EVALUATION OF A NOVEL EEG DEVICE AND ALGORITHM FOR COGNITIVE STATE MONITORING

Evan Frantz [1,2], Yong Yuan [1,3], Melissa Key [1,2], Walter Piper [4], Robert Voorhis [1,2], Adelina Geraghty [1,3], Rick Helton [1,2], Nathaniel Bridges [1], William Aue[1] (william.aue@us.af.mil)

[1] *Air Force Research Laboratory 711th Human Performance Wing*, Wright-Patterson AFB, OH
[2] *Infoscitex Corp*, Beavercreek, OH
[3] *Oak Ridge Institute for Science and Education*, Oak Ridge, TN
[4] *Neurable Inc.*, Boston, MA

AFRL

INTRODUCTION

- Changes in human cognitive state (e.g., workload, distraction) impact task performance and are detectable using EEG [1]. Detecting cognitive state changes in a participant and intervening could prevent performance errors.
- Typical research-grade EEG systems (e.g. Biosemi Active2) provide great signal quality with "wet" gel-based sensors but are difficult to don/doff and restrict the mobility of the participant. [2]
- Consumer-oriented EEG devices (e.g., Muse, Attentive U, Emotiv) have the potential to capture signal relevant to cognitive state in a more usable form-factor, however the device tend to have fewer electrodes, poorer signal quality, and have challenges with the misplacement of individual electrodes.[2]
- Neurable's Enten™ EEG headset has 20-channel of dry sensor electrodes in a design that provides reasonably consistent placement and contact. Neurable also provides an EEG-derived *Focus Score* representing an individual's level of focus while performing a task [3]
- In the current project, participants performed cognitive tasks while periodically experiencing distraction events. The ability of Neurable's hardware to monitor neural activity and the ability of Neurable's *Focus Score* algorithm to capture distraction events were evaluated. Specifically, we sought to evaluate whether:
  1. Neurable's *Focus Score* captures distraction events
  2. The *Focus Score* is indicative of changes in behavioral performance

METHOD

Stroop Task

- Participants (N = 29) performed the stroop task over the course of 2 visits, during each visit they performed the task 4 separate times (see Task Progression).
- Congruent (color and word are the same [red]) v. incongruent trials (color and word differ [blue]) with 64 trials per block with a mostly incongruent list
  - During distraction blocks (1 & 3), the participant was randomly prompted with an auditory notification. Once prompted, they were to complete an arithmetic problem then return to the stroop task.
  - Blocks 2 and 4 were non-distraction blocks

Stroop task example

Neurable's Enten EEG device. Source: Neurable Inc.

Neurable Enten Device

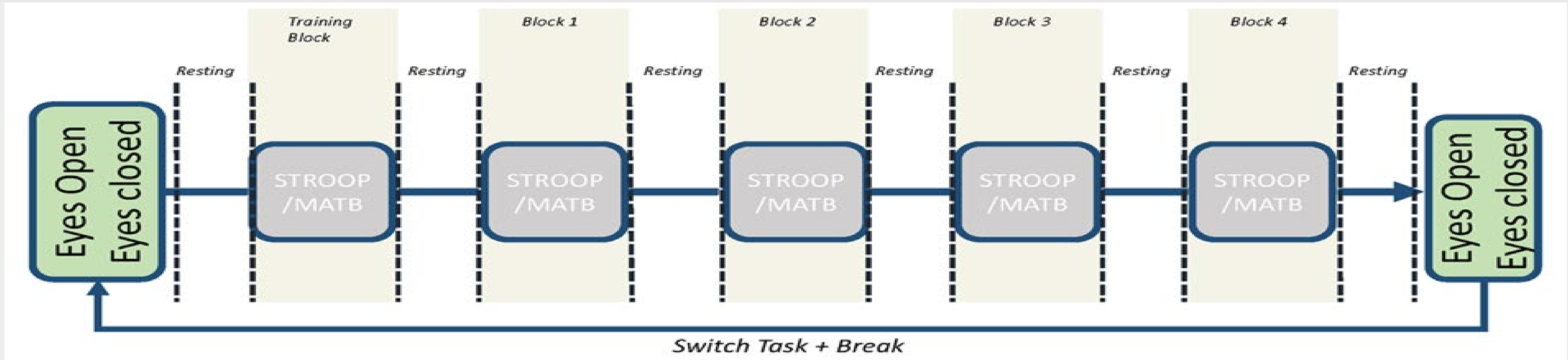
- Over-the-ear headphone with integrated
- 20-channel dry fabric-based EEG sensors
- 500Hz sampling rate with active amplification and signal shielding
- 3-axis accelerometer to capture head movements.

***Focus Score* Estimation and Statistical Analysis**

- Raw focus scores were calculated offline using Neurable's proprietary algorithm. [3]
- Behavioral results were analyzed using a repeated measures within-subject ANOVA and linear mixed effects modeling in R & RStudio [4,5]
- Logit transformed focus scores were modeled using as a smoothed subject-specific function of elapsed time (since the start of the run) and smoothed (group-level) functions of time since the last distraction and time since last stimulus. [4,5]

ABSTRACT

Consumer-grade noninvasive neurotechnology to facilitate brain-computer interfacing is a burgeoning market and is a growing contestant to traditional research-grade systems. Research-grade systems (e.g., BioSemi) produce high signal quality and reliable data using wet electrodes but require trained technicians to administer and leaves behind a mess when removed. Consumer-grade products that involve semi-wet or dry electrodes, tend to be faster and more convenient to don outside of the lab and tend to be less messy but struggle with signal quality issues. The current effort focused on evaluating a consumer-grade, over-the-ear electroencephalography (EEG) device with the potential to bridge the gap between research-grade and consumer-grade systems in assessing attentional states. The Enten™ from Neurable® embeds a 20-channel dry electrode system in a headphone form factor. Over two days, individuals were evaluated on performance during two cognitive tasks while donning the Enten and a forehead-based EEG from Neuroelectrics. Individuals completed multiple blocks of both the Multi-Attribute Task Battery - II (MATB-II) and a modified Stroop Task under a distracted and a non-distracted condition. Raw EEG data from the Enten were processed to generate a "focus score" (FS) using Neurable's proprietary algorithm. The ability of the FS to accurately capture distraction events was evaluated and the correspondence of the FS to performance outcomes was analyzed for each task. Implications and considerations for consumer-grade neurotechnology to be leveraged in more naturalistic research settings are discussed.



RESULTS

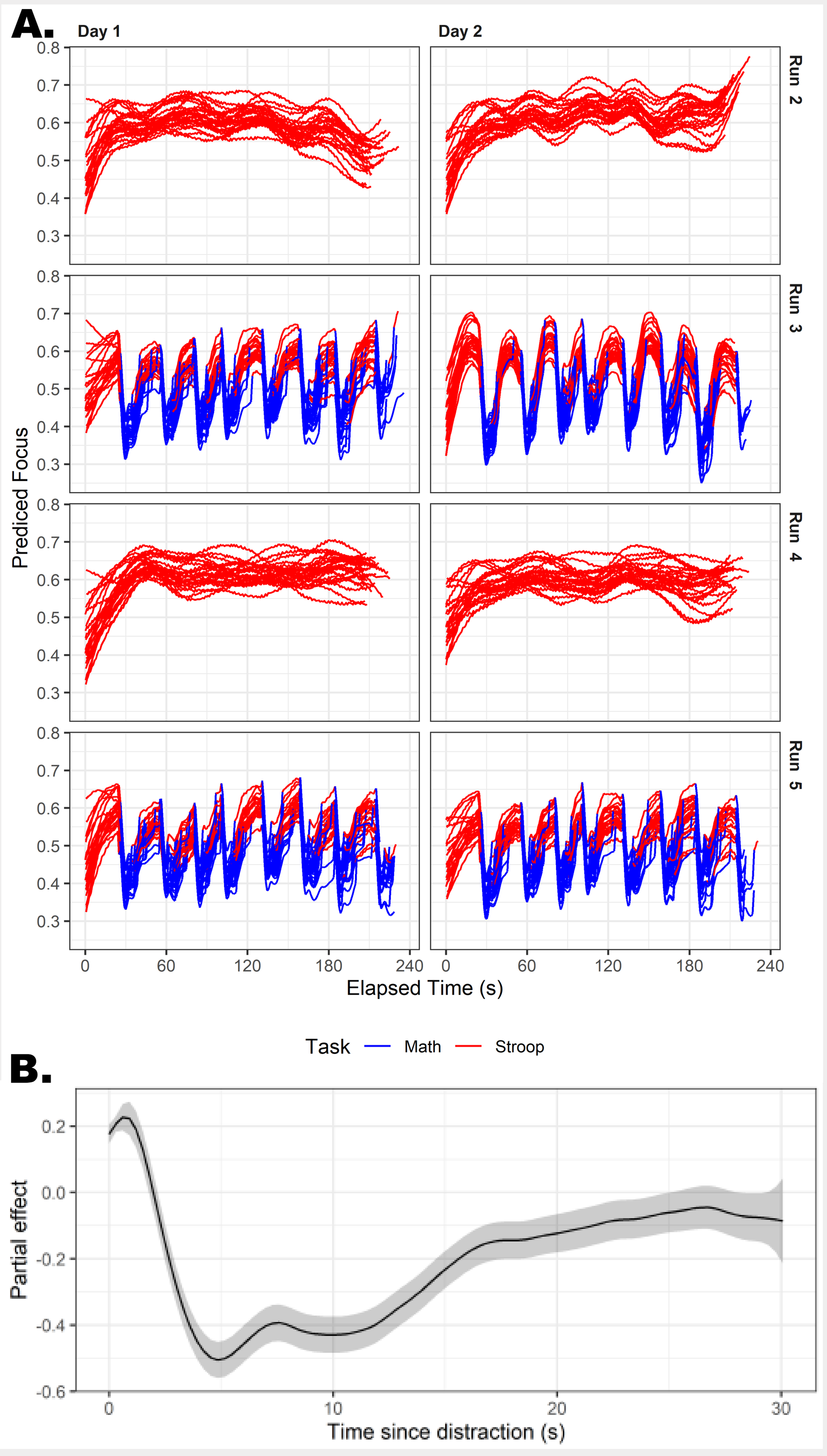
1. **Does *Focus* Score respond to distractions?**

Predicted focus score for each participant (Panel A).

- *Focus Score* drops when subjects shifts from the stroop (red line) to the math task (blue line) and recovers over the next 20-30 seconds before the subject receives the next distraction.
- The extremely small deviations are the modeled change in focus when a new Stroop stimuli is observed.
- Participants do not always return to a pre-distraction focus state prior to the next distraction.

The effect of a distraction on focus (Panel B).

- At the onset of the distraction, the predicted focus is slightly higher than pre-distraction levels. For approximately 5 seconds after the distraction, the focus score drops sharply, before a slow recovery over the next 15 - 20 seconds.
- On average, subjects return to a pre-distraction state approximately 20 seconds after the distraction (not including the initial spike).

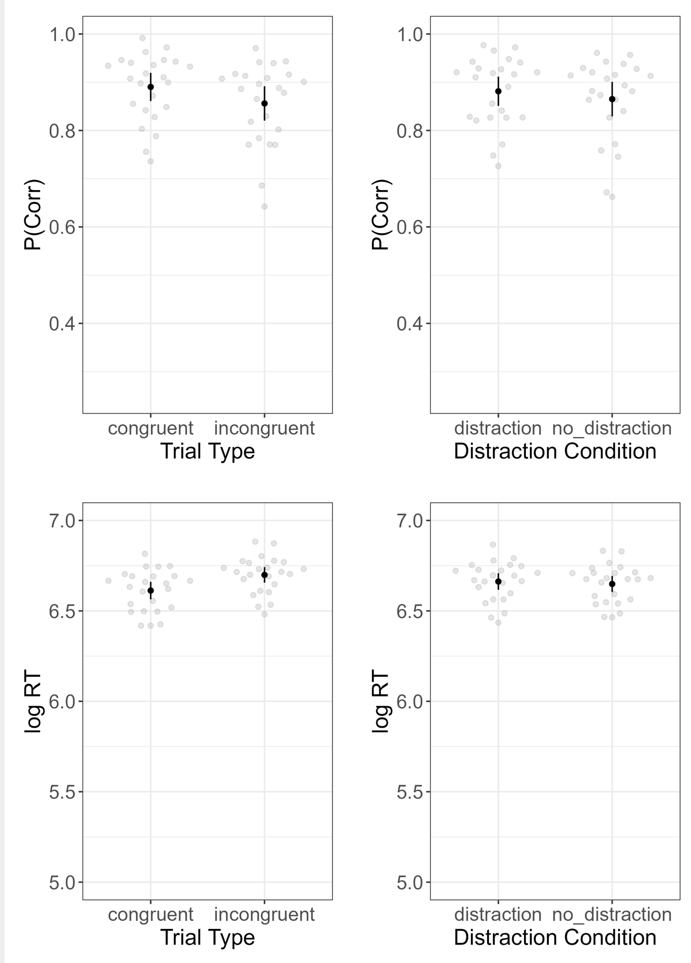


RESULTS (con't)

2. **Does *Focus* Score correspond to changes in performance**

Stroop Behavioral Results (right)

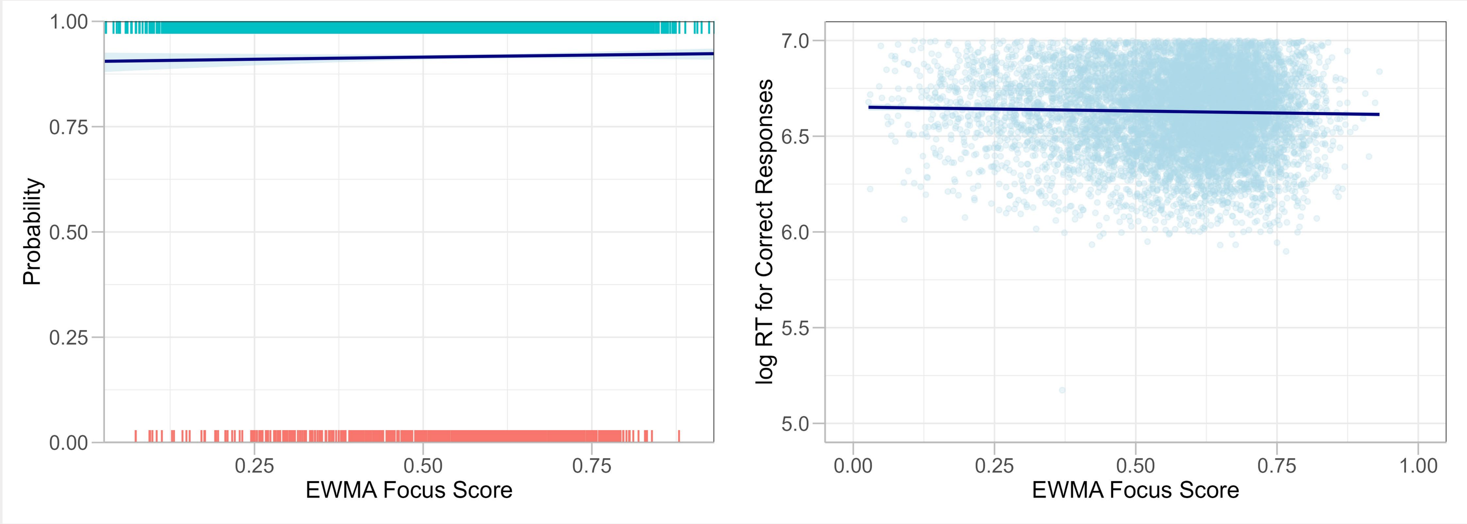
- Accuracy was higher (top left; p < .001) and responses were faster (bottom left; p < .001) for congruent than incongruent stroop trials
- Distraction did not harm stroop performance accuracy (top right; p = .14) or response time (bottom right; p = .07)



Error bars represent a 95%CI

Stroop Focus Score Results (below)

- An exponentially weighted moving average (EWMA) of *Focus* Score was not associated with response accuracy (below left; p = .33)
- Higher focus scores were significantly associated with faster RTs for correct responses (below right; p < .001) but not incorrect responses (p = *.26).*



DISCUSSION

- Neurable's *Focus Score* algorithm reasonably captured distraction events even though the distraction manipulation did not significantly impact Stroop task performance
- Roughly 30 seconds was needed to refocus on the stroop task after a distraction event, whereas focus remained stable during undistracted runs.
- Response times for correct Stroop responses were negatively associated with *Focus Score* such that faster RTs were associated with higher focus scores.
- The predictive potential of EEG-informed algorithms like *Focus Score* could be leveraged to provide personalized interventions (e.g., customized break schedules, neurostimulation, dynamic displays) to avoid performance lapses, but greater personalization and training data is necessary.
- Future work will focus on further examining Neurable's Enten hardware and algorithms for capturing neural features predictive of cognitive performance in more operationally relevant tasks and scenarios

REFERENCES

1. Van Orden, K. F., Limbert, W., Makeig, S., & Jung, T. P. (2001). Eye activity correlates of workload during a visuospatial memory task. *Human factors*, 43(1), 111-121.
2. Sawangjai, P., Hompoonsup, S., Leelaarporn, P., Kongwudhikunakorn, S., & Wilaiprasitporn, T. (2020). Consumer Grade EEG Measuring Sensors as Research Tools: A Review. In IEEE Sensors Journal (Vol. 20, Issue 8). https://doi.org/10.1109/JSEN.2019.2962874
3. Alcaide, R., Agarwal, N., Candassamy, J., Cavanagh, S., Lim, M., Meschede-Krasa, B., ... & Yousefi, A. (2021). EEG-based focus estimation using neurable's enten headphones and analytics platform. bioRxiv, 2021-06.
4. R Core Team (2022). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.
5. RStudio Team (2020). RStudio: Integrated Development for R. RStudio, PBC, Boston, MA URL http://www.rstudio.com/.