EVENT ABSTRACT

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Towards Neuroadaptive Personal Learning Environments: Using fNIRS to Detect Changes in Attentional State

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Aims:

Current ubiquity of online learning tools has led to an increased interest in developing neuroadaptive personalized learning environments using non-invasive brain imaging tools (Anderson et al., 2009; Heraz and Frasson, 2009; Keating et al., 2016; Liu, Walker, Solovey, 2017). Detecting mind wandering (MW) is one target for assessing the state of a learner. Mind wandering can be detrimental to student learning, where instead of processing external task-related information, students engage in internal non-task thoughts (Smallwood, Fishman, & Schooler, 2007; Mills et al., 2013). Examining direct brain activity during non-response periods can help disentangle focused from mind-wandering states.

Functional near-infrared spectroscopy (fNIRS) has increasingly been used to assess cognitive state in real-time during interactive computing tasks (Solovey, et al., 2012, Afergan et al., 2014). fNIRS is also an ideal tool for detecting MW due to the involvement of the frontal cortex in attentional regulation through activation of the default network (Christoff et al., 2009; Gruberger et al., 2011). Prior work by Durantin et al. (2015) indicated significant differences in oxygenated hemoglobin (HbO) between mind wandering and focused states. Closely following the protocol of Durantin et al. (2015), we explore the detection of mind-wandering states from fNIRS data. Preliminary results indicate significant differences in HbO levels over periods of mind wandering as compared to focused states. This work serves as a foundation for modeling attentional state using machine learning tools to enable the creation of better and more personalized technology-based learning experiences.

Methods:
We conducted a study with 12 participants (8 female) between the ages of 18-41 (Mean: 28, SD: 6.48). A Sustained Attention to Response Task (SART) (Manly et al., 1999) was used to elicit mind wandering while capturing frontal lobe activity with fNIRS. A number (1-9) was presented at the center of a white screen for 0.5 seconds followed by a 1.0 second pause. Participants were instructed to press the spacebar for each stimulus other than the number 3 (target stimulus). Stimuli were presented in 6 blocks, with 10 targets and 190 non-targets presented pseudorandomly in each block such that targets were not presented back to back. Hemodynamic data was collected with an 8-channel fNIRS device manufactured by ISS, Inc., with sensors placed against the forehead and kept in place with headbands that reduced light interference. The SART program sent markers to an iMotions data acquisition platform indicating the stimulus type (target or non-target). Additionally, fNIRS raw data was sent in real-time via TCP/IP to the iMotions platform, which synchronized stimuli with the fNIRS signal.

We were interested in examining the behavioral and brain activity differences between correct target responses (refrained from key press, not mind wandering) and incorrect target responses (key press, mind wandering). Raw fNIRS intensity values were converted to changes in oxygenated (HbO) hemoglobin using the modified Beer-Lambert Law (Villringer & Chance, 1997). Analysis was completed in MATLAB. Mean correct response accuracy for target and non-target stimuli was calculated along with 95% confidence intervals. For each target appearance, we extracted fNIRS data from 30 seconds prior to the target and 10 seconds after each target (referred to as target periods). Window length was informed by the work of Durantin et al. (2015). Target periods with significant artifacts were excluded using a threshold of +/- 2.0 □□M. In order to assess change in HbO over time, we used the 5 seconds before each 40-second window as a baseline. We calculated the average value in the baseline window and subtracted that value from the values in the 40-second window. Finally, we calculated the folded average of HbO change across all participants for the correct and incorrect target responses. One participant was excluded from all analysis due to lack of in-range fNIRS data.

Results:
Across all six blocks, mean accuracy in target stimuli responses was .7041 (SE .0372), with a 95% CI from .6223-.7860 (Fig. 1). This was significantly lower than mean accuracy for non-target stimuli (Mean: .9493, SE: .0226). In fNIRS channels 2 and 3 (located at left anterior prefrontal cortex), and 7 and 8 (located at right anterior prefrontal cortex) (Fig. 2), HbO decreased significantly in the 15

seconds preceding a missed target, and remained relatively constant in all channels during correct target hits (Fig. 3). There were no significant differences in Hb over SART errors vs. no errors.

Conclusion:
Consistent with prior work, we observed significantly lower response accuracy to target stimuli than non-target stimuli. Periods of poor performance during SART have been associated with mind wandering and have also been associated with activation in the medial prefrontal cortex, measured by fNIRS (Durantin, Dehais, & Delorme, 2015). Consistent with the findings of Durantin et al. (2015), our work shows that there are differences in frontal lobe blood oxygenation patterns between periods of mind wandering and periods of focus. In contrast to previous findings that showed a significant decrease in HbO immediately after the appearance of a target, our results showed a significant decrease in the 10 to 15 seconds before a target. Furthermore, where Durantin et al. noted temporal differences only in one optode near the right medial prefrontal cortex, our preliminary results indicate that frontal lobe areas in both the left and right sides of the anterior prefrontal cortex may have distinct temporal patterns of HbO change during MW, and should be considered when modeling MW using machine learning. This builds a foundation for exploring brain patterns during mind wandering in more realistic and complex tasks during learning. We aim to continue exploring this data through different signal processing methodology, including noise reduction using short separation channels, and plan to correlate behavioral and fNIRS data to subjective responses from the post-experiment survey. Using this behavioral and physiological dataset, we also plan to build and test various machine learning models to differentiate between mind wandering and focused states. Ultimately, we aim to build on these findings and detect attentional state in real time during the use of neuroadaptive personalized learning environments (Keating, et al., 2016; Liu, Walker & Solovey, 2017).

Figure 1

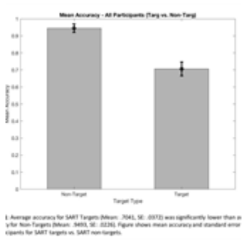


Figure 2

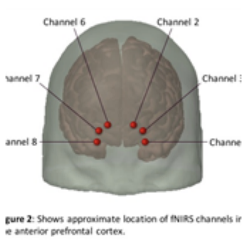
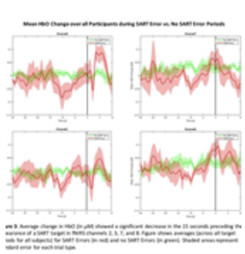


Figure 3



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