking. A large proportion of this literature deals with the risks of automobile crashes due to driver mind wandering. For example, He et al. (2011) highlighted deficits in vehicle control while mind wandering [39]. Others emphasize the increased chance of mind wandering due to the emergence of autonomous driving systems and offered suitable predictors [38, 40].

Mind wandering was also assessed in the context of attention while performing reading and learning tasks. Bixler et al. (2014–2016) aim for a fully automated mind wandering detection system using a machine learning model. To approach this goal, the researchers pseudo-randomly probed participants to report mind wandering episodes while performing computerized reading tasks. Meanwhile, the machine learning model tried to predict mind wandering due to gaze data followed up by a learning process based on the self-reported data [31–34]. Our findings indicated, that large chunks of eye tracking literature centers around utilizing objective data to create neural networks or machine learning models [41, 42]. Other researchers also probing for mind wandering in attention-tasks, familiarized test subjects with massive open online courses. Establishing on prior knowledge on objective mind wandering detection equipment, Zhao et al. (2017), successfully detected mind wandering with a common webcam [48].

Most of the discussed research used eye tracking devices in the form of cameras below or above the computer monitor (e.g., Tobii eye tracking devices) to record mind wandering. It is clear that eye tracking has a number of advantages over other methods for mind wandering research. However, there is a gap when it comes to the investigation of mind wandering in VR. In the remainder of this paper, we will describe an experiment which seeks to bridge this gap.

3 Methods

3.1 Participants and Materials

30 participants will be recruited at two different universities located in Canada and Germany to participate in a mailroom sorting task. Stimuli delivery and eye tracking will be conducted using HTC Vive PRO Eye SRanipal SDK, will be developed using the Unity engine and delivered using SteamVR. Participants will be screened for normal or corrected-to-normal eyesight, use of upper limbs and proficiency in English or German. Participants will be informed that we are investigating mind wandering in a simulated work environment. We will seek approval from our university's research ethics board and each session will last for 30 min in a controlled setting. At the completion of each session participants will receive CAD $15 or 15€ depending on where they conducted the experiment.

3.2 Procedure

Participants will undergo a consent protocol, complete an initial demographic questionnaire and will then be fitted with the HTC Vive PRO Eye VR-system. Participants will then take part in a virtual corporate mail room sorting task where they are given a series of addressed virtual envelopes and asked to place them in the appropriate bin. Participants will be asked to repeatedly retrieve a letter using the VR wand, read the address, and determine which of 16 bins to place it. The virtual letters will contain a selection of information consisting of addressee, title, department and address. Bins will be arranged according to department and will be clearly labelled at the base of each bin. Participants will not be required to walk during the routine.

3.3 Questionnaires and Physiological Measures

At three points throughout the experiment participants will be prompted with an experience sample where they will be asked about their degree of experienced mind wandering immediately preceding the sample [49]. Following the experiment, participants will complete a questionnaire about perceived degree of mind wandering throughout and its degree of spontaneity [50]. Task engagement times will be recorded by the software using events that record the time of letter retrieval and letter delivery, as well as task success (operationalized as the proportion of successful tasks/total number of tasks) and eye tracking engagements with task objects. During the time between each retrieval and delivery, eye fixation counts and fixation durations on 17 areas of interest will be recorded by the VR software.

3.4 Data Analysis

One of the challenges of eye tracking in a VR environment is that the environment is fluid and involves user-directed motion. This task was selected because though it creates a realistic simulation, it also constrains motion considerably and the equipment is optimized for such tasks. Eye fixation targets will consist of Unity objects which are pre-designed and modified for this VR environment. When eye fixations lock on to one of the programmed objects, a method will be called which records eye fixations and durations during which they are fixated on the object. Each participant is expected to yield between 5000 and 7000 trials which each correspond to a retrieval/delivery window. Analysis will be conducted on trials with time windows that completely precede the 30 s before a mind wandering probe samples. Trials will be labeled afterwards based on whether participants reported being in a state of mind wandering. The result is a largely automated process and manual intervention is only required to add data about the mind wandering state.

Two linear mixed effects investigations will be conducted on the resulting data. In the first investigation, fixation counts and fixation durations (for both target and non-target areas) as well as task duration will be investigated as fixed effects. Reported mind wandering will be investigated as the intercept variable. The reported mind wandering and on-task states will be treated as random effects to account for differences in number of trials and variances in reported mind wandering. This will identify variables which influence mind wandering. In the second investigation, the same variables will be investigated, though the mind wandering condition will be included as a fixed effect and task success as the intercept variable. Finally, multivariate linear regression will be used to assess the effects of the ex post measures on task success rates.

3.5 Outlook

As noted by Thornhill-Miller and Dupont [7], VR can be a promising technology to enhance cognitive processes. Consequently, this study seeks to extend current insights in terms of how to stimulate (or reduce) mind wandering episodes in technology-related settings. With a better understanding of the cognitive processes at play in everyday business tasks, we can uncover new insights into how to design our environments. Virtual reality promises to help create realistic, yet controlled environments which make new research directions possible. The results from this project can also inform organizations how to use VR to design processes that could be affected by mind wandering.

Perhaps the most promising way that this work can be further developed is to design and implement adaptive systems. Adaptive systems change based on a users' mental or physical state with the goal of improving an information system. When complete, we would have demonstrated eye-tracking correlates of mind wandering, which might be implemented to create such environments. In the future, we may extend this work to investigate how mind wandering interventions can change behavior, and whether these changes have implications to the productivity of organizations.

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