AttentivU: Evaluating the Feasibility of Biofeedback Glasses to Monitor and Improve Attention

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AttentivU: Evaluating the Feasibility of Biofeedback Glasses to Monitor and Improve Attention

Our everyday work is becoming increasingly complex and cognitively demanding. What we pay attention to during our day influences how effectively our brain prepares itself for action, and how much effort we apply to a task. To address this issue we present AttentivU - a system that uses wearable electroencephalography (EEG) to measure the attention of a person in real-time. When the user’s attention level is low, the system provides real-time, subtle, haptic or audio feedback to nudge the person to become attentive again. We tested a first version of the system, which uses an EEG headband on 48 adults over several sessions in both a lab and classroom setting. The results show that the biofeedback redirects the attention of the participants to the task at hand and improves their performance on comprehension tests. We next tested the same approach in the form of glasses on 6 adults in a lab setting, as the glasses form factor may be more acceptable in the long run. We conclude with a discussion of an improved third version of AttentivU, currently under development, which combines a custom-made solution of the glasses form-factor with built-in electrooculography (EOG) and EEG electrodes as well as auditory feedback.

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Introduction
Given the increasing amount of information surrounding us, our 24x7 connection to the Internet and the constant shifting between increasingly complex tasks, all of us these days suffer from low attention spans. The problem represents an even bigger issue for as many as 10% of all school-aged children who suffer from ADD/ADHD, limiting their ability to do well in school. Current solutions - pharmacological and therapy - have modest success rates and many drawbacks. We believe that real-time monitoring of attention level and issuance of feedback may be valuable to both children and teachers and produce improved learning outcomes. We envision a future in which users can choose when they want to be attentive and make use of “smart attention glasses” to help them do so.

Prior research has used both subjective and objective methods to provide information to teachers and/or presenters about the engagement levels of their students/audience [6; 1; 8; 9; 10]. However, the feedback loop in these works was never closed and the information about the attention/engagement level of a person was never presented to him/her in real-time. In this work we argue for the importance of designing solutions to (a) measure attention level of users in real-time without adding a cognitive burden, and (b) provide feedback when their attention level is low in order to help them improve their attention to and performance on the task at hand. We present a wearable solution - AttentivU - a system that uses an EEG device to measure the attention of a person in real-time. When attention level is low, the system provides real-time, subtle, haptic feedback. Using 24 such devices we have tested our approach on 48 adults over several sessions in both a lab and classroom setting. The results show that the biofeedback redirects their attention to the task at hand and improves their performance on comprehension tests (paper under review).

We next evaluated our approach with a glasses form factor with built-in EEG on 6 adults in a lab setting. The preliminary results discussed below show that the glasses are an interesting form-factor to be considered for attention measurement. The overall feedback from the test users was very positive and indicates that it is viewed as practical and socially acceptable. We consider this to be important factors to be taken into consideration for a wider adoption of AttentivU, especially in a classroom setting. We are now developing a 3rd form factor, which consists of a custom-made solution of the glasses form-factor with built-in electrooculography (EOG) and EEG electrodes as well as auditory feedback.

Assessing Attention and Engagement Level
Several technologies are currently available for monitoring user attention and engagement with computer interfaces including gaze and eye-tracking systems, video recording devices, and a variety of sensors for measuring users’ biological data including heart-rate variability [4], galvanic skin response [3], and EEG [14; 5]. Out of these potential technologies, EEG was chosen for our project as the basis of the attention monitoring component due to the numerous...
studies that have demonstrated that EEG signals can be used to identify subtle shifts in user alertness, attention, perception, and workload in both laboratory and real-world contexts [2;7; 12].

**Our approach**
The AttentivU system consists of the following components:

1. an EEG sensing device to measure attention of the student in real-time during class;

2. a device that gives minimally disruptive haptic and/or auditory feedback to the student when his/her attention level is below a threshold;

3. software for real-time signal processing of brain signals;

4. an application to provide real-time data about the attention levels of multiple children to the teacher and enable him/her to turn the feedback on or off depending on the classroom activity.

We designed AttentivU as a solution to (a) measure attention level of users in real-time without adding a cognitive burden on users, and (b) give them feedback in order to help them improve their performance on tasks at hand. We have chosen the haptic modality for the first version of the system to provide subtle feedback to users who might already be engaged in processing a large number of visual stimuli, particularly in the classroom. We tested our approach using an EEG headband BrainCo (https://www.brainco.tech, Figure 1b) on 48 adults in both a lab and classroom setting in order to validate the feasibility and effectiveness of haptic feedback to improve engagement of users. The results show that the biofeedback redirects their attention to the task at hand and improves the learning outcomes [paper under review]. In this paper we discuss two newer versions of AttentivU: one version uses the Smith Lowdown Focus Eyewear to measure attention and the same necklace as in version one to provide haptic feedback about attention level in real-time. The third version is built using custom made glasses, which incorporate both EEG and EOG electrodes to measure attention/engagement of the student and feedback about the attention level is provided to the student in the form of an audio signal.

**AttentivU – using Smith Eyewear**

**EXPERIMENTAL SET-UP AND EEG PROCESSING**

We asked 6 subjects to watch a 25 minute video lecture on Fourier Transform. Each subject was sitting comfortably in a chair in a study room at the lab and was wearing a Smith Lowdown Focus Eyewear, a lightweight, dry-electrode pair of EEG glasses (Figure 1a, Figure 3). We recorded the EEG data at 512 Hz from the electrode sites TP9 and TP10 according to the 10–20 positioning system (Figure 4). Fundamental EEG research [11] provides a formula to calculate cognitive engagement using $\alpha (7−11 Hz)$, $\beta (11−20 Hz)$, and $\theta (4−7 Hz)$ frequency bands, where E, representing the engagement index, is calculated as: $E = \beta / (\alpha + \theta)$. The engagement index E reflects visual processing and sustained attention [2] and is able to identify changes in attention related to external stimuli. We built on top of prior research that uses consumer EEG headbands, which are used widely to detect cognitive engagement in the learning domain [6; 1; 8; 9; 10] as well as in other domains [13]. To collect and process EEG signals,
we developed an iOS application that connects to the glasses via Bluetooth. We apply a Fast Fourier Transform to the raw signal to extract the relevant frequency bands ($\beta$, $\alpha$, $\theta$) averaged over 1 second. We calculate the 1-second engagement index $E$. To filter the signal from muscle artifacts (e.g., blinking), we use a five second sliding window approach as proposed by [12; 8]. We then smooth the engagement index using an Exponentially Weighted Moving Average to pick up general engagement trend and further remove movement artifacts [12; 8]. This outputs a smoothed engagement index per 20 seconds $E_{\text{smooth}}$ sent to the necklace, which provides the haptic feedback once the system detects that a person is not engaged with the content of the lecture for at least 20 seconds. This interval was chosen empirically, based on the fact that EEG provides an imperfect measurement of brain activity and that the signal can be contaminated with noise related to the movement artifacts. We also recorded the EEG signals of each subject when they were solving a visual puzzle to obtain EEG signals corresponding to the engaged state ($E_{\text{max}}$). This is done to calibrate the system for each participant individually as the engagement process might be very different from one person to another depending on age, profession, background, etc. Furthermore, we recorded EEG signals for every subject while they were simply sitting with their eyes open (eye blinks were allowed), eyes open (eye blinks were not allowed), and eyes closed, so as to obtain the EEG signals corresponding to the non-engaged state ($E_{\text{min}}$). During this stage users were explicitly instructed not to attend to any particular imagination or other internal process or thought. This task took about 5 minutes. Based on the minimum $E_{\text{min}}$ and maximum $E_{\text{max}}$ engagement scores we calculate a normalized engagement score between 0 and 100 as $E_{\text{norm}} = \frac{(E_{\text{smooth}} - E_{\text{min}})}{(E_{\text{max}} - E_{\text{min}})} \times 100$ for each participant similar to [8;13]. The engagement range is represented by 3 different levels. An engagement score between 0-30 is considered low attention, 31-70 is medium, and high is 71-100. The haptic feedback in the form of two motors in the necklace is activated (e.g., sends a vibration) only when attention is considered to be low.

FEEDBACK COMPONENT: NECKLACE
The necklace is made in a form of a scarf, using a soft, cotton fabric (Figure 2b). It contains a 3D printed case with removable electronics consisting of an Adafruit Feather M2 WiFi Arduino board, 2 vibrating motors controlled by an Adafruit DRV2605L haptic motor controller, and a 1000mAh LiPo battery for a full day of use (Figure 2a). The vibration motors are located outside of the 3D case inside of the scarf so as not to create noise within the 3D case and interfere with the rest of the electronics. The vibration lasts for one second and when the user wears the scarf, the motors are roughly positioned below each of the collar bones. In order to design subtle haptic stimuli, we adjusted the voltage used to control the motors (pulse-width modulation), which changed the motor’s vibration frequency and vibration amplitude. A low intensity of 0.3g (40Hz) was chosen and considered as appropriate and did not interfere with any audio stimuli in the environment of the users.

PRELIMINARY RESULTS
All 6 participants reported that the necklace provided accurate feedback (vibrated at moments when they were not paying attention to the lecture contents). One subject reported that he was very sleepy and the necklace helped him to stay awake. All the subjects...
reported that they would use the glasses in the everyday life and three subjects pointed out that if the system was incorporated in one, integrated form-factor – they would buy it for use in everyday life. These results are preliminary, as the number of participants is very low but as this experiment is following a previous, more in-depth set of experiments (48 participants for the headband form factor), we find these results encouraging enough to build a model of the glasses which not only incorporates EEG electrodes and feedback in the form of an audio signal, but also EOG electrodes to further confirm the attention/engagement measurement with additional metrics.

Future Work and Limitations
We are currently developing a new version of AttentivU in the form-factor of glasses that incorporate both EEG and EOG electrodes and provide real-time auditory rather than haptic feedback to the user. We are using EOG as an additional modality to measure attention of a person, as EEG alone might be prone to errors due to noise induced by movements (although in our test use cases, the movements were limited). Moreover, in comparison with the EEG headband, the EEG electrode locations used in the glasses require additional confirmation to be used for accurate engagement measurement. EOG has previously been implemented and used for attention monitoring and hence may offer a complementary data source. As for the feedback component, we are considering the use of auditory feedback in this latest version of our project, rather than a haptic necklace, as we are interested in creating one integrated device and using haptic feedback in a glasses form factor is likely to be too distracting. If we are successful, the device in question can become something analogous to classic eye glasses: a solution for students to improve their mental focus, as opposed to their eyesight. The form factor of eye glasses is likely to ensure social acceptability of the device and can easily be put on or taken off at times when full attention is or is not required.

For future work we plan to first test the accuracy of EEG+EOG for real world attention measurement, design and evaluate the auditory form of biofeedback. Next, we plan to do extensive tests with children in lab and school settings to evaluate whether the device may help children to redirect their attention to the task at hand and whether it can improve their school performance. We will additionally test whether use of the system will gradually improve their natural ability to be attentive and whether effects last when the student is no longer using the device.

Our hope is that the system can provide an alternative option for children with attention problems, one that is potentially more effective and has fewer side effects and drawbacks than pharmacological solutions or expensive therapy. There is a possibility that the continuous, in-the-moment feedback will teach a child how to pay attention, so that his/her attention problem can be lessened or cured, rather than accommodated.

Apart from the expected benefits for children, the system will also benefit teachers and teachers-in-training by giving them a tool to monitor classroom attention level in real time and correlate it with specific class-time moments. Using this information teachers will be able to better adapt to class needs (for example, if the attention of all the children is below normalized value, this content of a lecture could be redesigned by the teacher).
While we will focus on experiments with school-aged children, the project’s impact is not limited to the K-12 age group but will potentially benefit students of all ages, including higher education and adults in workspaces.

**Conclusion**

In this paper we presented AttentivU - a system that uses wearable EEG glasses to measure the attention of a person in real-time. When attention level is low, the system provides real-time, subtle, haptic or audio feedback. Our initial results show that the biofeedback redirects the attention of the users to the task at hand. We discussed an improved version of AttentivU, which incorporates a custom-made solution of the glasses form-factor with built-in EOG and EEG electrodes as well as auditory feedback for further investigations in classroom setting. Overall feedback from our initial users indicates that glasses are a promising and realistic form-factor to be considered for attention measurement and regulation.

**References**

1. M. Andujar and J E. Gilbert. (2013). Let’s Learn!: Enhancing User’s Engagement Levels Through Passive Brain-computer Interfaces. In CHI ’13 Extended Abstracts on Human Factors in Computing Systems (CHI EA ‘13). ACM, New York, NY, USA, 703–708. DOI: http://dx.doi.org/10.1145/2468356.2468480
2. C. Berka, D. J Levendowski, M.N Lumicao, A. Yau, G. Davis, V.T Zivkovic, R.E Olmstead, P.D Tremoulet and P.L Craven. 2007. EEG correlates of task engagement and mental workload in vigilance, learning, and memory tasks. Aviation, space, and environmental medicine 78, Supplement 1 (2007), B231–B244.
3. W. Boucsein, A. Haarmannand and F. Schaefer. Combining skin conductance and heart rate variability for adaptive automation during simulated ifr flight. In Engineering Psychology and Cognitive Ergonomics, vol. 4562. 2007, 639–647.
4. E. A., Byrne and R. Parasuraman. Psychophysiology and adaptive automation. Biological Psychology 42, 3 (1996), 249–268.
5. E. Cutrell and D.Tan. BCI for passive input in HCI. In Proc CHI’07 (2007).
6. S. Dikker, L. Wan, I. Davidesco, L. Kagen, M. Oostrik, J. McClintock, J. Rowland, G. Michalareas, J.J Van Bavel, M. Ding and D. Poeppel. (2017). Brain-to-Brain Synchrony Tracks Real-World Dynamic Group Interactions in the Classroom. Current Biology, Volume 27, Issue 9, 1375 – 1380.
7. F. G. Freeman, P. J. Mikulka, L. J. Prinzel and M. W. Scerbo. Evaluation of an adaptive automation system using three eeg indices with a visual tracking task. Biological Psychology 50, 1 (1999), 61–76.
8. M. Hassib, S. Schneegass, P. Eiglsperger, N. Henze, A. Schmidt and F. Alt. EngageMeter: A System for Implicit Audience Engagement Sensing Using Electroencephalography In CHI ‘17: Proceedings of the 34th SIGCHI Conference on Human Factors in Computing Systems. ACM.
9. J. Huang, C. Yu, Y. Wang, Y. Zhao, S. Liu, C. Mo, J. Liu, L. Zhang and Y. Shi. 2014. FOCUS: enhancing children's engagement in reading by using contextual BCI training sessions. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI ’14). ACM, New York, NY, USA, 1905-1908.
10. M. Marchesi and B. Riccò. 2013. BRAVO: A Brain Virtual Operator for Education Exploiting Brain-computer Interfaces. In CHI ’13 Extended Abstracts on Human Factors in Computing Systems (CHI EA ’13). ACM, New York, NY, USA, 3091–3094. DOI: http://dx.doi.org/10.1145/2468356.2479618

11. A. T. Pope, E.H. Bogart and D. S. Bartolome. 1995. Biocybernetic system evaluates indices of operator engagement in automated task. Biological psychology 40, 1 (1995), 187–195.

12. D. Szafir and B. Mutlu. 2013. ARTFul: Adaptive Review Technology for Flipped Learning. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI ’13). ACM, New York, NY, USA, 1001–1010. DOI: http://dx.doi.org/10.1145/2470654.2466128

13. C.T. Vi, J. Alexander, P. Irani, B. Babaee and S. Subramanian. 2014. Quantifying EEG Measured Task Engagement for use in Gaming Applications.

14. T. O. Zander, C. Kothe, S. Jatzev and M. Gaertner. 2010. Enhancing human-computer interaction with input from active and passive brain-computer interfaces. In Brain-Comp Int. 2010, 181–199.