FOCUS: Enhancing Children's Engagement in Reading by Using Contextual BCI Training Sessions

1st Author Name
Affiliation
Address
e-mail address
Optional phone number

2nd Author Name
Affiliation
Address
e-mail address
Optional phone number

3rd Author Name
Affiliation
Address
e-mail address
Optional phone number

ABSTRACT
Reading is critical for deriving knowledge and for children's personal growth. The reading achievement can be enhanced by increasing reading engagement. To enhance the children's reading engagement, we designed a reading system - FOCUS with a combination of contextual brain-computer interface (BCI) training sessions. The BCI training sessions are activated when the system detects significant engagement drops and closed automatically when the engagement returns to a high level. An experimental evaluation of our system showed that FOCUS significantly improves children's reading performance in reading engagement and comprehension. The score of the recall task increases by 40.9% and the accuracy rate of the quiz increases by 26.8%.

Author Keywords
Reading engagement; brain-computer interface (BCI); contextual reading

ACM Classification Keywords
H.5.2. Information interfaces and presentation: User Interfaces – input devices and strategies, evaluation/methodology, user-centered design; K.3.1. Computer Uses in Education.

INTRODUCTION
Reading is the primary method to derive knowledge and reading achievement is critical for children's future academic achievement and personal growth. Reading achievement is strongly correlated to reading engagement [1]. Reading engagement can be measured by the Brain Computer Interface (BCI) technique with a record of the brain's electrical activity. In this paper, we design and evaluate a novel reading system - FOCUS to enhance children's reading engagement through contextual BCI training sessions. Once detecting significant reading engagement drops, FOCUS will activate BCI training sessions associated to the reading content. And the training session will be automatically closed once the engagement returns to a high level.

An experimental evaluation of our system illustrated that FOCUS significantly improves children's reading performance both in engagement and comprehension. We also found that each participant had his/her own stable reading engagement and a few participants kept the adjusted high level of reading engagement for a long period. In addition, it is useful and effective to customize one's engagement span by providing warm-up tasks related to the upcoming experiment tasks in advance.

RELATED WORK
Electroencephalography (EEG) is a technique that records the brain's electrical activity. These brain's electrical signals are recorded as different wavy lines that we call brainwaves. Brainwave patterns are generally categorized in four categories: Delta (0.5-4Hz), Theta (4-8Hz), Alpha (8-13Hz) and Beta (13-30Hz). Delta and Theta are known as slow wave activity and are associated with states such as daydreaming and drowsiness. Alpha is associated with a relaxed state of unfocused attention. Beta is referred to as fast wave activity and is characterized by a state of high alertness, concentration, and focused attention [4]. Specifically, a previous research has provide the following formula for calculating a signal E based on $Alpha\ (\alpha)$, $Beta\ (\beta)$, and $Theta\ (\theta)$ waves that is highly correlated with participant task engagement [7]:

$$E = \frac{\beta}{\alpha + \theta}$$

BRAVO is an e-learning application that provides customizable lectures for students by detecting each user's brain activity, in particular attention and meditation levels, during taking courses through a commercial BCI [5]. This application is smart and personalized, but lectures change as long as temporal boredom state appears. Because it is common for students to take some basic courses that are less interesting to them. LET'S LEARN, on the contrary, focuses on helping users to better learn a material even when it is uninteresting by displaying engaging videos related to the reading when the engagement drops under the baseline through the detection of a wireless EEG headset [6]. The engaging videos mentioned in LET'S LEARN are from YouTube that are not specific design for the reading content. PAY ATTENTION designs an adaptive embodied agent that monitor and improve user engagement by offering attention-evoking immediacy cues including modulating spoken volume and using gestures to regain participants' attention [2]. Previous works in this area are innovative and illuminating. Researchers have applied the

BCI engagement mode to measure subjects' learning performance while providing optional interventions for regaining subjects' engagement. However, works above, instead of stimulating participants' inner motivation for going back to an engaged state, they offered traditional media without users' participation.

FOCUS

FOCUS, different from previous researches, increases the user's engagement by requiring the user actively participate in the immediacy media rather than passively receiving information. In our system, the immediacy media are specifically designed brain computer interface (BCI) training sessions, which follow the medical principle of neurofeedback therapy. The training sessions use the BCI technology to translate the user's mental conditions, especially the attention state, into task control. Thus, they need participants highly involved. Since BCI training sessions are proved to be effective for improving one's attention [8]. These engaging training sessions are not only helping children regain their engagement in reading but also offering training methods for improving their attention ability in reading. The activation mechanism and the driven mode of BCI training sessions in FOCUS system are based on the highest and lowest customized thresholds of engagement of each participant. Once detecting drops in the user engagement, the corresponding BCI training session will appear with a prompt. And it will automatically close with another prompt when the user has recovered to an engaged state.

System Description

FOCUS, as shown in Figure 1, combines three major components: an Emotiv wireless EEG headset, a fixed pocket projector and a physical book with designed reading contents. There is a host computer as the backend system connecting these three components for data input, data processing and data output.

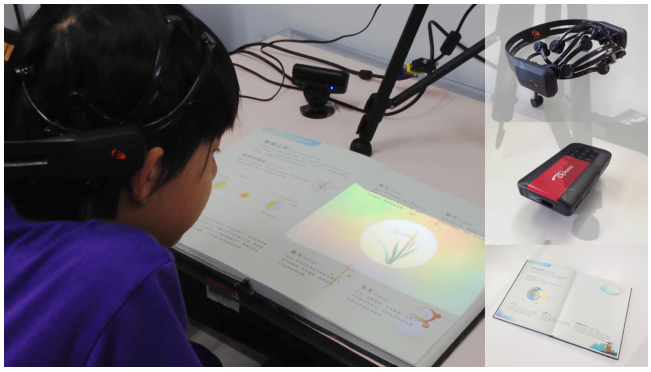

Figure 1. The System of FOCUS

Emotiv wireless EEG headset: The Emotiv headset exposes 14 EEG electrode sensors with two bipolar reference electrodes spatially organized using the International 10-20 system. They are AF3, AF4, F3, F4, F7, F8, FC5, FC6, T7, T8, P7, P8, O1 and O2. We picked up useful information about attention activities from these sensors through the Emotiv TestBench that provides real-time EEG data of the mental state. Besides, we translated these electrical signals into different engagement levels by using the *E* formula.

The Pocket Projector: The projector fixed in a table lamp, which is well fitted in the reading environment, projects virtual contents on the physical book.

The Physical Book with Designed Reading Contents: The contents of the book dividing into four lessons with a coherent theme of "Our Planet" are picked from the Children's Encyclopedia. These four lessons are Solar System, Earth Rotation, Earth Revolution and Earth's Climate. For guaranteeing the same level of difficulty between the four lessons, we adjusted and finalized the reading contents with a literature teacher from the Primary School nearby. The contents have been edited and reformatted on left pages for experiments, because right pages are left for virtual contents from the projector, including BCI training sessions, prompts and rewards.

Virtual Contents

BCI training sessions: Corresponding to four lessons, there are four BCI training sessions, which are well integrated into the reading content. For instance, the training session of Earth Rotation, participants are asked to concentrate on imaging the earth keep right rotating in order to promote the development of a scene that slowly changes from day to night. These training sessions are strongly related to the knowledge of reading contents with the help of enhancing children's understanding. In addition, the progress of each session depends on one's engagement performance by real-time mental state detecting through the wireless EEG headset.

Prompts: Prompts guide participants switch smoothly between reading contents and training sessions. Prompts consist of three types: (1) Leading the participants to take the training session, (2) Reminding the participants to take once more of the training session if one's engagement level fails to reach the good reading state, (3) Leading the participants to go back to continue reading.

Rewards: An incentive mechanism is very important for developing a learning system for children, and providing right kind of rewards is critical for children to form good behaviors. Social rewards, which involve attention, praise, or thanks, are often more highly valued by children than a toy or food. Simple gestures like pats on the shoulder, verbal praise, nods, or smiles can mean a lot [3]. In designing our rewards for children, we aim to use images to act as virtual social rewards, such as a smile face, hugging, praise (text/audio) and sample music.

EXPERIMENT

Participants

A total of 24 participants (14 girls and 10 boys) took part in this experiment. All participants were from the primary

grades of a nearby Primary School. The average age was 7.56 (SD=0.86) with a range of 6-8.5.

Design

In the experiment, a lesson with its BCI training session is defined as an experimental unit, each participant takes two units by following two different reading mode: (1) In-order Reading: reading the passage before taking the BCI training session. Adding the BCI training session is to guarantee the amount of information is equal to the contextual reading mode, (2) Contextual Reading: reading the passage with an activation mechanism of the BCI training session according to the participant engagement state. In the contextual reading mode, participants only need to follow prompts to switch between the passage and its BCI training session until finishing reading the passage. In this study, participants took the two reading modes of experimental units in a random order to guarantee the results were counterbalanced. For data analysis of the engagement level between the two reading modes, we picked out data of engagement within reading for comparison.

In order to define the highest and lowest customized thresholds of engagement that are essential for running the whole system, we design three warm-up tasks for each participant. The three tasks are 5-minute resting, 5-minute of a similar passage reading and 5-minute of a system-provided BCI training session. A pre-study of the average value of engagement of the three tasks in sequence from low to high is resting, reading and training. Resting as a low frequency brain activity, its average engagement level is considered as the value of one's lowest threshold. A similar passage reading helps researchers to have a basic understanding of one's engagement span of the upcoming reading task. Training in advance lets participants get used to the training mode. For defining the highest threshold, we select the larger value between the highest value of reading engagement and the average value of training engagement with a consideration of the engagement span of reading. The average reading engagement is the threshold for driving the progress of BCI training sessions.

Procedure

Before the experiment, we showed a demonstration video guiding children to use the EEG headset controlling virtual objects through motor imagery in order to complete a simple task, because all participants were so interested but confused about this unusual interactive equipment at first. After signing a content form and being given a brief description of the experiment, participants were brought into a controlled room. For each unit, we asked each participant a brief question related to the theme of the upcoming reading content in order to ensure that the participant had no prior task knowledge. Then the researcher aided the participant in putting on the wireless EEG headset and ensured effective connectivity. Here the researcher asked the participant to perform three warm-up tasks for customizing the highest and lowest threshold of engagement. Once the two thresholds were defined, the participant started the experiment. After finishing a unit, each participant was presented with a recall task and a quiz that assessed the participant's understanding of the reading content. And there was a subjective evaluation of FOCUS for each participant at the end of the experiment. Among the data we obtained from the 24 participants, 4 experimental unit data were abandoned due to the failure of activating the BCI training session in the contextual reading task.

RESULTS

We utilized with-in subjects one-way ANOVA to analyze our data. There was no statistically effect of four lessons on both engagement ($F(3,11696) = 1.35$, $P=0.43$) and understanding (Recall: $F(3,39) = 2.14$, $P = 0.13$).

Engagement Results - Engagement of contextual reading (Mean=1.705) is significantly higher than that of in-order reading (Mean=1.693) ($F=382.16$, $P<0.001$) as shown in Fig 2.

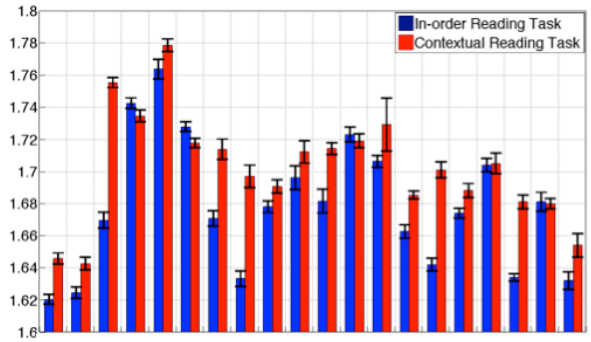

Figure 2. Comparison of engagement between in-order and contextual reading tasks with

Comprehension Results - Understanding of contextual reading is significantly higher than that of in-order reading (Recall: $F(1,39)=10.61$, $P=0.002$, Quiz: $F(1,39)=13.03$, $P=0.001$) as shown in Fig 3. On average, recall score increases by 40.9% (0.90) and quiz score increases by 26.8% (0.725).

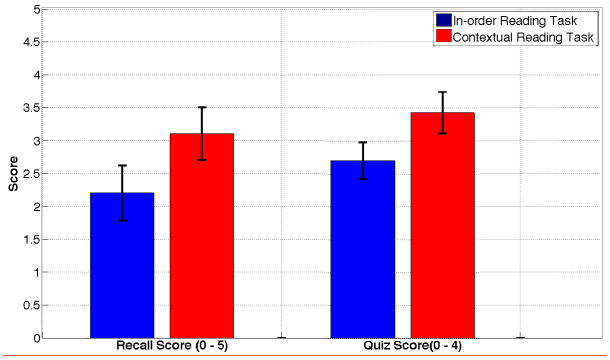

Figure 3: Comparison of knowledge understanding between in-order and contextual reading tasks

All participants showed great interest in FOCUS. They felt a sense of achievement to fulfill a task by the power of focus and said that they were more interested in reading with associated BCI training sessions. It was not a burden for most participants to read by wearing an EEG headset except one participant reported that it was uncomfortable.

DISCUSSION AND FUTURE WORKS

Through data analysis, we found that each participant had his/her own stable engagement level of reading with a range of 1.605-1.800 (Mean=1.702, SD=0.06). And all participants had an excitement with a rapid decline afterwards at the very beginning of reading, and gradually stabilized around an engagement level of their own.

Since we found that reading with contextual BCI training sessions could effectively improve children's engagement in reading. The BCI technology was not only work as a monitor but also a driver for enhancing children's engagement in learning activities, in this case of reading. It provided a new kind of interventions in enhancing children's learning performance through BCI technology. However, even though the engagement level of contextual reading was higher than that of reading in order, the upward tendency of engagement level stimulated after taking the BCI training sessions was not stable. Only six of the participants could maintain the adjusted high level of engagement for a long time span. The rest participants were back to their own stable reading engagement level in a short period. It probably could be that BCI training sessions based on the medical principle of neurofeedback therapy often require an intensive and long-term training schedule. We are looking forward to have a long-term experiment on children for observing if the original stable engagement level in reading of each participant could be enhanced by FOCUS.

The observation of engagement levels of three designed warm-up tasks in advance was useful and effective for customizing one's engagement span in reading. In the experiment, The average level of engagement of these three tasks in sequence from low to high is resting (Mean=1.618, SD=0.045), reading (Mean =1.674, SD=0.043) and training (Mean=1.712, SD=0.067). The changing curve of engagement of resting maintain steady in a low level, while the curve of training fluctuate wildly within a high level span. And the maximum difference between the highest and the lowest values based on the E formula of one's engagement is 0.302 among the participants.

This study provided first-hand data for further study in ADHD (Attention Deficit Hyperactivity Disorder) children's performance in reading for comparison. We aim to ultimately modify this reading system for ADHD children. With the suggestions of psychiatrists for ADHD treatment, we researched and experimented healthy children as the first step.

CONCLUSION

We created FOCUS that a reading system provides contextual BCI training sessions appropriately by the real-time state detecting of one's reading engagement. We found children's engagement and comprehension in the contextual reading mode were significantly improved compared to those tested in the in-order reading mode. Furthermore, participants showed great interest in FOCUS and preferred to read with contextual BCI training sessions. We hope that we can take a long-term experiment on children for observing the development of children's reading performance with the contextual reading mode and have a further study based on this first-hand data for comparison of ADHD children's reading performance.

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