Measuring the Impact of Mind Wandering in Real Time Using an Auditory Evoked Potential

Colin Conrad and Aaron Newman[1]

[1]Dalhousie University, Halifax, Canada
{colin.conarad, aaron.newman}@dal.ca

Abstract. In this research-in-progress paper, we propose an experiment to investigate the neurophysiological correlates of mind wandering using electroencephalography (EEG). Auditory oddball event related potentials have been observed to be sensitive to the mind wandering state and can be used as a real-time passive measure. This has advantages over standard survey techniques because it is an objective, non-disruptive real time measure. We describe an experiment to observe the neurophysiological correlates of mind wandering in online learning environments using an auditory oddball. In doing so, we introduce a new experimental paradigm to the IS literature which could be used to extend other attention-related research.

Keywords: Auditory oddball · Mind wandering · Online learning · EEG

1. Introduction

Mind wandering refers to processes commonly described as "daydreaming," or "spontaneous thoughts" [1]. More precisely, mind wandering represents a phenomenon where sustained attention is brought away from a stimulus and toward self-generated experiences [2]. It is commonly thought that mind wandering occurs in the higher education environment, and though it varies from student to student, it is often perceived to have an overall negative impact on student performance [3, 4]. In the case of common online learning systems such as Massive Open Online Courses (MOOCs), it is tempting to make similar inferences, as they often likewise follow a lecture format. One key difference between the classroom and the online lecture format however, is that good classroom teachers can often observe behaviors characteristic of mind wandering and improve their teaching to increase engagement. Detecting mind wandering in an online learning environment would be useful to improving e-learning systems and identifying improved methods for objectively measuring mind wandering would be instrumental to the improvement of such systems.

In order to measure the impact of mind wandering on education, we explore using two electroencephalography (EEG) measures. The first measure is commonly referred to as the P1-N1-P2 auditory event related potential (ERP), which consists of a sequence of three peaks that consistently appear in response to the onset of auditory stimuli, with characteristic timing and scalp distributions [5]. Studies in mind wandering have found an effect where the amplitude of the P2 elicited by auditory oddball stimuli is reduced in individuals who have attention directed away from task-relevant stimuli and toward self-generated information [6, 2]. The second measure consists of oscillatory patterns in specific frequency bands, commonly referred to as delta, theta and alpha activity, which have been found to be correlated with mind wandering [6]. In this research-in-progress paper, we describe an experiment to identify the differences in these two patterns and their correlation with self-reported mind wandering. We propose employing these methods to conduct research in real-time changes in covert attention, which are relevant to predicting performance in online learning.

2. Hypothesis Development

Mind wandering is a common phenomenon that plays a significant role in general thought processes, even taking up to 50% of our waking time [7]. Mind wandering is also understood to be associated self-generated thoughts and with the default mode network, which is the series of mental functions active in the absence of an explicit task. The activation of self-generated thought processes carry both costs and benefits from the perspective of cognition, depending on the context in which they are active. Self-generated thoughts have been observed to contribute to absentmindedness and unhappiness, but also have the benefit of facilitating creativity and planning [8].

Though self-generated thoughts seem to play an essential role in common human experience, the role they play in learning is inconclusive. In the context of information technology, Sullivan, Davis and Koh performed exploratory work on this subject and found that not all types of mind wandering are detrimental to learning and some forms might in fact be beneficial [9]. However, other studies affirm its overall negative impact on learning. In a study of 463 undergraduate students, Lindquist and McLean found that students who experienced frequent task-unrelated images and thoughts performed poorer in course examinations and that experiencing task-unrelated thoughts was negatively correlated with degree of course interest [4]. Mind wandering has also been found to be correlated with the activation of brain regions associated with cognitive control and executive networks, and may even compete for resources with learning stimuli [10]. Though it far from conclusive, we can hypothesize that mind wandering is generally detrimental to knowledge acquisition, at least when it comes to the sorts of knowledge acquired with executive networks, such as rote learning.

H1 – Reported mind wandering will be negatively correlated with rote learning.

2.1 Measuring Mind Wandering Using Neurophysiological Indicators

Though mind wandering can be effectively measured using ex post questionnaires, these methods do not offer insight into the temporal impact of mind wandering. It is desirable to develop measures that can offer insight on the changes in mind wandering patterns over time, as temporal data can help identify which portions of an online learning system account for changes in mind wandering patterns. One method for doing this is experience sampling, a series of very short self-reports designed to capture the temporal experience of participants. Studies using these methods often employ a simple yes/no measure in order to determine the occurrence of mind wandering [11, 12]. This comes with the advantage of measuring mind wandering in real time, but with the disadvantage of disrupting the person's current cognitive processes, be they task-related or mind wandering.

Neuroimaging can be used to mitigate this problem. Oddball protocols can be used to elicit event-related potential responses from a given stimulus during a sustained task such as an e-learning session and have already been demonstrated in the IS context [13]. The P1-N1-P2 complex is a series of event related potentials triggered by an auditory or visual stimulus and can be adapted to this task. Established by Hillyard, Vogel and Luck, this complex is a mandatory response triggered by early attention control mechanisms in the occipital regions [5]. The P1-N-P2 complex has been found to be a significant indicator of the switch of general selective attention from one stimulus to another, most notably by differences in amplitude between attended and ignored stimuli. The amplitude of the P2 component was also observed to be sensitive to mind wandering by Braboszcz and Delorme [6]. Using an passive auditory oddball protocol, they demonstrated significant differences between the P2 amplitudes between participants reporting to be in a mind-wandering state versus on task.

In addition to the P2 response, correlations between oscillatory activity and mind wandering have been found at the delta, theta, alpha and beta bands [6]. Neural oscillations are caused by neural activity in the central nervous system and underline at least two modes if cerebral activity: fast-frequency waves reflective of high degrees of task-related attention (beta activity at 12-30 Hz) and a low-frequency waves reflective of low task-related attention (theta activity at 3-7 Hz). Braboszcz and Delorme also observed the impact of oscillatory activity on mind wandering ultimately found theta and beta to be significant correlates of mind wandering, while noting that delta and alpha activity was suggestive. We are led to the following hypotheses:

H2a – Mean P2 amplitude will be positively correlated with reported mind wandering.
H2b – Delta power will be positively correlated with reported mind wandering.
H2c – Theta power will be positively correlated with reported mind wandering.
H2d – Alpha power will be positively correlated with reported mind wandering.
H2e – Beta power will be negatively correlated with reported mind wandering.

3. Experiment Design

Participants will be asked to attend to a 51-minute English language video on Machine Learning as auditory stimuli are presented [14]. The subject matter and video were chosen because the subject matter is not commonly taught in the standard business curriculum, had some utility to the participants, and was observed triggering variations in mind wandering during pilot studies. The video consists of a standard lecture along with a visual aid created in Microsoft PowerPoint. Participants are asked to pay attention to the video, while being presented with one of two audio stimuli every 1-1.5 seconds (mean 1.25). Participants are asked to report when they experience mind wondering by pushing a button on the computer keyboard, which is recorded on the parallel port. Following the video, participants complete a multiple-choice quiz to measure retention. Participants also complete a short multiple-choice quiz before and after the video. The differences in results are used as a measure of rote learning.

3.1 Participants

Twenty-four healthy students between the ages of 19 and 29 will be recruited from Dalhousie University to participate in the study. Power analysis on the oddball response suggest that this number would be for 99% confidence. Participants will be screened for neurophysiological, emotional, medical, hearing and vision conditions that could lead to abnormal EEG. Participants will also be excluded if they are majoring in computer science, have taken a course related to machine learning or are not fluent in English. Participants will be compensated CAD $25 for their time.

3.2 Experimental Stimuli

All stimuli will be presented in a controlled computer environment in a small, quiet testing room. Audio stimuli consist of 100 ms tones delivered every 1-3 s (randomly distributed with mean of 2 s). Task standard stimuli (80% of trials) consist of 500 Hz tones while the oddball (20% of trials, pseudo-randomly distributed) stimuli are 1000 Hz. Exactly 2448 tones are presented in the course of the experiment. The PsychoPy Python library is used to present the audio stimuli and record manual responses [15]. The onset of each audio tone is communicated to the EEG amplifier via TTL codes sent from PsychoPy via the parallel port.

3.3 Procedure

After completing the informed consent procedure, participants are fitted with the EEG cap (see next section) and brought to the controlled environment. Participants watch the 51 minute machine learning video, and are asked to press a button on the computer keyboard every time they become aware that their mind is wandering. Following the study, participants complete a multiple-choice quiz to test their retention of the material presented in the video.

3.4 EEG Data Acquisition

Participants are fitted with 32-channel scalp electrodes (ActiCap, BrainProducts GmbH, Munich, Germany) positioned at standard locations according to the International 10-10 system, and referenced during recording to the midline frontal (FCz) location. Bipolar recordings are made between the outer canthi of the two eyes, and above and below one eye, to monitor for eye movements and blinks. Electrode impedances are kept below 15 kOhm throughout the experiment. EEG data are sampled at 512 Hz using a Refa8 amplifier (ANT, Enschende, The Netherlands), bandpass filtered between 0.01 and 170 Hz, and saved digitally using ASAlab software (ANT).

3.5 Artifacts Correction and Data Processing

The MNE-Python library [16] is used for data preprocessing. A 0.1–40 Hz bandpass filter is applied to the data, followed by manual identification and removal of electrodes and epochs with excessive noise. The data are then segmented into epochs spanning 200 ms prior to the onset of each auditory tone, to 1 s after. Independent Components Analysis is then used to identify and remove artifacts such as eye blinks and movements [17]. The epochs that occur in the 10 s before the reported mind wandering (excluding the 1 s window before the report) are assigned a “mind wandering” label, while epochs that occur in the 10 s after the reported mind wandering (excluding the 1 s window after the report) are assigned an “on-task” label. Fig. 1 illustrates how the data are prepared for analysis.

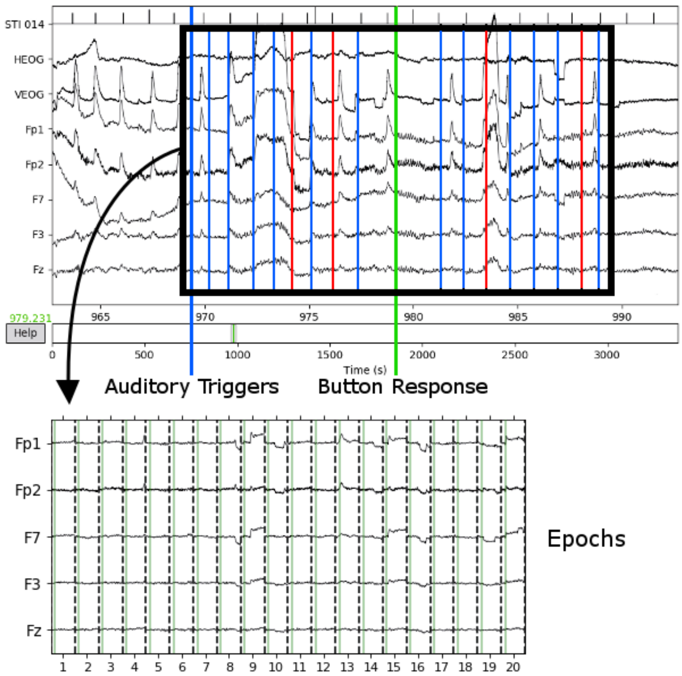

Fig. 1. Auditory events are triggered in PsychoPy and recorded in the parallel port. Though thousands of events are recorded, only the 1.2 s epochs from the auditory events in the 10 seconds before the button response ('mind wandering condition') and the 10 seconds following the response ('on task condition') are compared.

Planned comparisons are between standard and oddball stimuli, within and between mind wandering and on-task conditions. Pilot results (n=11; see below) suggest a high variance in mind wandering reports among participants, ranging from 1 to 60 responses. Following the recommendations of Braboszcz and Delorme [6], participants with fewer than 20 oddball responses will be excluded. Each participant is expected to yield between 20 and 140 mind wandering or on-task oddball events. In addition to temporal domain (ERP) analyses of the P1-N1-P2 components, time-frequency analysis will be investigated in the 10 s pre- and post-report. These longer epochs will assessed for power spectral density (uV^2/Hz) in each standard EEG frequency band.

4. Pilot Study and Future Work

We conducted a pilot study of this paradigm with 11 participants. Of the 11 participants recruited, 3 had to be excluded due to technical errors or lack of mind wandering measures. After data processing there were 2251 standard and 474 oddball epochs with the "on task" label, and 1887 standard and 417 oddball usable epochs with the "mind wandering" label. Fig. 2 visualizes the differences in the grand average between the standard and oddball ERP and the two conditions.

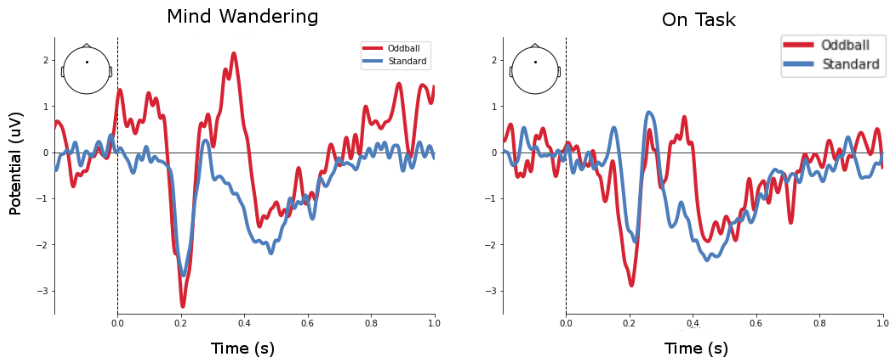

Fig. 2. Grand average ERP observed during mind wandering and on task conditions for channel Fz

In both mind wandering and on-task conditions, clear differences were observed between standard and oddball stimuli over midline frontal electrodes at two times: at approximately 200 ms—with a greater negativity for oddballs—and from approximately 300-400 ms—with oddball stimuli showing a more positive amplitude over midline frontal electrodes. These correspond to the typically described N1 and P3 components, respectively. Though the N1 effect appears similar to that observed by Braboszcz and Delorme [6], the enhanced positivity occurs on the P3 component, rather than on the P2 as reported by Braboszcz and Delorme. The P3 is commonly elicited by oddball stimuli in paradigms such as this, however it is more commonly associated with task-relevant stimuli—whereas here the stimuli were to be ignored.

Interestingly however, the P3 appears larger in the present data during the mind wandering thank on-task periods. We speculate that this could be caused by participants' paying greater attention to the auditory stimuli when their attention was less focused on the video (i.e., during mind wandering) the auditory stimuli drawing attention away from the video to a greater degree in the mind wandering state. As these were pilot data no statistical analyses were performed, but linear mixed effects analysis will be used once the full sample has been collected.

These preliminary results provide encouraging support for the proposal that this paradigm represents an automatic, covert, and temporally sensitive measure of mind wandering that can be applied in a range of task settings. If the auditory oddball correlates of mind-wandering are successfully established for online learning research, we can envision extending this measure to answer questions about the role of mind wandering in other technology environments. This could complement other psychophysiological measures such as eye movements or electrodermal activity, which could in turn be used to investigate the role of mind wandering outside of human-computer interaction, such as in-group dynamics or conversation [18,19]. Additionally, a robust understanding of these correlates open up the potential of attention-adaptive interfaces, which have applications to information technology generally.

Acknowledgements. This research is supported by the Killam and NSERC Doctoral scholarships to Colin Conrad, and an NSERC Discovery Grant to Aaron Newman. We also thank the participants of the 2017 NeuroIS training course for their feedback**.**

References

1. Christoff, K., Gordon, A., and Smith, R.: The role of spontaneous thought in human cognition. In: Vartanian, O., Mandel, D. (eds.) Neuroscience of decision making, pp. 259-84. Psychology Press, New York (2011).
2. Smallwood, J.: Mind Wandering and Attention. In: Fawcett, J., Risk, E., and Kingstone, A. (eds.) The Handbook of Attention, pp. 233-255. MIT Press, Cambridge (2015).
3. Wilson, K. and Korn, J. H.: Attention during lectures: beyond ten minutes. In: Teaching of Psychology vol. 34, no. 2, pp. 85-89 (2007).
4. Lindquest, S. I. and McLean, J. P. Daydreaming and its correlates in an educational environment. In: Learning and Individual Differences vol. 21, no 2, pp. 158-167 (2011).
5. Hillyard, S. A., Vogel, E. K., and Luck, S. J.: Sensory gain control (amplification) as a mechanism of selective attention: electrophysiological and neuroimaging evidence. In: Philosophical Transactions of the Royal Society of London B: Biological Sciences vol. 353, no. 1373, pp. 1257-1270 (1998).
6. Braboszcz, C., and Delorme, A.: Lost in thoughts: neural markers of low alertness during mind wandering. In: Neuroimage vol. 54, no. 3, pp. 3040-3047 (2011).
7. Schooler, J. W., Smallwood, J., Christoff, K., Handy, T. C., Reichle, E. D., and Sayette, M. A.: Meta-awareness, perceptual decoupling and the wandering mind. In: Trends in cognitive science vol. 15(7), pp. 319-326 (2011).

8. Smallwood, J., and Andrews-Hanna, J.: Not all minds that wander are lost: the importance of a balanced perspective on the mind wandering state. In: Frontiers of Psychology vol. 4, no. 441 (2013).
9. Sullivan, Y., Davis, F., and Koh, C.: Exploring Mind Wandering in a Technological Setting. In: Proceedings of the 36th International Conference on Information Systems, Fort Worth (2015).
10. Moss, J., Schunn, C. D., Schneider, W., and McNamara, D. S.: The nature of mind wandering during reading varies with the cognitive control demands of the reading strategy. In: Brain Research vol. 1539, pp. 48-60 (2013).
11. Smallwood, J. and Schooler, J. W.: The restless mind. In: Psychological Bulletin vol. 132 no. 6, pp 946-958 (2006).
12. Schooler, J. W., Reichle, E. D., and Halpern D. V.: Zoning Out while Reading: Evidence for Dissociations between Experience and Metaconsciousness. In: Levin, D. T. (ed.) Thinking and Seeing: Visual metacognition in adults and children, pp. 204-226. MIT Press (2004).
13. Léger, P. M., Sénecal, S., Courtemanche, F., Oritz de Guinea, A., Titah, R., Fredette, M., Labonte-LeMoyne, E.: Precision is in the eye of the beholder: Application of eye fixation-related potentials to information systems research. In: Journal of the Association for Information Systems vol. 15, no. 10, pp 651-678 (2014).
14. Grimson, E. Introduction to Machine Learning. YouTube (2017).
15. Peirce, J. W.: Generating stimuli for neuroscience using PsychoPy. In: Frontiers in neuroinformatics vol. 2, no. 10 (2009).
16. Gramfort, A., Luessi, M., Larson, e., Engemann, D. A., Strohmeier, D., Brodbeck, C., Parkkonen, L., Hämäläinen, M. S.: MNE software for processing MEG and EEG data. In: Neuroimage vol. 86, pp. 446-460 (2014).
17. Delorme, A. & Makeig, S.:. EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. In: Journal of Neuroscience Methods vol. 134, no. 1, pp. 9–21 (2004).
18. Douglas, K., Tremblay, A., and Newman, A.: Measuring the N400 during naturalistic conversation: An EEG hyperscanning study. Poster to be presented at the Neurobiology of Language meeting, Quebec City, August 18-22 (2018).
19. Tremblay, A., Flick, G., Blanchard, A., Cochingyan, E., Dickie, K., Macgillivray, K., Ashraf Mahmoud-Ahmed, H., Schwartz, S., Sher, C., Asp, E., and Newman, A.J.: Free, Unscripted Conversation with MEG Recordings is a Viable Experimental Paradigm for Research into Language Processing. Paper presented at The 40th Atlantic Provinces Linguistic Association (APLA-40), October 28-29, 2016, Mount Saint Vincent University, Halifax, Canada (2016).