BCI and Physiological Computing for Computer Games: Differences, Similarities & Intuitive Control

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ABSTRACT

This paper is concerned with how Physiological Computing (PC) and Brain-Computer Interfaces (BCI) may be used to enhance computer games. It is argued that PC offers a greater range of possibilities for future development. An analysis of both approaches revealed that PC functions at the meta-level of the Human-Computer Interaction (HCI) whilst BCI offer a novel communication channel within the HCI. It is argued that both offer distinct possibilities for intuitive control for both single- and multi-player games. It is concluded that PC and BCI may be combined for the next generation of computer games.

1.INTRODUCTION

Brain-Computer Interfaces (BCI) are designed to be used as a communication channel and an alternative mode of input control [1]. Physiological Computing (PC) [2] is concerned with monitoring naturalistic changes in psychophysiology during the human-computer interaction (HCI) and transforming these data into a control input for the computing system. This latter category is associated with affective computing [3] and neuroadaptive interfaces [4].

Development of BCI devices has focused on the restoration of communication for users with severe physical disabilities. The purpose of PC is to increase existing communication bandwidth within HCI for healthy users [4]. For example, enabling computer systems to classify and respond to the emotional responses of the user [5] or adapting system automation to the cognitive workload of an operator [6].

Several arguments have been forwarded to promote the use of BCI by healthy users [7], such as novelty or to offer an alternative mode of input for the 'hands-busy' operator. In addition, training required to use certain categories of BCI may not be as onerous as commonly believed [8]. However, it is difficult to imagine this technology being attractive to healthy users in light of the limited bandwidth offered by the current generation (e.g. two degrees of spatial freedom, or two-choice direct selection). A hybrid system where BCI are used alongside a keyboard, mouse or console appears to be a more likely option, but the design of such a system faces two primary obstacles [7]: (1) assigning functionality to the BCI that are intuitive, complimentary and compatible with other input devices, and (2) limitations on human information processing in a multi-tasking framework. The multiple-resource model [9] predicts that control via BCI may distract attention from other input activities via two routes: sharing the same processing code (spatial vs. verbal) or by demanding attention at an executive or central level of processing. However, there is evidence that these types of time-sharing deficits may be overcome by training [10].

By contrast, PC remain unhindered by obstacles such as training or input-output compatibility. Issues of training are minimized because PC implementations are relatively intuitive and naturalistic (although these systems may require regular baselining sessions). With respect to the input-output compatibility, there is no requirement for the user of a PC to formulate a specific command response. The range of measures used by PC is often more inclusive compared to BCI; PC may encompass autonomic measures as well as those electrocortical indices that are the sole preserve of explicit BCI systems. This inclusiveness aspect of PC is double-edged; on one hand, PC may draw upon cardiovascular and respiratory variables, which are very accessible and easy to measure. The disadvantage of autonomic variables is that they require careful measurement and filtering to correct for physiological confounds such as gross movements, room temperature etc. Finally, the principal distinction between BCI and PC is that they function at completely different levels of the HCI; BCI are analogous to command inputs (e.g. keystrokes, mouse movement) whereas PC function at a meta-level of the HCI, i.e. controlling the availability of functionality and manipulating different modes of interaction.

Both PC and BCI have several broad features in common: both follow similar stages of signal acquisition and digitization, followed by extraction of relevant features and translation into output for computer control. To date, both have been developed primarily to produce one-dimensional output, although there are two-dimensional examples of both BCI [11] and PC [12]. The issue of sensitivity gradation is common to both categories of device. Some forms of BCI and all forms of PC rely on an attenuated signal for output, for example, a steady and gradual increase over a specified time window. The issue of sensitivity gradation refers to the way in which this attenuation is converted into meaningful categorization scheme, which in turn is translated into specific instances of computerized control. Many BCI rely on two-choice outputs [10] whereas PC constructs such as operator engagement have been expressed as three categories (high, medium, low) [13].

This paper will focus on PC as a means of managing the HCI. The secondary goal of the paper is to consider how both BCI and PC may be used, both separately and together, within the context of gaming applications.

2.META-MANAGEMENT OF THE HCI

2.1 The biocybernetic loop

The design of a PC system is based upon the biocybernetic loop [14-16]. This loop describes how psychophysiological data from the user is captured, analysed and converted to a computer control input in real-time. The function of the loop is to monitor psychophysiological changes in order to initiate an appropriate adaptive response that appears both intuitive and timely from the perspective of the user.

The biocybernetic loop is designed according to a specific rationale, which serves a number of meta-goals. For instance, the biocybernetic loop may be designed to:

- Promote and sustain a state of positive engagement with the software/task
- Minimise any health or safety risks to the user that are inherent within the HCI

The capability of the biocybernetic loop to sustain engagement has been demonstrated within the context of the computer game [13]. The second meta-goal is concerned with health and safety. The goal of research into biocybernetic control of adaptive automation is to avoid the use of automation during hazardous states of awareness, e.g. fatigue and boredom, when aircraft safety may be jeopardised [17]. The same protective logic underpins the use of psychophysiology to detect negative states of frustration [18], which may have implications for the health and wellbeing of the user in the long-term.

The biocybernetic loop is equipped with a repertoire of adaptive interventions [19], e.g. to provide help, to give emotional support, to make the task easier or more difficult. The biocybernetic loop employs this dynamic dialogue in order to 'manage' the psychological state of the user. Correspondingly, the response of the user to each adaptive intervention is how the user 'manages' the biocybernetic loop. It may be useful for the loop to monitor how the user responds to each intervention in order to learn about user preferences. This is a dynamic and recursive model of dialogue design that emphasises the importance of: (a) accurately monitoring the psychological state of the user, and (b) equipping software with a repertoire of adaptive responses that covers the full range of possible outcomes within the human-computer dialogue.

Given that the meta-goals of the biocybernetic loop are to engage and protect the user, how should the loop response to cases when both goals are incompatible? For example, when the player of a computer game registers boredom because of an extended period of play? If the primary goal of the loop is to engage the player, the software may respond with a stimulating increase of task demand. With the goal of protecting health in mind, the loop may suggest that the player takes a rest break. This scenario draws attention to the requirement for a primary directive or meta-goal for the loop. The designer must decide whether the biocybernetic loop emphasises engagement, health, or safety as the "bottom line."

The structure of contemporary computer games is for the player to overcome a static series of challenges presented in linear order of increasing difficulty. In addition, the player can select the range of task difficulty (lowest to highest level of challenge) as a skill setting before the game begins. Recent research has emphasised the importance of autonomy and competence for players of computer games [20]. The intrinsic motivation for players (i.e. willingness to play the game) is related to the provision for choice and freedom within the game, as well as the need for challenge and to opportunity to acquire new skills. The question then arises: does the introduction of a biocybernetic loop, which 'manages' the HCI according to preconceived meta-goals, represent a threat to the autonomy and competence of the player? A game designed to manipulate task demand to consistently engage runs a risk of disempowering the player by preventing excessive exposure to either success or failure. This potential problem stems from over-corrective activation of the loop, and therefore, it may be prudent to design the biocybernetic loop to respond conservatively and subtly within gaming applications. It is important that the loop does not anticipate or constrain the player to an excessive degree.

The biocybernetic loop may use two inherent dynamics: negative or positive feedback control. This is another important design option for PC. Negative control loops create stability by reducing the discrepancy between the input signal (real-time psychophysiological measure of engagement) and a desired standard (the desired level of engagement). Negative feedback control is perfect if the system has been designed to keep the user within a 'safe' zone, such as avoiding extremes of fatigue or stress. By contrast, positive feedback control is designed to amplify the discrepancy between the input signal and the desired standard in an exponential fashion. Positive feedback control leads to performance instability [21]; a biocybernetic system working on this basis would adjust the desired standard of engagement upwards as the person became more engrossed with the task. In the case of safety systems, such as adaptive automation, it is desirable to keep the operator within a stable zone that optimises the effectiveness of performance. However, this kind of stability is an anathema to the computer gamer who is motivated by new challenges and personal autonomy [20]. It is argued that one technique to preserve the motivation of the gamer is to use positive feedback control in order to "push" performance to a higher level. It may be possible to base biocybernetic control of the game on a positive control dynamic in its entirety, but this may be prove to be exhausting for the player (and hence may be detrimental to health). For sustained game play, it is envisaged that intervals of stability achieved via negative control will be interspersed with unstable episodes courtesy of a positive control dynamic. In this way, the player is 'stretched' and then granted an opportunity to consolidate his or her new skills. Alternatively, this strategy of alternation or cycling between negative and positive control represents an attempt to fulfil both meta-goals simultaneously, i.e. to use positive control to provoke intense engagement and negative control to assuage any resulting accumulation of stress and/or fatigue.

2.2 Co-evolution

Previous work [22] emphasised the importance of sensitivity and fidelity for the biocybernetic loop. The loop embodies a model of the psychophysiological inference and labelling of the user state, e.g., when the heart rate of user 1 increases by 10% then this user is stressed. However, this inferential mapping between physiological activity and psychological concepts is prone to change over time. There is evidence that psychophysiological reactivity to increased task demand may change dramatically as the person develops from novice to experienced user [23], this change is particularly apparent during the initial phase of the learning curve. The simplest countermeasure to this instability is for the biocybernetic loop to evolve those absolute or relative levels used to trigger an adaptive response in tandem with the changing profile of user; for example, by taking a baseline reading at the beginning of each session or calibrating the psychophysiological reactivity to standard stimuli or scenarios.

However, simply updating trigger levels in accordance with user experience may not be sufficient. The sensitivity of physiological variables themselves may vary over time, e.g. increased heart rate may be associated with a transition from low to high demand for the novice, whereas increased task demand can only be gauged by EEG variables in the case of the expert. The integrity of the PC concept depends on the psychological state being accurately represented within the biocybernetic loop; therefore, PC systems must be able to learn and evolve with the user.

The opposite side of this equation concerns how the PC system is perceived by the user. Much depends on the transparency of the system intervention and the clarity of the biocybernetic contingencies employed by the system, e.g., the IF THEN rules embodied within the loop. Some systems may use a PC approach to offer explicit assistance or switch modes of operation whereas other types of intervention may be relatively implicit and difficult to perceive subjectively, e.g. subtly changing the volume or background music during a computer game. When adaptive interventions are explicit, the experienced user will develop an understanding of how their moods/feelings/emotions relate to the adaptations performed by the PC system. The main consequence of this development is that the user may intentionally induce a particular psychological state in order to evoke the desired response from the system. For example, the user may focus concentration to induce a particular mode of operation or feign negative emotion to receive assistance from the system. This point will be expanded in the next section.

The relationship between the person and the biocybernetic loop is one of co-evolution. The response of the system to the psychophysiology of the user and vice versa is dynamic over time and will require repeated synchronisation to preserve the integrity of biocybernetic control. This process of mutual evolution permits the system to exert a selective pressure on the user and vice versa. The representation of the user within the loop must keep pace with the reality of skill acquisition and evolving human intelligence. In response, the user may learn to intentionally alter the behaviour of the system, which casts the dynamic of the biocybernetic loop in a completely different light.

3.INTUITIVE CONTROL

PC has a number of advantages over BCI for integration into computer game software for healthy users. By working at the meta-level of the HCI, the biocybernetic loop can manipulate a large range of variables in real-time: skill level, AI of assistants and opponents, availability of game resources and additional functionality, information provision etc. In terms of game settings, a PC system could also modulate aspects in real-time that are traditionally set prior to the gaming session, e.g. sensitivity of controls, sound and music settings, appearance of game world. As well as offering tremendous flexibility of control, PC systems do not require an overt response from the user to function or any explicit training. The biocybernetic approach can be used with combination with conventional control input without any distraction or task interference. Finally, some PC systems may function on purely autonomic variables, which are relatively easy to measure compared to existing EEG apparatus, e.g. LifeShirt [24]. As described in the previous section, the main obstacle for the PC system is to acquire and to sustain an accurate representation of psychological state of the user. By contrast, BCI function as a communication channel within the actual HCI that offers a novel mode of 'hands-free' input control, which may become highly intuitive and automated with sufficient practice [7].

This fundamental mismatch is not intended to forward an argument for the abandonment of BCI in favour of PC for computer games; both approaches operate at different levels of the HCI and both occupy a specific niche. The basis of the biocybernetic loop is to mediate an implicit interaction between the psychological state of the user and the meta-goals of the HCI. BCI represent an explicit channel for communication within the HCI.

One variable underpinning user satisfaction with computer games is the extent to which game controls are perceived to be intuitive [20]. This quality is captured by users' perceptions of the innate qualities of the game controls such as stimulus-response compatibility, ease of learning and ease of use. Intuitive control is also important for presence, which is defined as the *illusion of non-mediation* [25]; if control of the game is burdensome, this represents a barrier to any genuine sense of being within the game world. It has been argued that presence is an important source of intrinsic motivation for gamers [20].

This criterion for intuitive control for games may be applied to PC and BCI. With respect to the former, it is important that the biocybernetic loop responds to the psychological state of the player in an intuitive and logical fashion. For example, if the player is bored, game difficulty should be increased (see [22] for more detail). The means by which the biocybernetic loop engages the player may be direct or indirect. In the former case, gaming demand is adjusted directly by enhancing the capabilities or knowledge of the player or by reducing the difficulty of overcoming enemies or obstacles. Indirect manipulation of player engagement by the loop represents a more intuitive mode of control. Given that PC is concerned with the psychological state of the player, it is logical to use the representation of player state to modulate the perceptual qualities of the game world. For example, the definition and clarity of the visual scene may be adapted to correspond to the level of alertness or cognitive effort exhibited by the player. Similarly, the appearance of the game world may be adjusted to reflect the emotional state of the player. Manipulation of lighting, shadowing of object, ambient sound and background music may be adapted in real-time by the biocybernetic loop to enhance the threatening qualities of the game world and provoke feelings of fear. The same adjustments could be made under different circumstances to counteract feelings of boredom or complacency from the player. The biocybernetic loop may adjust the appearance of the game world to 'match' and heighten the state of the player or to provide a 'mismatch' with an undesirable state in order to provoke the player.

BCI have been used by healthy users to control movement through a virtual world [26] or to control a virtual craft [27]. It is anticipated that BCI optimise presence (i.e. the illusion of non-mediation) once control has been sufficiently practiced, and there is some evidence that BCI training is enhanced within an immersive environment [28]. The great strength of BCI for healthy users is its novelty. But the bandwidth for communication remains low and novelty will fade with experience, hence hybrid systems [29] (i.e. where BCI devices co-exist with conventional input controls) is the most likely design option for gamer BCI [7]. From the perspective of intuitive control, movement through the game environment is best suited to consoles and conventional input devices. This raises a question as to which categories of computer game functionality would be most intuitive for BCI? It has been suggested that a BCI may be used in combination with keyboard input to control modes of movement as a means of avoiding the use of multiple keys simultaneously [7]. An argument may be made that the innate qualities of the BCI (being psychological in basis and highly novel) provide an intuitive match for games where the player may imbue their avatars with extraordinary abilities, such as flying or psychokinesis (i.e. moving inanimate objects by mental effort alone). One could also envisage a gaming option whereby the player uses a BCI input to turn the hands of a clock in an anti-clockwise direction within the game to effectively manipulate "game-time" and 'rewind' to an earlier state. The kind of explicit feedback provided by the clock will be important for the player to develop expertise with the BCI. The exact form of these extraordinary abilities will obviously depend on the game genre. Given that BCI are: limited in terms of degrees of control, less than 100% accurate and require specific training, it is intuitive that this novel channel of communication is matched to "special" or extraordinary categories of game functionality.

Section 2.3 raised the notion of users learning to manipulate their psychological states in order to control the biocybernetic loop. This phenomenon was reported in earlier research where experienced users learned to activate and deactivate system automation by purposefully controlling EEG activity [30]. As stated earlier, if the contingencies used by the biocybernetic loop are perceived by the user, it is possible for the users to control the loop via a process of implicit learning very similar to conventional biofeedback. This possibility is very important. If exposure to the biocybernetic loop allows the player to learn how to self-regulate psychological state, they have the means by which to control the meta-management of the HCI. This skill represents one logical end-point of co-evolution between user and system, where the user has learned to master the biocybernetic loop and to control the rules of the HCI. This phase also brings PC closer to the functionality of BCI, where the management of psychological state is used as a proxy for communication with the system, albeit at a meta-level.

The transition from implicit PC to explicit control of the HCI provides designers the possibility of using the process of self-regulation and control of biocybernetic loop as part of game play itself. The criterion of intuitive control would suggest that self-regulation of the psychological state is ideally suited to "mode-shifting" function within a game. Like BCI, the ability to self-regulate may be rewarded with special categories of functionality. For example, the player must enter a state of deep relaxation in order to re-fuel or heal, or the player must induce a state of high activation during combat to obtain extra strength or weapons. In the game 'Brainchild' [31] for example, a state of relaxation grants the player an ability to telepathically pick a lock. Alternatively, sustaining psychological states that are contradictory to the game play scenario may be rewarded, e.g. maintaining a state of relaxation during combat may activate a protective shield or similar defensive resource. It is also possible to employ 'mode-shifting' functionality to navigate the game world. Inducing states of excitement or deep relaxation may be used to access special areas of the game world; in keeping with the notion of intuitive control, these areas may not be part of the explicit geography of the game world, but exist in a more ethereal realm, e.g. dream-worlds.

If the player is encouraged to actively self-regulate psychological state during a game, this raises ethical issues for the biocybernetic loop, particularly concerning the meta-goal of minimising health risks (section 2.1). Games that use the biocybernetic loop must be carefully designed to avoid sustained episodes of high autonomic activation and associated consequences, e.g. increased blood pressure, hyperventilation, increased secretion of catecholamines and corticosteroids. It could be argued that increased autonomic activation is a natural response to an exciting and engaging computer game; however, there is a large difference between inducing that kind of psychological state as a by-product of game play and encouraging the same psychological state as part of game play. For this reason, games that encourage the player to self-regulate should take their lead from biofeedback and emphasise 'healthy' psychological states such as deep relaxation [31]. There are current products on the market designed at blending immersive environments with deep relaxation, such as the Wild Divine [32]. The use of the biocybernetic loop for relaxation reinforces this trend towards healthy or 'transcendental' gaming where the goals of game play involve the production and maintenance of healthy psychological states [33].

This discussion of computer games has emphasised single-player genre whilst millions of players interact daily via Massively-Multiplayer Online Role Playing Games (MMORPGs). Studies of this type of game are in their infancy, but recent work provides some evidence that MMORPG players are engaged three primary goals: to achieve (to advance, to compete), to socialise (to work as part of a group, to develop relationships), and to immerse oneself in the game world (role-playing, escapism) [34]. If PC or BCI devices were available to players of MMORPGs, are these motivations enhanced by this technology? It is argued that both PC and BCI could enhance achievement by providing a means by which to obtain and exercise additional abilities. In addition, both PC and BCI could be used competitively in a multi-player scenario. With respect to the latter, game concepts based upon competitive relaxation, such as Relax-To-Win [35] have already been developed. The same logic could be extended to BCI that confer special abilities that may be used offensively or defensively. In a competitive situation, the fidelity of control (over psychological state or BCI) becomes a crucial skill for players to master. The goals of socialisation and immersion may be subsumed within the concept of relatedness [36]. Relatedness enhances motivation by making the players feel connected to one another, i.e. socially connected or connected because they share the same virtual world with its own terminology, customs and culture. It has been suggested that monitoring the psychopsychological state of the player may be used to represent the emotional state of each player by adjusting body language, facial expression etc. of each avatar within a MMORPG [37]. This process of mirroring may be extended by displaying intuitive physiological signals (e.g. heart rate) to other players as part of the interaction within a MMORPG. For instance, if players were attempting to detect deception or involved in a bartering process. The possibility of aggregating emotional responses across groups of players in order to influence the attributes of game world have also been suggested [37]. Mirroring the state of the player or aggregating signals to compile a group state are both examples of how the PC approach may enhance feelings of relatedness within a shared, virtual world.

This discussion of BCI and PC has effectively reduced the gap between the two approaches. PC is designed for implicit management of the HCI at a meta-level, but this technology also provides an option for explicit, intentional control at the same meta-level. BCI has been developed for intentional control as a communication channel within the HCI. It is possible to design a system where BCI are used to switch 'modes' of control or manage the HCI, but this may not only be just onerous for the user, but also unintuitive. Similarly, the biocybernetic loop could be used to control movement within a virtual space, but the speed of response may be too slow and the user may find it difficult to self-regulate aspects of psychological state with sufficient precision. If BCI and PC have their own niches within the HCI, would it be possible for healthy users to use both devices in combination? One may imagine a system where the PC component regulates the psychological state of the user in order to optimise the efficacy of BCI control. For example, if control over a BCI device is maximised under conditions of alert relaxation, then the biocybernetic loop could be used to induce and reinforce this state whilst the BCI was in use. This approach may be particularly useful when the user is training with BCI and prone to detrimental psychological states such as stress and fatigue. Another option would be to combine autonomic variables that may be controlled intentionally, such as breathing, with BCI devices in order to extend the functional vocabulary of the latter. For example, event-related desynchronisation of the β rhythm over the sensorimotor cortex may be associated with a different output when the person adopts a slow breathing rate compared to when the person is breathing at a faster rate. This suggestion uses autonomic control as the equivalent of a 'shift' key to expand the functional range of the BCI. This option may be difficult to learn in practice because the user must engage with dual-intentions and exercise dual-control.

The best combination of PC and BCI may be to use the former to implicitly control the HCI at the meta-level and the latter as a novel mode of communication. This combination avoids an overlap in terms of intentionality and system functionality.

4.CONCLUSIONS

Physiological computing offers greater utility for implementation into game software compared to BCI. Physiological computing can function at a number of levels within the HCI; no training is required and it may be used in combination with conventional input devices. The purpose of physiological computing is to manage the HCI according to meta-goals, such as engaging the user whilst promoting health and safety. The challenge faced by physiological computing is the requirement to accurately represent the psychological state of the user over a longitudinal period. It is argued that physiological computing and BCI have different intuitive niches within the HCI and there is some overlap between both approaches. It is also suggested that physiological computing and BCI may be used in combination for the next generation of computer games.

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