No hands needed: Investigating the affordances of using a Brain Computer Interface (BCI) as a game controller and its potential effect on learning and user experience

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Abstract

Recently, Brain Computer Interfaces (BCIs) have attracted attention in the educational gaming field, but research with such devices is sparse. This study used the Emotiv EPOC BCI neuroheadset to investigate the affordances of using BCI as a game controller and its potential effect on learning and positive player experiences, with a view to providing implications for designing educational games. The study showed that the Emotiv interface helped participants learn abstract symbols and their associated English meanings as well as those who did not use the headset. Additionally, the BCI shows promising potential as fun and engagement were consistently higher throughout the game. Educational game designers can consider the potential of BCIs and how they can take advantage of increased engagement towards better learning.

Introduction

Educational researchers have been dabbling with interactive media that allow learners and users to explore educational content through various theoretical approaches, including digital (virtual) immersion, (serious) games, simulations, situated learning, embodied cognition, multimedia learning based in cognitive theory, etc. (Annetta & Bronack, 2011; Dede, 2009; Mayer & Moreno, 1998). Particularly, in immersive digital gaming environments, the user's experience depends vastly on whether he or she believes that he/she is fully immersed in the environment using (all or some of) his/her senses. "The more a virtual immersive experience is based on design strategies that combine actional, symbolic, and sensory factors, the greater the participant's suspension of disbelief that she or he is 'inside' a digitally enhanced setting" (Dede, 2009, p. 66). New interfaces, such as Brain Computer Interfaces (BCIs) particularly focus on the actional and sensory factors, specifically the user's neural activity that is triggered while performing a cognitively demanding task such as playing a game. Nijholt, Bos and Reuderink (2009) suggested several ways to use BCI for game designs; generally concentrating on its use as a controlling interface and feedback mechanism based on EEG signals. The present exploratory study used the Emotiv EPOC neuroheadset to investigate the affordances of using BCI as a game controller and its potential effect on learning and positive player experiences with a view to providing implications for designing educational games.

Brain Computer Interfaces (BCIs)

BCIs are devices designed to detect neural activities, particularly the ongoing electroencephalogram (EEG) signals, of a brain in a non-invasive way that offers "an alternative communication and control channel that does not depend on the brain's normal output pathway of periphery nerves and muscles" (Millan, 2003, p. 75). BCIs can translate those neural activities into operative control signals (Leeb et al., 2007; Allison, Wolpaw & Wolpaw, 2007) that can be recognized by a computer for interpretation. BCIs have predominantly been used in the physical rehabilitation and medical fields, but are now being researched in other areas, including education. Education researchers may be interested in the possibility of BCIs in learning contexts as off-the-shelf wireless EEG headsets become more available for public consumption, and as many move away from interfaces that require touch or clicks to explore motion and sensor-controlled interfaces. In game development, input obtained from the measurement of brain activity through electroencephalography (EEG) headsets such as NeuroSky's Mind Set and Emotiv's EPOC neuroheadset are attracting attention.

BCIs and Games

Some studies have shown that simple error detection triggers relatively fixed EEG patterns in a certain brain region. Other studies have taken such research one step further and shown that imagined movements trigger the same cortical areas in the brain as in the areas when such movements are executed in real life (Arzy, Thut, Mohr, Michel & Blanke, 2006; Astafiev, Stanley, Shulman & Corbetta, 2004). These are important findings because BCIs require that users control movement of game objects with their thoughts, not their body. In addition, regarding human-computer interaction, there is a lack of research on communication, user experience and user sense of control from a healthy person's brain to a computer in a game-based environment (Müller, Krauledat, Dornhege, Curio & Blankertz, 2004).

BCIs are not a replacement for other modalities (e.g. physical movement), but can be used as one of multiple input modalities, although application and research is still rare in this area. While BCIs potentially afford richer game experiences, they bring challenges as well. Users are less likely to be able to control a BCI environment because it is difficult to concentrate on a consistent thought and maintain it through the course of use (Guger et al., 2009). Lack of full and seamless control may prevent users from enjoying game play and pose bigger threats to learning in the case of educational games.

Sense of Control

Although sense of control has different constructs in the literature (see Stipek & Weisz, 1981 for a review), it generally promotes motivation (Boggiano et al., 1988) and self-efficacy (Schunk & Pajares, 2009) in academic settings. Likewise, providing sense of control over an activity is an important design consideration for intrinsically motivating instructional programs (Lepper, 1988) and is widely applied to the designs for effective Computer Assisted Instructions (CAI). In CAIs, research that examined the effect of control over the instructional programs on achievement revealed mixed results; however, research yielded consistently positive influence of the sense of control on user reactions (Hannafin & Sullivan, 1995). Needless to say, control has been identified as one of essential characteristics of games (e.g. Cordova & Lepper, 1985; Gee 2003). Therefore, this study also has relevance to questions about whether or not players' sense of control moderates the impact of a BCI interface on learning.

Rationale for Current Study

Incidental Learning in Games

Some studies (Filipczak 1997; Griffiths and Davies, 2002; Gee, 2003) have shown that online adventure games (i.e., MUDs) and fantasy role-playing games can provide opportunities for experiential learning, as these games are innately social and therefore support social and situated learning. These different types of learning occur either incidentally or intentionally through playing a game in different ways to become a better gamer (Dempsey et al., 1996). This is one of the reasons why educational game designers should consider incorporating an incidental learning strategy to an intentional learning task within a game (Mitchell & Savill-Smith, 2004). Prensky (2001) refers to incidental learning in games as "stealth learning" because the gamers would be incidentally learning the embedded content material without realizing they are learning something (Oblinger, 2004).

Different Interfaces for Learning

Several studies reported that different interfaces in educational software lead to different learning outcomes. For instance, Han and Black (2012) showed that the use of a haptic interface was more effective than a non-haptic interface in learning a concept in physics from a computer simulation. Paek (2012) also reported better learning outcomes from a touch interface than from a mouse interface in mathematical learning. Most recently, education researchers have become highly interested in exploring the potential of BCI devices such as the Emotiv headset to see if they can offer a better understanding of the relationship between learning and cognitive activities. Our particular interest in the current study is the device's potential to harness the overt thinking and concentration required to move on-screen objects and how this may promote vocabulary learning, i.e., learning abstract rune-like symbols and their association with English words.

Research Questions

The present study addresses the following overarching question: Does the use of the Emotiv BCI headset while playing a game promote incidental learning? This general question was addressed by evaluating the incidental learning of English word meanings for previously unknown, abstract symbols, and through a set of more specific questions, noted below.

1. When compared with the control group, does the use of the Emotiv BCI headset while playing

a game result in better learning of English word meanings for unknown, abstract symbols?

(i) Within the Emotiv BCI headset group, do those who believe they are in actual control of the game learn more English word meanings for unknown abstract symbols than those who do not believe they are in actual control?

2. When compared with a control group, did the Emotiv BCI headset group report more fun?

3. When compared with a control group, did the Emotiv BCI headset group report more engagement?

We hypothesized that the use of the BCI will be positively related to learning outcomes, the users' perceptions of fun, control and engagement, and that the sense of fun, control and engagement will be an important factor predicting any learning gains

Methods

Participants and Design

Participants were recruited through fliers on public billboards at a large-sized East Coast University. Volunteers who responded to the fliers for the first several months of the study were assigned to the Emotiv headset treatment group (TG). At the end of a cut-off period 72 people had participated in the TG. Volunteers who came to participate after this time were assigned to the control group (CG). At the end of the next cut-off period, there were 68 volunteers who had participated in the CG activity. On data analysis, it became evident that some CG data were not captured adequately, which resulted in a loss of 12 CG participants, yielding a CG of 56. Thus, 128 participants (TG *n*=72 and CG *n*=56) completed the study. In the TG, participants used the Emotiv headset to move objects in the game they were playing. In the CG, without the headset participants were asked to watch an animation of the same movement. There were two subgroups within the TG, those who reported that they believed they had full control over the gameplay and those who believed they did not.

Stimuli: The game and computer activity used in this study were designed by researchers to measure learning outcomes and user experience. The goal of the game was to have participants learn eight randomly presented, unknown symbols and their assigned English meanings.

Self-Report Questionnaires: To assess participants' gameplay and computer activity experience, quantitative data were collected during the game/activity. Three feedback questions on a five-point Likert scale were given in each of four rounds of gameplay on fun, engagement and sense of control.

Post-Interviews/Surveys: After participants completed the post-test, a semi-structured interview was conducted with the TG while the CG filled out an online post-survey of similar questions. Both groups were asked about the strategies used in the game/activity to memorize the symbols.

Data Analysis: Independent samples *t*-tests were conducted to test differences between Control and Treatment group on post-test accuracy. RM-MANOVAs were used to measure the possible change in players' game experience (i.e., perceived control, engagement and fun) over four rounds.

Figure 1: A Snapshot from the Game.


FEEDBACK

1. this game is fun for me.

STRONGLY DISAGREE ... STRONGLY AGREE

1 2 3 4 5

2. how much do you want to continue?

NOT AT ALL ... COMPLETELY

1 2 3 4 5

3. how in control of the game do you feel?

NOT AT ALL ... COMPLETELY

1 2 3 4 5

Figure 2: Feedback Screen.

Procedure

Participants were provided with an informed consent document upon arrival in the university's game lab. After each participant signed the document, the procedure was explained, and the participants from both TG and CG were asked to complete the pre-survey about their demographic information and their past experiences with computer games.

The TG used the Emotiv headset to control the game. The headset was first calibrated to fit each participant to ensure that the EEG data were transmitted and recorded. Then, the participants were given a “Relaxation” task. They closed their eyes for 90 seconds and listen to the sound of babbling brooks to quiet their minds and center themselves. Then they had a 7-10 minute training session on using the headset to control an onscreen activity: they practiced concentrating on a specific motion, which is moving a virtual object to the right. The next task was called “Persistence” (the participants were not told explicitly that they were being assessed for task persistence measurement). Participants were asked to look at two pictures that are similar but not identical and identify four differences (when in fact there were only three) using a computer mouse. The activity was timed for 15 seconds in each round and the participants could retry and repeat the round up to ten times. After the Persistence task, the participants proceeded to the Relaxation task for the second time in order to quiet their minds and center themselves before continuing on to the “Game.” In the Game, participants were asked to move a symbol using the Emotiv headset to the right of the computer screen (see Figure 1) until the symbol overlapped with an English meaning. Participants were told to use the same consistent thought they practiced in the training to move the symbol to the right. They did this with eight symbols, presented in sets of two, with each set followed by three short Likert-scale questions. The questions asked about fun, sense of control and engagement after moving two symbols in each round of the four rounds of play (see Figure 2).

The CG participated in an on-screen computer activity and were told to use the computer mouse/pad only when they were asked to complete the survey within the computer activity. The computer activity was equivalent to the game given to the TG, only the CG group were asked to watch an animation of each of the eight random symbols moving to the right of the screen to overlap with their matching English meaning. As was the case for the TG, there were also four in-game surveys of three questions about engagement after each set of two symbols were moved to the right of the screen.
After the game/activity was completed, both groups completed a post-test. Following the post-test, which asked participants to watch each symbol with its English word meaning, the TG was engaged in a semi-structure interview and the CG completed a user experience questionnaire. Some of the interview questions included; “Tell me about your experience with the Emotiv headset”, “What were the strategies that you used to memorize the symbols?” Both groups received an online seven-day delayed post-test. If participants did not respond, a reminder was sent after another week.

Results

Accuracy

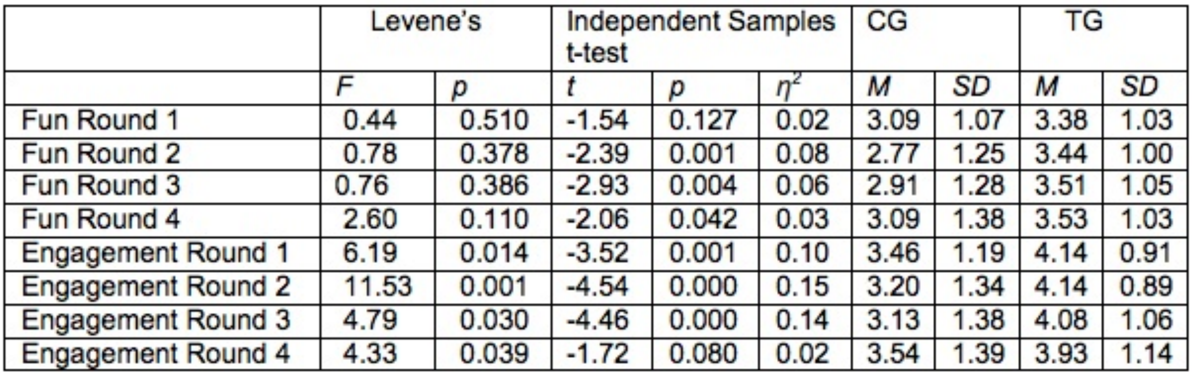
On average, the CG recalled 5.00 (SD = 2.61) symbols correctly and TG recalled 4.14 (SD = 2.62) symbols correctly. We found no statically significant difference between groups on their immediate recall test of matching symbols to English words ($t = 1.81$; $p = 0.07$; $\eta 2= 0.026$).

Within the TG, an independent samples t-test was conducted to detect possible differences between subgroups who stated that they did, or did not, believe that they controlled the symbols’ movement in the game. Those who believed they did scored on average 3.81 points (SD = 2.66) on the immediate recall test, whereas those who did not think they moved the objects scored 5.00 points (SD = 2.36). However, this difference was not statistically significant ($t = 1.75$; $p < 0.08$).

There was also a statistically significant correlation between participants’ immediate test scores and delayed test scores ($p < 0.001$; $r = 0.67$). This means that people who did well at the immediate tests did well at the delayed test as well. However, we should keep in mind that for the delayed test there is a selection bias. It might be the case that people who believed they would do well completed the delayed test. However, as no feedback was given in terms of the immediate test result, this is unlikely.

Self-report game experience

Independent samples *t*-tests revealed statistically significant differences between CG and TG (see Table 1) for fun and engagement. Except in the final round, the TG reported significantly higher levels of Engagement than did CG. After the first round, TG reported significantly more fun than CG. Assuming the normality of the data, RM MANOVA was conducted to assess the difference between CG and TG in the amount of change in their ratings on the three items of the game experience. Prior to conducting the MANOVA, a series of Pearson correlations were performed between all the dependent variables in order to test the MANOVA assumption that dependent variables would be correlated with each other in the moderate range. This assumption was met.

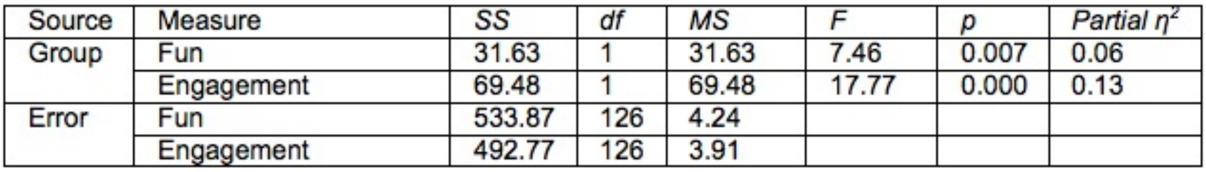


	Levene's		Independent Samples t-test			CG		TG	
	F	*p*	*t*	*p*	η^2	*M*	*SD*	*M*	*SD*
Fun Round 1	0.44	0.510	-1.54	0.127	0.02	3.09	1.07	3.38	1.03
Fun Round 2	0.78	0.378	-2.39	0.001	0.08	2.77	1.25	3.44	1.00
Fun Round 3	0.76	0.386	-2.93	0.004	0.06	2.91	1.28	3.51	1.05
Fun Round 4	2.60	0.110	-2.06	0.042	0.03	3.09	1.38	3.53	1.03
Engagement Round 1	6.19	0.014	-3.52	0.001	0.10	3.46	1.19	4.14	0.91
Engagement Round 2	11.53	0.001	-4.54	0.000	0.15	3.20	1.34	4.14	0.89
Engagement Round 3	4.79	0.030	-4.46	0.000	0.14	3.13	1.38	4.08	1.06
Engagement Round 4	4.33	0.039	-1.72	0.080	0.02	3.54	1.39	3.93	1.14

Table 1. Statistics for Game Experience for Each Round

Since the *Box's M* value of 265.046 is associated with a $p < 0.001$, *Pillais' Trace* was used for the multivariate tests. A statistically significant MANOVA effect was obtained for the treatment, *Pillais' Trace* = 0.13, F (2, 125) = 8.99, $p < 0.001$, $\eta^2_{partial} = 0.13$. The multivariate effect size was estimated at 0.13, which implies that 13% of the variance in the canonically-derived dependent variable was accounted for by treatment. A statistically significant MANOVA effect was also obtained for Rounds, *Pillais' Trace* = 0.19, F (6, 121) = 4.71, $p < 0.001$, $\eta^2_{partial} = 0.19$, and for the interaction between Groups and Rounds, *Pillais' Trace* = 0.14, F (6, 121) = 3.39, $p < 0.005$. This means that there was a significant difference between CG and TG on player experiences over four rounds.

Tests of the Between-Subjects effects table indicate that there is a significant main effect of group on Fun, Engagement and Control (see Table 2).



Source	Measure	*SS*	*df*	*MS*	*F*	*p*	*Partial* η^2
Group	Fun	31.63	1	31.63	7.46	0.007	0.06
	Engagement	69.48	1	69.48	17.77	0.000	0.13
Error	Fun	533.87	126	4.24			
	Engagement	492.77	126	3.91			

Table 2. Tests of Between-Subjects Effects of Group on Game Experience

Follow-up repeated measures ANOVAs for each dependent variable showed that main effects of round of play is statistically significant only for Fun, (F (2.47, 311.68) = 3.01, $p < 0.001$, $\eta^2_{partial} = 0.02$. Interaction between groups and rounds is statistically significant for Fun, F (2.47, 207.83) = 3.29, $p < 0.05$, $\eta^2_{partial} = 0.03$ and Engagement, F (1.65, 207.83) = 4.64, $p < 0.05$, $\eta^2_{partial} = 0.04$. This indicates that the change over rounds is associated with the intervention, but only for Fun and Engagement.

No statistically significant differences were found within TG's subgroups (believed they moved the symbols vs. not) on any of the game experience items except the sense of control in the last round. In that round those who believed they moved the symbols reported significantly higher sense of control than those who did not think they moved the symbols ($t = -2.23$; $p < 0.05$).

Relationship between Accuracy and Game Experiences

A total engagement variable was created by taking an average of engagement scores over four rounds. Similarly, a total fun rating was created. There is a statistically significant correlation between the total engagement and accuracy scores for immediate ($r=0.21$, $p<0.05$) but not for delayed post tests ($r=0.18$, n.s.). Similarly, no significant correlation was found between total fun and accuracy scores for immediate ($r=0.13$, n.s.) or for the delayed test ($r= - 0.06$, n.s.).

Discussion and Conclusion

Although this research project is preliminary, findings from the study indicate significant implications for the research questions (RQ) noted earlier.

In terms of RQ1, immediate post-tests for both groups revealed that half or more of the symbols were learned from a baseline of zero, since the symbols were made-up abstract ones created by the researchers. The non-significant difference between the groups indicate that the TG did no worse than the CG. We believe the novelty of the BCI for the TG might have affected the results. Many participants reported that they felt moving the symbols were interruptive to learning, although experiencing BCI itself was enjoyable. Research suggests using movement that is conceptually congruent with the content, if the learning environment involves movement, improves learning outcomes. (Black et al, 2012). Although BCI does not involve physical movements, imagined movement activates the similar region of cortex as the physical movement does (Arzy, Thut, Mohr, Michel & Blanke, 2006; Astafiev, Stanley, Shulman & Corbetta, 2004; Barsalou, 2008). Thus, future studies could investigate whether imagined and/or physical movement that is conceptually congruent with the knowledge affects learning outcome with gamers. In the self-report in-game/activity survey, majority of CG indicated they wished they had control over the movement of the symbols instead of passively viewing the animation. When comparing between those who believe they moved the symbols and those who did not within TG, there was no significant difference between the two groups.

In terms of RQ2, although there were no significant differences in post-tests for the two groups, the fact that the TG had more fun and was more engaged with the game is promising. Learning educational contents would normally be much longer than the time spent on the game in the present study. If learners are engaged and have fun in a learning environment, then positive learning outcomes are typically expected.

In terms of RQ3, the results show that participants in TG reported higher level of engagement overall than those in CG. However, over time (from first to last round), participants in both groups reported that their level of fun increased over the previous round of play. In addition, higher engagement resulted in higher scores in the immediate post-test. This supports the current literature on a correlation between engagement and learning.

The findings from the present study show potential for using the BCI in the game-based learning environment. The participants using a BCI headset learned new random symbols and their English-word meaning, and they did so as well as those who learned from watching an animated movement of the symbols. We feel it is impressive that such learning occurred even though the randomly presented symbols were seen only once for each symbol, for a relatively short period of time (averaging approximately 8 seconds). Given the BCI headset was a completely new interface to the participants, with more time and practice, additional experience with the interface could result in even greater learning. Moreover, the participants reported that using the headset was fun and engaging; they wanted to try it again. While our study did not find differences in sense of control between BCI players and animation watchers, this may well have been a result of the novelty and disbelief that the headset was actually being controlled by users' "thoughts." For example, we note that 20 of the 72 BCI users did not believe that they had controlled the symbols' movement. A greater sense of control could result as such interfaces become commonly used, familiar, and accepted by players. Given that BCI interfaces provide a more direct link between thought and action than interfaces to date, we encourage additional studies that address sense of control with users of such devices.

In summary, the positive responses we received regarding perception of fun and engagement, and the fact that half of the unknown symbols and English word meanings were learned in essentially one trial, imply that a BCI headset has potential for gameplay, including games that embed learning activities.

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