2010 International Conference on Cyberworlds

Human-Computer Interaction for BCI Games

Usability and User Experience

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***Abstract*—Brain-computer interfaces (BCI) come with a lot of issues, such as delays, bad recognition, long training times, and cumbersome hardware. Gamers are a large potential target group for this new interaction modality, but why would healthy subjects want to use it? BCI provides a combination of information and features that no other input modality can offer. But for general acceptance of this technology, usability and user experience will need to be taken into account when designing such systems. This paper discusses the consequences of applying knowledge from Human-Computer Interaction (HCI) to the design of BCI for games. The integration of HCI with BCI is illustrated by research examples and showcases, intended to take this promising technology out of the lab. Future research needs to move beyond feasibility tests, to prove that BCI is also applicable in realistic, real-world settings.**

Keywords - Brain-computer interfaces, physiological computing, psychophysiological signals, affective computing, multimodal interaction, games

I. Introduction

Brain-computer interfaces (BCIs) have provided severely disabled people with new communication and motor abilities, so they can interact with the outside world. Recently, the focal point has shifted to a new group of potential users: the general population. From a commercial perspective, such a large target group could be a very lucrative endeavor. Especially gamers are great potential users, as they are early adopters, willing to learn a new modality if it could prove advantageous, and it is a large part of the population [7]. However, BCI still has many issues: it is slower and less accurate than other modalities, and requires a lot of training to be used. Unlike the severely disabled, healthy users have no reason to prefer BCI to existing modalities. Why would healthy people use BCI?

To make BCI an interesting interaction modality, it should enhance the user experience, by offering new information in a way that comes with its own unique features. BCI provides a direct measurement of the user's mental state while at the same time providing new means of control. Like voice commands it is hands-free, but at the same time it has the rare quality of being private, as no external expression is required. Parallel to exertion interfaces having the ability to make the user more physically fit, depending on the mental tasks, BCIs can make the user more relaxed and concentrated (e.g. by using mental tasks that increase activity in certain frequency bands). This in turn can increase intelligence and make the user better equipped to cope with stress [2,12].

Another interesting feature is the fact that, like virtual game worlds, our thoughts are not constrained by what is physically possible. For example, in a game world we can readily accept that we are able to cast spells. BCI could make it possible to express ourselves directly in this game world without bodily mediation (such as pressing a button), enabling gamers to express themselves directly, in ways that would be more realistic considering the rules of that particular environment.

Most current BCI games for research are proof-of-concepts, with one modality for control: a two-class BCI [8]. Often, such games are slowed down to allow for BCI control, and the systems are evaluated solely in terms of speed and detection accuracy.

However, there is a new trend towards more fine-grained control, smooth, application-specific interpretation of BCI control signals, precision timing, and a movement beyond feasibility tests [8]. The focus shifts to the role BCI can play in improving the game experience. Research groups are also tentatively testing the feasibility of BCI in real-world applications. Future BCIs will have to deal with natural behavior of the user, be able to function in combination with other modalities, multiple users, different contexts, and different mental tasks and signal types (e.g. [5]).

II. BCI Games

There are many examples of games where BCI has been used as an input modality. As mentioned, most of them are proofs of concepts. In these games different BCI paradigms are explored, rather than it is explored how these paradigms can be incorporated in the design of a game. Among the important paradigms are event related potentials (ERP) in brain activity, that is, particular events evoke activity in certain regions of the brain and this activity can be measured to adapt or control game events. A similar paradigm concerns the explicitly externally evoked potentials, where

978-0-7695-4215-7/10 $26.00 © 2010 IEEE
DOI 10.1109/CW.2010.22

visual, auditory or tactile stimuli are reflected in activity in the brain, for example, in the visual cortex, and this measured activity can be used to make yes or no decisions, depending on how and where the user's attention is measured. Implicit event related potentials, explicit externally evoked potentials, and internally evoked potentials allow the system to provide the user with control opportunities and they allow the system to accept brain-activated control and to adapt interface appearance or interaction modalities to the mental or affective state of the user.

One useful BCI control modality is the employment of mental tasks. A mental task can be the imaging of a movement, doing a difficult calculation, focusing on a particular event, relaxing, or doing inner speech. As an example, imagining a movement leads to brain activity in the motor cortex. When able to measure this voluntarily induced activity, it becomes possible to steer a cursor or to navigate an avatar in a virtual reality environment. In a BCI controlled game the user or gamer consciously uses mental activity to control progress in the game. The mental activity is measured and used to control the game. Monitoring of mental activity can also be used to adapt the game progress. Workload, frustration, and interaction flow are then issues that need to be addressed.

Multimodality is another issue. In a 'hybrid' BCI different EEG measured brain activity is used to control a system or let the user control a system. In a multimodal BCI system we assume that a gamer is free to move, possibly walk around, use the keyboard and mouse, a Wii controller, a playstation controller, or has other modalities (gestures, facial expressions, gaze, ..) to consciously or unconsciously control or adapt a game. This requires robust EEG technology, wearable wireless headsets and dry electrodes [1]. In particular it requires knowing how to fuse information at the signal processing level, at the feature extracting level, or at a semantic or pragmatic level where we take into account semantic and pragmatic constraints that follow from domain and task knowledge and reasoning about constraints and information. Below two recent examples of multimodal BCI games that we introduced are presented.

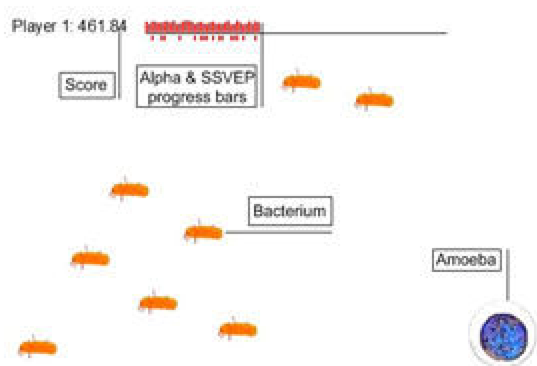

Figure 1. A screenshot of the Bacteria Hunt game.

A first example of BCI in a real-world setting is a multi-modal, multi-paradigm game called Bacteria Hunt [4] (Figure 1). The user controls the amoeba with keyboard. Controllability of the amoeba is modulated by the user's alpha activity (more relaxation results in more control). The goal is to eat as many bacteria as possible. Eating is done via steady-state visually evoked potentials elicited by looking at a flickering stimulus, which is shown when the amoeba is on a bacterium. This game is a platform to investigate the influence of using BCI in combination with other modalities, and also to look at the influence of using multiple mental tasks at the same time.

A second example of such an approach is a BCI sheepherding game (Figure 2). 'Mind the Sheep!' is a game where one or two players must herd a flock of sheep(white dots) across a field. They do this by directing a group of herding dogs (black dots). A player can select a dog with a multi-modal selection system that combines the measured brain activity with a WiiMote or mouse. Players have to choose between speed and accuracy, which makes the time that is needed for successful classification of the brain activity part of a challenge instead of a disadvantage. New control modalities are easy to build-in, for example other selection methods which also use brain activity.

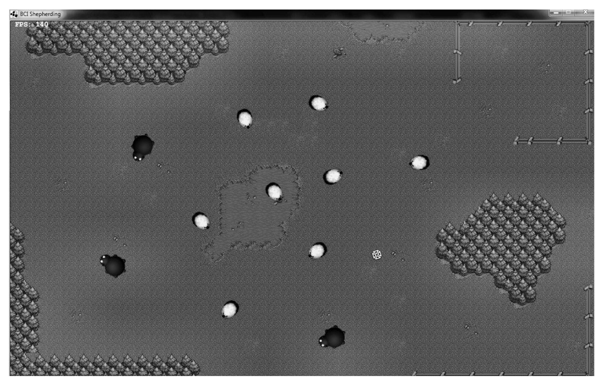

Figure 2: Screenshot of the BCI 'Mind the Sheep!' game.

The usability and user experience of BCI systems will play a key role in facilitating the acceptance of this new technology. Current research shows a general neglect in these areas. Usability can be divided into the following factors: learnability, memorability, efficiency, effectiveness, safety, and satisfaction [6, 9].

III. Learnability & Memorability

If the mapping between mental task and in-game action is not intuitive, this may reduce performance as the time and effort to memorize and perform the task is increased. Currently the most common mental tasks have only limited applicability for finding intuitive mappings, and there are not many alternatives [8]. We need to keep our eyes open to new possible mental tasks that might fill the void that consists of the large variety of interactions that current games offer.

Involving the users in the design process may help in moving beyond the limited mental tasks that are currently common in BCI systems. To illustrate the usefulness of these methods to BCI, we currently involve potential users in the design process of a BCI system. In our research we use the popular videogame World of Warcraft. We introduced AlphaWoW (Alpha-World of Warcraft), a BCI version of Worlds of Warcraft [8], (see Figure 3).

In this game you can control a character in a virtual environment by using your brain. In the game you play an elf druid. You are very close to nature and can change into animals. In elf form you are very capable of casting spells, but you are also more fragile. You can change into bear form, which is naturally more suited for claw-to-claw combat. Each form requires a unique style of play. The brain activity is analyzed for alpha activity, which is related to relaxation. A short period of stress will change you into an aggressive bear for close-combat, while being relaxed will revert you to the elf shape in which you use your relaxed but alert mind to cast spells.

Figure 3. A user playing World of Warcraft® with both conventional controls and mental states to control the character in the game [8]. World of Warcraft® is a registered trademark of Blizzard Entertainment.

One way to discover mental tasks that are suitable from a user perspective is to simply ask the user what they would like to do to trigger certain actions and then evaluate the experience of using these mental tasks. Results of our research indicate that for this particular game example user preference for certain mental tasks is primarily based on the recognition of the mental activity by the system, and secondly on the effort it takes to execute the task. Mental tasks that were investigated were (1) inner speech: recite a mental spell to change into one form or the other; (2) association: think about or feel like the form you want to be in; and (3) mental state: automatically change into a bear when the situation requires it. When you are attacked directly, this is stressful, and that could function as a trigger.

A series of experiments with these three paradigms was run for five weeks, with fourteen participants returning each week. The first week all participants were asked to just perform the tasks, without getting any feedback as to how well the system was recognizing any of it. In the last week everybody was given feedback, and in between half the group was given feedback and half was not.

Results indicate interesting differences between the feedback and non-feedback groups. The mental state paradigm was well-liked by the feedback group, because of the accurate recognition by the system, but disliked by the non-feedback group because of the effort it took to perform this task. Also, people did not like to put themselves into a stressed state voluntarily. On the other hand, inner speech was liked by the non-feedback group as it was most like a magic spell, and took very little effort and concentration to do. Participants also considered this task to be the most easy to interpret. However, the feedback group quickly discovered that the current system was not well-equipped to detect this task, quickly moving this paradigm to the bottom of their list of preference. The association task set seemed generally well-liked, as people felt it fitted well with the game. It encourages the player to become one with the character they are playing, and to immerse in the game world.

More generally, incorrect execution of the mental task can be a reason for a failing BCI system. Training with neurofeedback can help improve performance in this case [4]. Training sessions often are repetitive and tedious. Incorporating the training in the game can help to prevent boredom and keep the user motivated. Additionally, this creates a training period very similar to the game session, reducing the surface for generalization errors.

IV. Efficiency & Effectiveness

Efficiency (how fast a task can be performed) is a key issue in current BCI research, which focuses mainly on speed and detection accuracy. However with the current state of hardware and software, it is far from exceeding traditional input modalities such as the keyboard, with a current speed of about 25 bits/min [13]. On the other hand, it may yield an increased effectiveness (how well the user can reach the goals intended), considering the additional information about the user's state provided.

Besides, efficiency is not necessarily the main concern when developing BCI game applications. For fluent game play, it is also important that the commands operate at the right timescale (which could also be slow), and with minimal delays.

Slow-paced games can use BCI input based on slow changes in brain activity. Faster-paced games require quick responses, so brain signal spikes are required for control. When using brain signals in a certain time scale, it is recommended to reduce the influence of activity in other ranges. Taking again AlphaWoW, one of our prototypes using alpha activity for direct control, as an example: alpha activity takes at least a few seconds to be measured accurately, making it unfit for fast-paced commands (see Figure 3). To make it less vulnerable to short-term changes, we applied smoothing (weighted averaging over the last couple of results), dwelling (staying in a range for a certain duration), and hysteresis (having a neutral zone which triggers no action). Z-score normalization over the alpha values makes the application react to changes relative to the observed situation, adjusting for long-term changes and differences between subjects.

Similarly, in the case of Affective Pacman [11]. Affective Pacman is fast-paced game, similar to the well-known Pacman game, that is controlled with two buttons that rotate Pacman clock-wise or counter clockwise. As the user presses buttons, LRPs are elicited in the brain. These fast potentials fit well in the context of the pace of the game (see Figure 4).

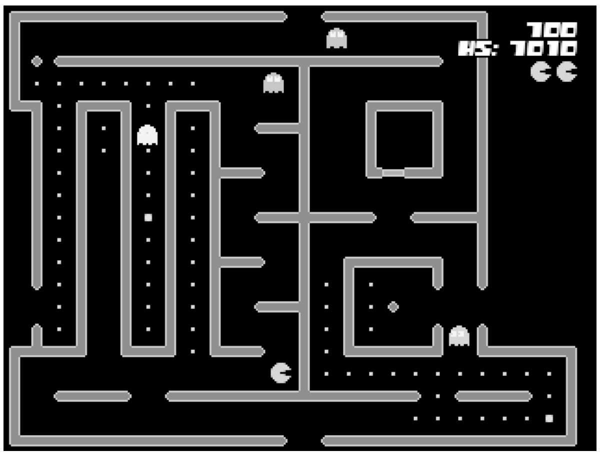

Figure 4. Screenshot of the Affective Pacman game..

Affective Pacman was initially developed to investigate to consequences of the change of the affective state of the user, in this case frustration (loss of control), on the effectiveness of the BCI. The frustration condition was induced by responding unreliably to keyboard commands, given the user the feeling of loss of control. One of the remarkable outcomes of the experiment was that the BCI trained in the normal condition (no frustration) is more effective (as a better performance) in the frustration condition compared to the normal condition.

Latencies are a problem inherent to BCI control: brain signals need to be observed over a period of time before they can be analyzed. The analysis itself may also take time. This can be dealt with by back-fitting the command in the game history, resulting only in a visual delay, not a semantic one. On the other hand, it is also possible to have mental tasks which seem to result in negative latencies to the user, as the preparation phase of the mental task can be observed. This is for instance the case with LRPs.

V. Safety

As detection accuracies of BCIs are around 80% [10], error handling is an important issue for designing BCI applications in general.

Brain activity sensors are often very sensitive, and thus vulnerable to artifacts and noise. This is one reason that might cause lower detection accuracies. In the case of voltage measurements like electroencephalography (EEG), the sensors pick up other electrical signals such as eye movement and muscle tension. It is possible to deal with such artifacts by removing contaminated periods, but then an application needs to be able to deal with missing input. Alternatively, certain artifacts can be filtered out. There are methods available to do this in an on-line fashion without the need for additional electrodes [3].

Instead of just getting rid of the 'noise', it can also provide additional information, whether it is separable from the recorded brain activity or not. It can be used as an additional modality, or as a means to increase detection accuracy. For example, detection of mental tasks to stress versus to relax can be greatly improved when using the muscle tension artifacts that are likely to be generated by the user.

Additionally, BCI can provide an interesting means for error correction: when the user is aware of an error, an error-related negativity potential is visible in the brain activity. With this information it is possible to automatically undo actions.

VI. Satisfaction

Satisfaction is the culmination of everything the user experienced during the game. Besides subjective measures such as questionnaires and interviews, it could be possible to use brain activity as an objective measure. Such measures of the user's mental state can also be used to adjust the application, ensuring user satisfaction by avoiding detrimental user states (like frustration), and supporting the occurrence of wanted user states (like flow). The game could be customized by manipulating the story line, the presentation, or the difficulty level.

VII. Conclusions

Applications for healthy people are becoming more and more important in BCI research. Gamers are a large potential target group, but why would a healthy person want to use BCI when it has still so many issues (delays, bad recognition, long training time, cumbersome hardware)? BCI needs to prove it can be used in distinctive new ways that will make it a valuable addition to current input modalities with a combination of features that no other modality can offer. Unconstrained by what is physically possible, it might also be a very natural interaction modality, allowing gamers to express themselves in their own unique way.

Some of such valuable features have already been uncovered. In human computer interaction the amount of information the user can provide is limited. In addition to control commands, BCI can provide new kinds of information, specifically on the user's mental state. There have been reports by users that the system seems to recognize a decision before they were consciously aware of it themselves. As with LRP, it may also be possible to detect actions before they are actually executed.

The medical research that lies at the foundation of current BCI research has been and still is very important. However, to move BCI forward as a viable interaction modality for everybody, the human element has to be given a more prominent place in the research. Whether the system is a 'pure BCI' is of secondary importance to healthy users. Usability and user experience, which lie at the core of human-computer interaction, should be considered when designing systems and applications, in order to increase the user satisfaction and acceptance of this new technology.

We believe that BCI could be seamlessly integrated with traditional modalities, taking over those actions which it can detect with sufficiently reliable accuracy. For game adaptation, affective BCI could be a fast and sensitive method on its own, or combined with other user state indicators it could help to create more robust and reliable systems. Timing and fine-grained control are important topics to look into, as these features are important for many applications. Artifacts and noise that are inherent to using BCI in a real-world environment should be dealt with or even better, used as additional information about the user.

We need to move beyond feasibility tests, to prove that BCI is also applicable in realistic, real-world settings. Only the study of BCI under ecologically valid conditions – that is within realistic HCI settings and with behaving users naturally – will reveal the actual potential, and also the real challenges, of this promising new technology.

Another way of thinking is required to make BCI part of HCI. 'The subject' should become 'the user'. The first steps have already been taken.

ACKNOWLEDGMENT

This work has been supported by funding from the Dutch National SmartMix project BrainGain on BCI (Ministry of Economic Affairs), the GATE project funded by the Netherlands Organization for Scientific Research (NWO) and the Netherlands ICT Research and Innovation Authority (ICT Regie), and ITEA2 project MetaVerse1.

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