Gamified Wearable EEG Technology to Support Controlling of Cognitive Load After Brain Injury

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Abstract. Traumatic brain injury (TBI) results from an injury to the head. Depending on the severity of the injury and the affected regions of the brain, consequences vary a lot. Apart from physical challenges, a person with TBI may have various cognitive deficits, which affect the cognitive load of the person in different situations. The paper presents an early paper prototype for a wearable cognitive load measurement device design using biomarkers from an electroencephalogram (EEG). The paper discusses how the rehabilitation and daily tasks could be adjusted and optimized for individuals' needs by using such a cognitive load measurement tool. Designing this kind of system requires skills from various disciplines. Thus, the early product design was created in a multidisciplinary workshop. As everyday EEG-based tools are still in their early development phase, it is very important to pay a lot of attention to technical development. However, in order to facilitate the implementation of such technology, it is also crucial to concentrate on easy-to-wear, user-friendly, and fashionable product design.

Keywords: EEG · cognitive load · traumatic brain injury · product design

1 Introduction

Developments in measurement technology, wireless communication, and signal analysis have enabled consumer-oriented EEG devices to the market. Common applications include monitoring of meditation sessions, brain-computer interfaces (BCIs) to control games or robotic devices, and assessment of sleep quality. In this study, we are creating a concept of using wireless consumer-oriented EEG devices for monitoring cognitive load and recovery from mental exercise. As the main target group, people suffering from TBI are considered. Persons with TBI often experience fatigue that restricts daily life and returning to school/work [1]. Therefore, it is important to have measurement tools for increasing self-assessment of fatigue and cognitive load to tailor goal-oriented and effective rehabilitation while heading back to as normal daily life as possible.

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1.1 Traumatic Brain Injury (TBI) and Wearable EEG Measurements

TBI is a common condition worldwide. It results from an injury to the head, which causes sustained changes to brain activity. Depending on the severity and place of the injury, consequences vary a lot. Apart from physical challenges, TBI patients may have memory and learning difficulties, difficulties with paying attention and concentrating, following instructions, understanding others, difficulties completing complex tasks, word-finding difficulties, problems with organizing materials and many others [2]. Even simple tasks can increase the cognitive load, which is the stress put on our brain when learning new information or skills, and it is a consequence of the limitations of our short-term memory [3]. Cognitive load increases fatigue, which is another common symptom of TBI. Fatigue can significantly impact one's ability to participate in daily activities even years after a mild TBI [4].

When a person with a TBI returns to school or work, special arrangements might be needed. Recognition of fatigue and minimizing its effect are important parts of the arrangements as it is usually difficult for the person to recognize the signs of becoming tired. The ways of measuring fatigue are mainly subjective and patient-reported whereas objective tools are lacking. However, the ability to monitor cognitive load in real time would benefit the TBI patient, by allowing adjustments to be made to guarantee sufficient pauses and rest needed during cognitive tasks such as learning.

EEG is probably the most common objective indicator of TBI [5]. EEG measurements have also been successfully used to measure cognitive load in various contexts such as reading text of various complexity [6], undergoing intelligence tests [7], engaging in basic, logic and problem-solving tasks [8] and simple-to-multiple-choice tasks [8].

In a recent study [8] by the authors, EEG data was collected with ENOBIO® EEG recording system by Neuroelectrics® while test persons were playing an N-back memory game at different difficulty levels. The data was only acquired from the Fp1 and Fp2 electrodes, located on the forehead, to mimic the recordings with more easy-to-use EEG devices for real-life situations. Cognitive load variations were detected and EEG biomarkers for cognitive load developed. A classification accuracy of 81% was obtained when the data were categorized into segments of three levels of cognitive load. In a more recent, yet unpublished study even better classification accuracy was obtained by the authors using the MUSE® EEG consumer headband by InteraXion Inc. Recently, these kinds of wearable EEG devices have entered the consumer market. Common to all is a lower cost, lower number of electrodes, easier application, and no need for conductive gels as opposed to EEG devices in clinical applications.

1.2 Multidisciplinary Concept Creation and Product Design

The development of cognitive load measurement tools for everyday environments requires multidisciplinary skills and co-designing. Co-design refers to the collective creativity of a multidisciplinary group of people [9]. The users/user proxies play an important role in this process. The process starts with a pre-design phase, in which understanding of users and contexts of use is increased, and technological opportunities are explored. After this, the process follows the traditional design process, where the resulting ideas are developed into concepts and prototypes that are refined based on the feedback of the users. This study concentrates on the concept-level development and creation of an early product design. Jesse Garrets framework in UX design [10] is used as a guideline to support the product design process.

2 Concept Creation and Product Design Workshop

A co-design workshop was organized to design a wearable tool which utilizes developed EEG biomarkers for cognitive load recognition, introduced in the article [8]. People with versatile professional backgrounds (physiotherapy (1), nursing (1), research (1), automation (1) and radiography (1)) participated in the workshop.

Prior to the workshop, the participants listened to presentations about existing EEG devices, their possibilities and use applications as well as about detecting stress and cognitive load via EEG. The first part of the workshop aimed at a concept determining users and their needs (Garret's user needs layer [10]). The participants first created a user persona, specified the problem to be solved and created ideas to solve the problem. User profile, problem definition and idea canvas were used to help in the work. After producing ideas, the team voted on the best idea to be further developed.

The second part of the workshop focused on product design. The participants were guided by the question "How do the user's needs turn into a product?". In the product design phase, Jesse Garret's [10] Scope, Structure, Skeleton and Surface layers were taken into consideration. The aim was to provide a concept-level solution for the identified problem of the described person.

3 The Concept-Level Product and the Early Product Design

First, for the concept, the group defined the user as a young school-aged boy with a TBI. His rehabilitation was agreed upon to be at the stage where he could start attending school again. The most challenging symptom is fatigue and cognitive load during school days. It is difficult for him to analyze on his own whether he still has resources to continue studying or should he have a break. There is a personal assistant, a special education teacher and therapists (occupational and physiotherapist) beside the teacher in the multidisciplinary team that helps him in the rehabilitation process in studying. It is challenging also for them to recognize whether the boy has resources to study more.

Because most commercial EEG devices are very visible and sometimes uncomfortable, the visual design was ideated to be easily wearable and beautiful: a jewel or a tattoo-like plaster (Fig. 1). The electrode would for example look like a diamond and it would be placed on the forehead. Different models could be designed according to the user. This device would contain a wireless sticker electrode(s) and miniaturized readout electronics. Results of cognitive load would be seen through an app that is connected to the measurement device using a wireless connection such as Bluetooth.

A cognitive load app was created to increase engagement and to ease the interpretation of the data. The game elements of the prototype were chosen by the participants especially to provide a quick status check. The main screen sketch is presented in Fig. 1. From the main screen the user, therapist, or other stakeholder can quickly check the current status and the total cumulative cognitive load of the day, or navigate to see some more detailed statistics (trophies, progress, activities, cognitive load setting and status for different times of the day).

The health bar indicates how much resources for cognitive load the person still has for the day. The "max health" (maximum total cognitive load the person can experience in one day) is preset by the therapist according to the calibration discussed later. The current status is visualized as traffic lights which are easy to understand and fast to check. Green indicates normal cognitive load, yellow indicates that the cognitive load is increasing and red is a sign of alert in cognitive load. Also, these levels are calibrated for each individual. There are also optional additional functionalities to preset and check health bars for 6-12am, 12am-6pm and for the evening (6pm-sleeping time), in case the user needs help in dividing the load during different times of the day. There could also be preset activities whose cognitive load the app is measuring and visualizing. These can be enabled and adjusted in the app. The user receives trophies when achievements exceed the average goals set for a day. After the days that did not go that well, he receives feedback on the actions or periods when he should have decreased the load. This is discussed with the therapist. This prototype is only worn when awake and charged during the night. In the future versions, the device could also be further evolved to measure sleep and adjust the "health bar" according to the recovery during night and day.

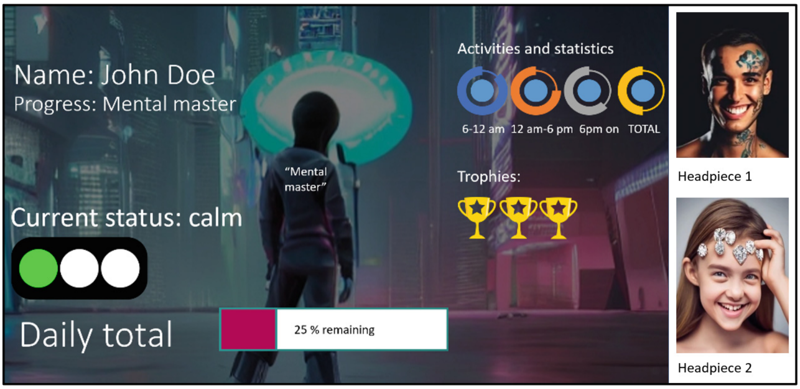

Fig. 1. A sketch of the app screen and headpiece designs (created with the help of [12] & [11]).

Since EEG and cognitive load are unique for everyone, a calibration must be done for each user. The calibration could be performed by measuring reference EEG data for an agreed time period during which the user performs the agreed activities in the agreed schedule while wearing the EEG device. In the first prototype, a data analyst could calculate the cognitive load which arose during the calibration period in different situations. In an advanced prototype, this could be automated and performed in the application. Based on the reference data, cognitive load settings would be then set up to the application by the therapist with know-how on the user's case and abilities. However, the rehabilitation process also includes constant interaction with the stakeholders and constant assessment for further adjusting the settings according to the user's progress.

4 Discussion

The purpose of the product design presented in this paper is to enhance the user's rehabilitation and education. The produced concept provides a tool for professionals such as the therapist as well as teachers to adjust the cognitive performance requirements according to the user's condition and state. It also teaches the user to control their own resources. However, the actual implementation of the prototype and the rehabilitation services needed in the use of the prototype should be further investigated and the processes modelled. The therapists and other stakeholders should be properly educated about the use and the purpose of the tool. The professionals should have an active, couch-like, role in setting the goals, observing the progress, and helping the user to recognize the signs of fatigue more easily using the app.

Although the prototype should be made enjoyable and easy to use, it is also highly important to implement gamified applications based on the needs and goals of the rehabilitee. The understanding of the symptoms and disabilities caused by TBI as well as tailored and goal-oriented rehabilitation is the key element when developing a device for supporting one's rehabilitation and coping in daily life.

Although the prototype is designed for a TBI patient, it can be easily modified for various other user groups. It could be used to adjust different kinds of activities of a person's everyday life according to personal goals and abilities. For the working-aged, it would offer a tool for supporting persons to achieve a more cognitively ergonomic working style. Additionally, it would serve various users with partial ability to work, to adjust the working conditions according to their situation. The tool could also benefit teachers in classrooms. It would allow them to more easily assess the need for breaks, and extra study support as well as apply adjustments in teaching while seeing the students' cognitive load status. This would contribute to optimizing the learners' capacity to make learning easier and more enjoyable. Such tools could promote the inclusion of all learners.

As everyday EEG-based tools are still in their early development phase, it is very important to pay attention to technical development. However, it is important to concentrate on easy-to-wear, user-friendly and fashionable product design. Since EEG is typically measured in clinical settings, there is still a lot of work in product designing for everyday environments. Our future work will focus on making the first functional prototype of the app with existing EEG measurement hardware as the development of new hardware requires long development and test phases and potentially fine-tuning the biomarkers. As the focus of this paper was on the user needs, further game design is also required. A well-known MDA framework [12] will be applied in the design process, as the "entertainment" element will play a crucial role in the next development steps.

5 Conclusions

Monitoring stress using physiological signals has recently achieved attention since cognitive load has a significant adverse influence on an individual's daily health and efficiency. In addition to technical development, the implementation of such technology requires a desirable design of the product. This paper concentrated on the product design of a wearable cognitive load measurement device using biomarkers from EEG. The development in this study focused on the product design of such a tool for the rehabilitation of a person with TBI. The aim of the tool is to enable adjustment of the rehabilitation and daily tasks according to the cognitive load experienced by the person. As this requires skills from various professionals, the concept was created in a multidisciplinary workshop. The next step is to focus on the technical development.

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