Using brain states to enhance user experience

Eun Youb J. Lee[1], Beste F. Yuksel[1], Daniel Afergan[1,4], Samuel W. Hincks[1], Tomoki Shibata[1], Erin T. Solovey[5],
Andrew Jenkins[1], Kurt B. Oleson[1], Lane Harrison[1,2], Evan M Peck[3], Remco Chang [1] and Robert JK Jacob[1]
| [1]Tufts University, Medford, MA [2]Worcester Polytechnic Institute, Worcester, MA
[3]Bucknell University, Lewisburg, PA [4]Google Inc., Mountain View, CA

INTRODUCTION

This presentation will present findings from colleagues in the Tufts Human Computer Interaction Lab. As neuroimaging technology improves, human computer interaction no longer has to rely solely on explicit commands of the user to adapt to the users' needs. **With functional near-infrared spectroscopy (fNIRS) passively sensing the brain activity of the user, people's mental states can now be inferred in real time, giving the computer an unprecedented opportunity to adapt and optimize itself to fit the user's needs without the user expending any of their resources.**

Experiments from the Tufts HCI Lab that successfully enhanced human performance through this approach will be explored in the unmanned aerial vehicles (UAV) experiment and the brain automated chorales (BACh) experiment.

METHOD: fNIRS

fNIRS uses non-invasive near-infrared light to detect levels of oxygenated (HbO) and deoxygenated hemoglobin (HbR) on the surface of the head. The light at this wavelength could go through the biological tissue and bone to be absorbed by hemoglobin in the bloodstream.
Because neural activity is accompanied by increased oxygen demands in order to metabolize glucose, fNIRS can detect activation at localized areas of the brain.

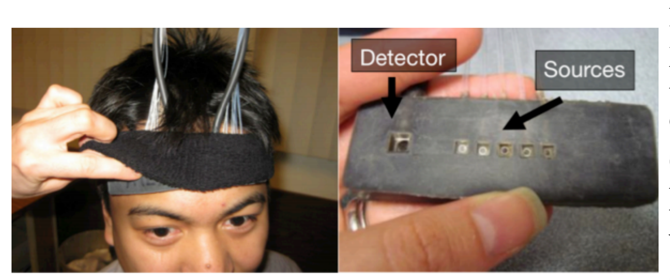


Figure 1. The fNIRS placed on the forehead via a headband to detect the prefrontal cortex activity. Each lights source (optical fibers) of the probe will emit near-infrared light at two different wavelength (690 and 830 nm) 1-3 cm deep into the cortex. Biological tissues are relatively transparent to these wavelengths, making the oxygenated and deoxygenated hemoglobin the main absorbers of the near-infrared light.

Studies in cognitive learning theory have shown that fNIRS could not only measure cognitive workload, but also track changes in brain function associated with improvements in performance of tasks.

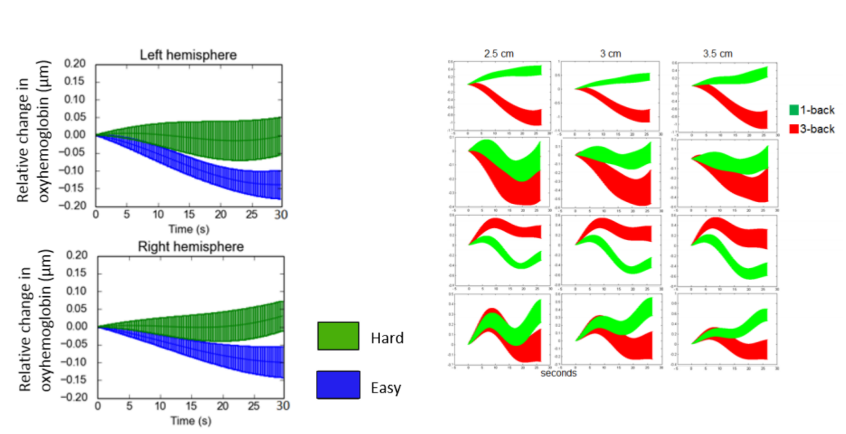


Figure 2. The mean change and the standard error of the fNIRS detecting the oxygenated hemoglobin in the prefrontal cortex. The fNIRS data of each individual participant varied, but showed a general trend of elevated levels of oxygenated hemoglobin correlating with tasks requiring higher cognitive workload from the user.

METHOD I: UAV paradigm

Unmanned aerial vehicle (UAV) experiment consisted of 3~7 moving UAVs being added or removed according to the cognitive workload of the user. The participant had to dynamically guide the UAVs to a sequence of targets as quickly as possible without crashing onto the obstacles. Cognitive workload was measured by by observing the general trend, while the UAVs were removed when there were no obstacles in the path because those demanded low attentional resources from the user.

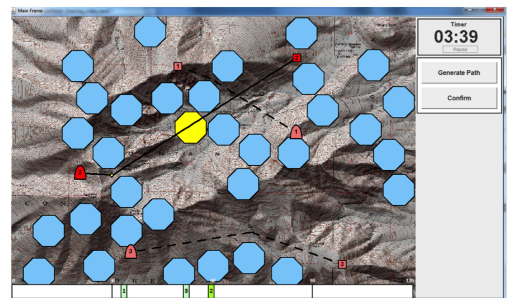


Figure 3. The UAV operator simulation. Participants had to navigate the UAVs to a sequence targets while avoiding moving obstacles (teal octagons) as soon as possible. The participant was penalized for flying through them or staying idle. Hence, the participant had to balance speed with control to avoid collision.

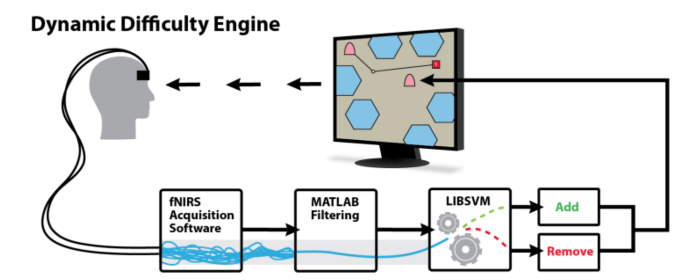
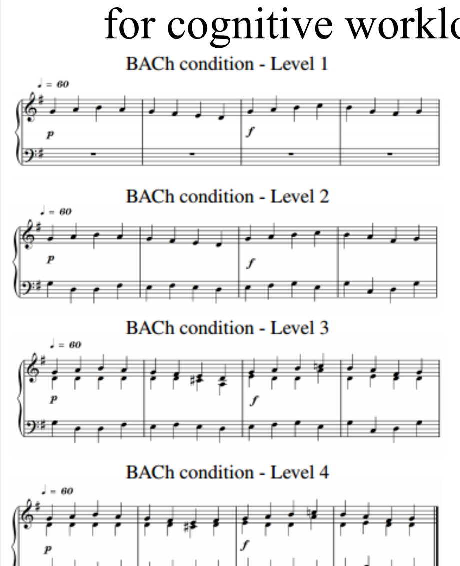


Figure 4. Closed-loop Dynamic Difficulty Adaptation Engine paradigm. The fNIRS data were filtered via MATLAB, then used to classify the cognitive workload of the user. When the user was in a suboptimal state with confidence average over 80% (boredom or anxiety), UAVs were either added or removed to assist the user in maintaining the optimal mental state.

METHOD II: BACh paradigm

Brain Automated Chorales (BACh) experiment had the computer dynamically adapt the level of difficulty of the material according to the user's cognitive state. The cognitive workload of the user was measured by how active the brain was relative to the baseline, as previous research has shown that increased proficiency leads to less necessity for cognitive workload resources to perform the same task.



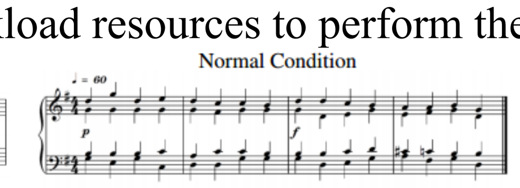


Figure 5. The scores used in the BACh Experiment paradigm. BACh added a full line of musical notes each time the user's cognitive workload was below a certain threshold, increasing the difficulty level and serving as a personalized tutor for the user. In contrast, the normal condition had the whole score present, with instructions to learn in any way they wished. BACh analyzed the last 30 seconds of real-time fNIRS data to make decisions and used a combination of brain data from training task and the user's current brain data to set an individual threshold for each learner.

Figure 6. The participant with fNIRS on during the BACh experiment. The user had a keyboard with weighted keys connected to the computer transmitting MIDI data via USB using Bitwig studio and the notes changed according to their proficiency with the piece

RESULTS: UAV Experiment

The UAV experiment showed that using a time series of confidence classifications to only change at times of high certainty could augment the user performance. The number of successful trials remained consistent for both groups, but the significant decrease in failures was observed. Adaptively alternating the number of UAVs not only reduced the operator's fail rate by 35% over the baseline, but also the variables associated with failures, showing that the Brain-Based Dynamic Difficulty Engine prevents user degrading in performance and enable a much longer span of attention.

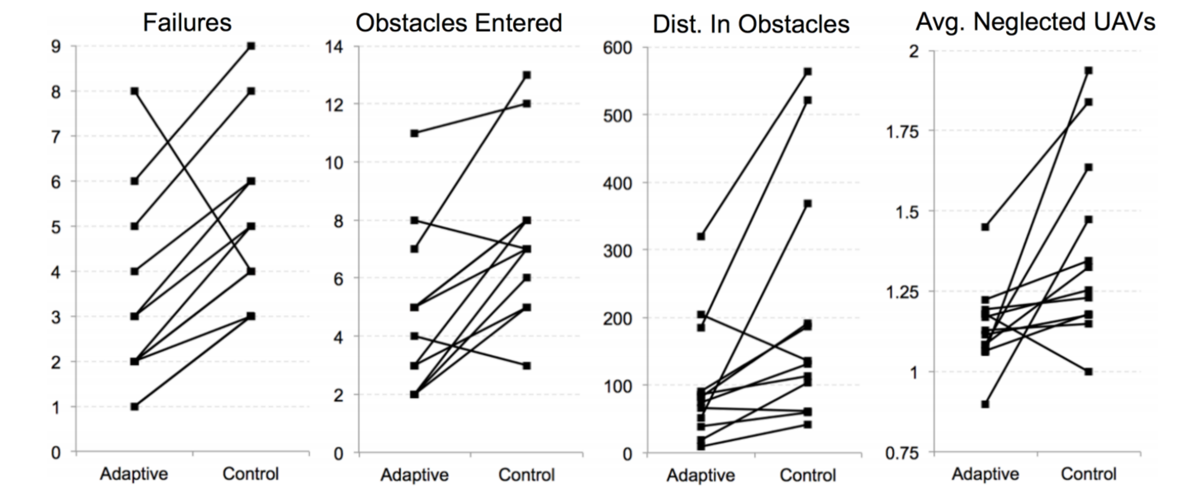


Figure 7. The slope graphs showing the effects of Brain-Based Dynamic Difficulty Engine for each participant.
Upward slopes indicate a better performance with the adaptive condition interface, while downward slopes indicate a better performance in the baseline condition. The following four measures showed significantly (p < 0.05) better performance in the adaptive condition interface.

RESULTS: BACh Experiment

The BACh experiment had measured the participants' performance level and those in the BACh group reported higher rating of mastery over the piece, playing correctly, easy to learn and enjoyment of learning over the control group. Personalization of the progress was also evident from the time each participant spent on each difficulty level.

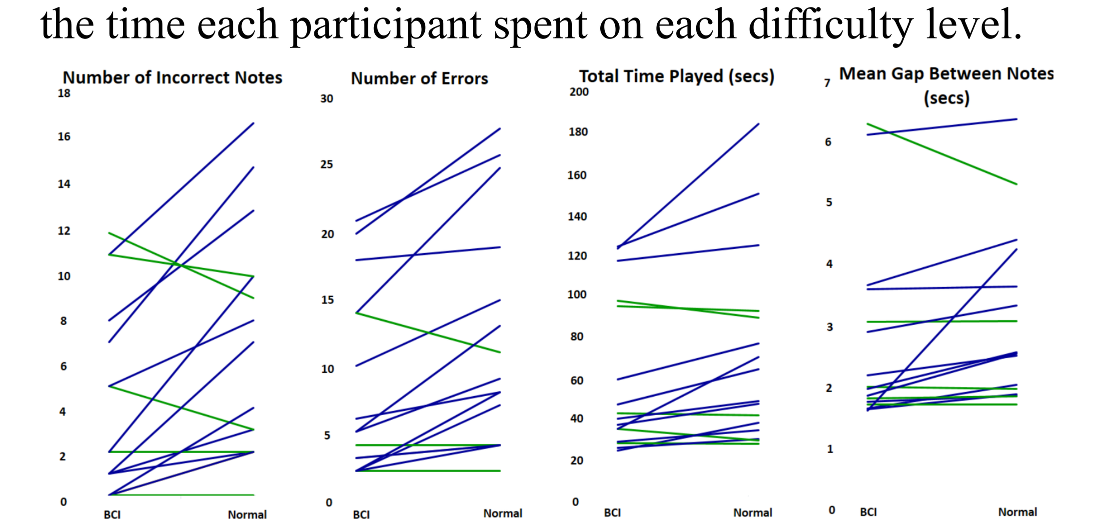


Figure 8. The slope graphs showing the effects of BACh for each participant. Upward slopes (blue) indicate a better performance with BACh, while downward slopes (green) indicate a better performance in the normal condition. Participants with BACh showed significantly better performance in all four conditions (p < .01), regardless of their initial skill set.

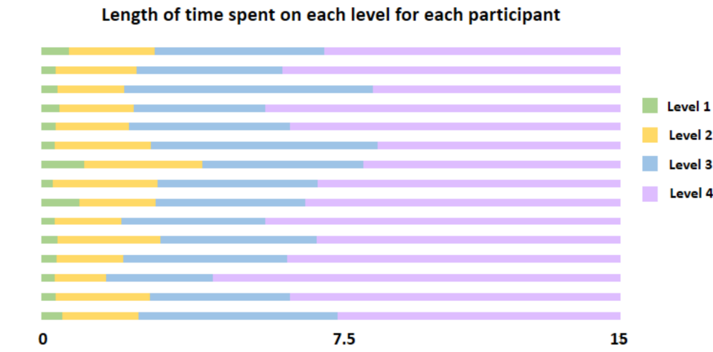


Figure 9. The time spent by participants on each level. The time spent on harder levels increased as expected, but the developmental time for each participant varied, suggesting that BACh was responding to user's cognitive workload like a personal tutor.

CONCLUSIONS

1. Uncovering cognitive workload via fNIRS could indeed provide useful information for the user to raise their performance during mentally demanding tasks.

2. These experiments show that the computers can now assist the user in learning or controlling their work flow, whether that be adjusting the pace of material presented to the individual or balancing the tasks load on the screen.

Findings suggest that fNIRS could have much potential in improving the performance of users with high-demand tasks. **With the resources for cognitive workload finite, computers could serve as a better guide for us to maximize the efficiency of our resources.**
Furthermore, computers having a better knowledge of the user's physiology could improve the user experience by controlling their attention span to be in the optimal state between mental states of boredom and anxiety.

Future research should **explore whether the confidence of the sensor data could be raised by increasing the number of sensors.** A limitation of fNIRS is that it detects slow trends of hemodynamic changes, like the fMRI. Thus, there will always be a slight delay between what the person experiences and what the sensors tell us. Moreover, fNIRS will be limited to only detecting the activity of the prefrontal cortex and fail to target the subcortical areas.

With research showing that certain level of stress is necessary for creative work, future research could integrate brain sensing data from fNIRS with electrodermal activity (EDA), which logs the stress level via measuring the sympathetic nervous system arousal, to notify the user at their peak creative mental state or with an eye tracker to help the computer implicitly detect the objects the user finds salient or challenging to assist the user's workflow.

ACKNOWLEDGEMENTS

I would like to thank Dan Afergan, Beste Yuksel, Sam Hincks, and Tomoki Shibata for not only giving me the opportunity to make a poster, but also providing me with abundant resources for me to complete this poster.
I would also like to thank Professor Jacob for giving me the opportunity to work in a field that I have always wanted to work in. My work was possible thanks to the support of Dan Afergan, Beste Yuksel and Professor Jacob.

FURTHER INFORMATION

For more information, please contact Josh Lee at josh.lee@tufts.edu

REFERENCES

Daniel Afergan, Evan M Peck, Erin T Solovey, Andrew Jenkins, Samuel W Hincks, Eli T Brown, Remco Chang, Robert JK Jacob (2014). Dynamic difficulty using brain metrics of workload. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (2014), InPress. DOI:* http://dx.doi.org/10.1145/2556288.2557230
Yuksel, B. F., Peck, E. M., Afergan, D., Hincks, S. W., Shibata, T., Kainerstorfer, J., ... & Jacob, R. J. (2015, March). Functional near-infrared spectroscopy for adaptive human-computer interfaces. In *SPIE BiOS* (pp. 93190R-93190R). International Society for Optics and Photonics.
Yuksel, B. F., Afergan, D., Peck, E. M., Griffin, G., Harrison, L., Chen, N. W., ... & Jacob, R. J. (2015). Braahms: A novel adaptive musical interface based on users' cognitive state. *New Interfaces for Musical Expression (NIME)*.
Yuksel, B. F., Oleson, K. B., Harrison, L., Peck, E. M., Afergan, D., Chang, R., & Jacob, R. J. (2016). Learn Piano with BACh: An Adaptive Learning Interface that Adjusts Task Difficulty based on Brain State. In *Proceedings of the SIGCHI conference on Human Factors in Computing Systems (2016), InPress. DOI: http://dx. doi. org/ 10.1145/2858036* (Vol. 2858388).
Yuksel, B. F., Afergan, D., Peck, E. M., Griffin, G., Harrison, L., Chen, N. W., ... & Jacob, R. J. *Implicit Brain-Computer Interaction Applied to a Novel Adaptive Musical Interface*. Technical Report TR-2015-01, Department of Computer Science, Tufts University, 2015. www.cs.tufts.edu/Technical-Reports. html.