Towards Contextual SSVEP-based BCI controller: smart activation of stimuli and controls weighting

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Abstract

Brain-Computer Interfaces became more available for general public and they have been already used to control applications such as computer games. One disadvantage is that they are not completely reliable. In order to increase BCI performances, some adjustments can be made on low levels, such as signal processing and on high levels - by modifying the controller paradigm. In this study, we explore a novel, context-dependant, approach for SSVEP-based BCI controller. This controller uses two kinds of behaviour alternation, commands can be added and removed if their use is irrelevant to the context or the actions resulting from their activation can be weighted depending on the likeliness of the actual intention of the user. This controller has been integrated within a BCI computer game and its influence in performance and mental workload has been addressed through a pilot experiment. Preliminary results have shown a workload reduction and performance improvement with the context-dependent controller while keeping the engagement levels untouched.

Index Terms

Brain Computer Interface, interaction, SSVEP, video game.

I. Introduction

Brain-computer Interfaces (BCIs) are an alternative way of controlling computer applications and electronic appliances. Indeed, state-of-the-art paradigms allow detection of several different mental activities and states that can be used as an input modality in computer applications, computer games in particular [1]. These paradigms include, among others, imagination of movements, evoked potentials such as P300 and Steady-State Visual-Evoked Potentials (SSVEP). BCI applications are leaving laboratories as cheaper electroencephalography (EEG) headsets aimed for general public become available. However, as pointed out by [2], BCI controls are yet a weak replacement for traditional input devices, but they could be used to increase the interaction possibilities, and thus the users' engagement [3].

One problem of BCI control today is that it is not 100% reliable. Previous studies have pointed out great inter-subject performance variability with BCI [4], [5], which in turn make difficult providing a constant correct rate of commands. Different methodological improvements, required to bring BCI technology beyond medical applications, have been already proposed with the goal of improving aspects such as the ease of use, training duration, general usability and control latencies [6]. To further improve the performance of a BCI, approaches on higher level than signal processing have been explored. One approach consists of providing the user with high level commands instead of the low level steps necessary to accomplish the given task. This goal-driven selection was explored in [7], where an important increase in performance was the main outcome. In line with this, [8] has used a P300 protocol to control a humanoid robot using high level commands, while low level control was being handled by an artificial intelligence technique.

The approach followed in the study presented here is based on sharing control between the user and the BCI system. Usefulness of such shared, contextual, control has been demonstrated in [9]. In particular, Motor-based Imagery BCI for fine control of a helicopter in 3D space has been successfully employed in [10] and pre-computed path planning was used in [11], both exploiting shared control features in order to leverage the difficulties associated with an unreliable BCI control. Both [9] and [12] have found that a control shared between the BCI and the user increases low performances, but, in some cases, it can also act in detriment of high level of performance controls. Thus, further research is needed to characterize shared controls properties that make them more reliable through a high level assistance.

SSVEP is a brain response to a visual stimulus oscillating at a constant frequency, such as a flickering light and has been shown to work with a large part of the population [5]. We have chosen the SSVEP paradigm as it can be used for continuous control effectively with little training. Such SSVEP controller was used to control an avatar in a VE in [13]. Authors of [14] used SSVEP to control a cursor on screen. The speed of the cursor movement was computed accordingly to the SSVEP response. In this study, we introduce a novel approach to improve an SSVEP-based BCI by designing and evaluating two kinds of contextual control. One type of contextual modification consists of adding and removing commands on-the-fly as they become available depending on the system state or the game workflow. The other assistance is based on modifying the impact of commands, depending of the game context. To the authors' knowledge, no study has been already performed to analyze assisted controls within BCI built upon a SSVEP paradigm. This study is based on the hypothesis that performance of an SSVEP controller integrated into a VE (mimesis controller) will improve with high level semantic assistance.

A study [15] has shown that, for self-paced BCI-based virtual reality (VR) applications, providing a continuous and informative feedback at any time may reduce the user's frustration. Its use with SSVEP-based BCI has been demonstrated in [13]. Thus, the BCI controller designed was also provided with co-located mental state feedback. This feedback was placed inside of the SSVEP targets with the aim of focusing users' attention in the middle of the flickering object. We illustrate our approach by a proof-of-concept application: a simple video game controlled by SSVEP-based BCI. Moreover, the study hypothesis has been evaluated in terms of human factors with a pilot experiment conducted with twelve participants.

II. Concept of contextual SSVEP control

Most of the nowadays computer applications incorporate some sort of contextual control in their graphical user interfaces (GUI). For example, contextual menus in text processing application contain a different set of commands depending on the selected content (text, image, etc.), commands or GUI controls that cannot be used are often disabled completely. Computer games, which rarely have a dedicated command for every action, often use an 'activate' action which serves multiple purposes depending on the situation. In the particular case of SSVEP, the context can require to place the stimulus on different positions, for example in the game *Bacteria Hunt* [16] the stimulus was placed under the target closest to the player.

The lower information transfer ratio of BCIs compared to standard control peripherals claims for the necessity of integrating contextual controls. In this study, two context-based techniques are presented and implemented within an SSVEP controller used in a game.

A. Binary contextual control: adding and removing commands on the fly

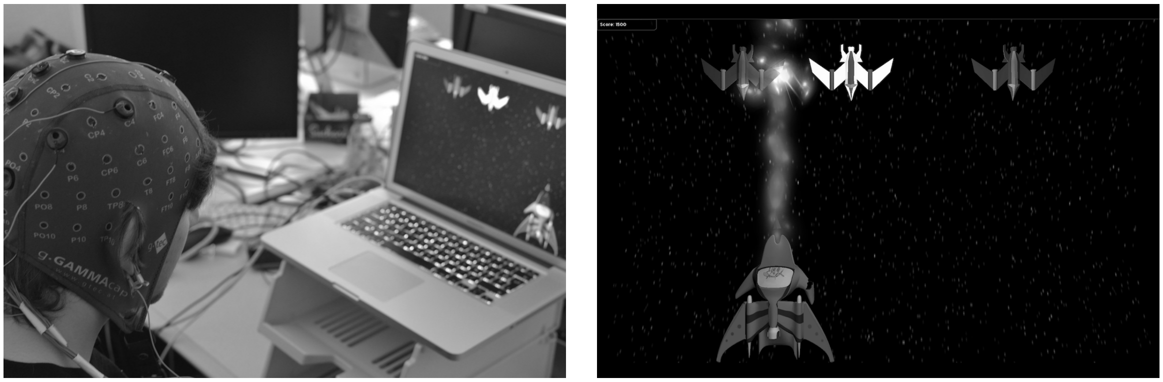
During interaction with an application, there are different situations in which the user cannot activate a command (GUI control or keyboard action in a game) or its activation does not have sense ('copy' command when no text is selected). On the other hand, the application may enable some previously unavailable controls associated to a context-specific action. This activation can result as a consequence of users' previous actions or due to the changes in the environment state.

A similar technique is introduced in this study for SSVEP controllers. Current SSVEP BCIs usually offer a fixed set of commands to control the application. This is the case of SSVEP writing applications ([17], [18]) that use SSVEP activated buttons to navigate on the virtual keyboard or separate the alphabet into groups. These kinds of controls have also been successfully integrated as interfaces to allow navigating within a VE ([13], [19]). A particular restriction to consider in human computer interfaces based on SSVEP controls is the limitation in number of commands due to the fixed frame-rate of the computer screen and the stimulation frequency. Several studies have been done in this regard, with the goal of increasing the number of commands ([20], [21]). An approach usually followed consists of using one command for several actions, through hierarchical decision trees of possible actions. Thus, one command can be used for several actions, as long as there is only one choice at a time. In [19], three commands were used for navigation and one to send an universal 'activate' command. In [22] four commands were used to separate a set of characters in an implementation of a spelling application.

The approach followed in this study, referred as *binary contextual control* is based on physically removing the flashing together with ignoring the commands activated that do not have effect due to the application running state. This translates to de-activating the flickering of the light and disabling the classifier. A similar technique was followed in [18], by limiting the cursor movements out of an alphabet grid.

B. Analog contextual control: weighting the commands importance

Previous studies [9] have shown that a shared control between the user and an AI technique increases users' performance. Indeed, in applications based on BCI and demanding a high level of precision and reliability, such as those designed to control wheelchairs ([9], [12]). In [9] an expert system has been employed to provide the BCI controller with reliability features, an obstacle avoidance system in particular. In non-critical systems, such as computer games,



(a) User playing the game during evaluation.

(b) Screenshot of the proof of concept game.

Fig. 1: Illustrations of the experiment

possibility of activation of commands which would have negative or undesirable effect might be part of the paradigm (such as increasing the difficulty). In this case, the application should allow users activating a command, despite of not being recommended by the system. Among the different solutions existing in traditional games, the technique implemented consists in not avoiding the control activation but reducing/moderating its effect within the application. The system will evaluate the controls with less probability of being activated and it will inhibit their effect to a certain extent (as an example, an avatar representing the user could move at slower speeds if it is approaching a wall). Alternatively, the selection probability of the command on the classifier level can be modified in a similar way.

III. Method

In order to illustrate our controller, we have conducted a pilot study with twelve participants. All had normal or corrected-to-normal vision and no history of major head injury. Three of the participants had previous experience with BCI applications. They signed an informed consent and the SSVEP controller fundamentals were described to them.

The shared controller has been implemented as a BCI-variant of a simple video game, described in Section III-A (see Figure 1b). In this game version, the user can control a spaceship displayed on the bottom of the screen by three commands activated through the BCI: “move right”, “move left” and “shoot”. Flickering objects used to trigger SSVEP response were placed directly on the model of the spaceship, i.e.: the wings were flashing in order to activate the commands associated with the spaceship movement and the front of the ship (or a "cannon") was flashing for shooting.

The effect of the two high level types of contextual assistance included within a SSVEP controller was evaluated by considering an intra subjects analysis with two independent variables (2 x 2 design). First variable being the presence of activation/deactivation of flashes depending on the context, referred from now on as Binary control. Second variable being the weighting of the command's impact, referred as Analog control. Thus, participants played the shooting game in four different conditions: controller without contextual modifications (*CTRL_0*), controller with binary contextual control (*CTRL_B* described in Section III-A2), controller with analog contextual control (*CTRL_A* described in Section III-A3) and a controller with both contextual controls (*CTRL_AB*). The human factors considered as dependent variables are grouped into performance, workload, engagement and perceived assistance.

Performance was assessed considering the success in the task proposed in the game, in terms of the score (SCORE) as defined in III-A, the number of shots landed on the enemy spaceships (HITS_E) and allied ships (HITS_A), the number of trials in which both enemies were successfully destroyed (KILLS_B), and the time required to destroy one spaceship (TIME). Workload was operationalized by NASA_TLX questionnaire [23] and participants' engagement with the Game Engagement Questionnaire (GEQ) [24]. Participants were also asked to rate the extent to which the contextual controller was helpful within the game with a seven Likert scale with three response choices ("Not at all", "Somewhat", "Completely").

NASA_TLX questionnaire consists of six questions that estimate Mental Demand, Physical Demand, Temporal Demand, Effort and Frustration. Each of these questions is answered with a 20 item scale and converted to a 100 scale. This conversion has been made without a weighting procedure.

GEQ has been developed to provide psychometrically strong measure of levels of engagement specifically elicited while playing video games. This questionnaire analyzes five factors: Presence, Absorption, Flow and Immersion; and it has nineteen items rated on a five Likert scale with three response choices ("No", "Sort of", "Yes"). The original version of nineteen questions has been reduced to sixteen by eliminating the following items: "I feel scared", "I feel different" for Absorption; "The game feels real" for Flow and "I play longer that I mean" for Presence.

A. Test Application: SSVEP Shooter Game

A proof-of-concept system has been designed as a simple game with a fixed duration. The goal of the game is to destroy the incoming enemy ships while avoiding shooting friendly targets. One round of the game consists of four waves of enemies. In each wave, three ships appear in front of the user-controlled spaceship. Two of these ships are enemies and one is a friendly ship. The enemies appear on right and left side of the screen. The enemy placed besides the ally is worth 1500 points and the other 500 points. Shooting down the allied ship penalizes the players by subtracting 500 points from their score. At the beginning of each new wave, the user-controlled ship is re-positioned in such a way that it finds itself between the enemy costing 500 points and the allied ship. The initial positions during a wave are illustrated on Figure 1b.

Once all the ships are in position, the SSVEP targets on the user-controlled ship begin to flicker and the user is given control. From this moment, they have one minute to attempt to destroy both enemies. At the end of this period, the enemy ships will leave and a new wave begins. If the current wave was the last one then the game ends and the players are informed about their final score by a message. These rules were explained to the participants prior to the first game after the training. They were told that the goal of the game was to obtain the maximum amount of points by destroying all of the enemies while avoiding shooting down the allies.

1) Implementation of the contextual control: In order to evaluate the impact in performance of the contextual control assistance, the two types or proposed controls (Binary and Analog) have been integrated in the proof-of-concept game. These controls were also integrated separately as different conditions of the game to assess the main source of the expected improvement in performance and user experience of the two types of assistance. In our particular example, each of the flickering targets could be either disabled or inhibited by the system depending on the relative position of the user to the enemy and/or friendly ships. Figure 2 illustrates various configurations in which the game could be found, in the case that all three non-player ships are present.

2) Implementation of the binary contextual controller: This contextual control consisted of adding and removing commands depending on the situation. In the proof-of-concept game, there are different relative positions between the user space-ship and the others (enemies and allies) that

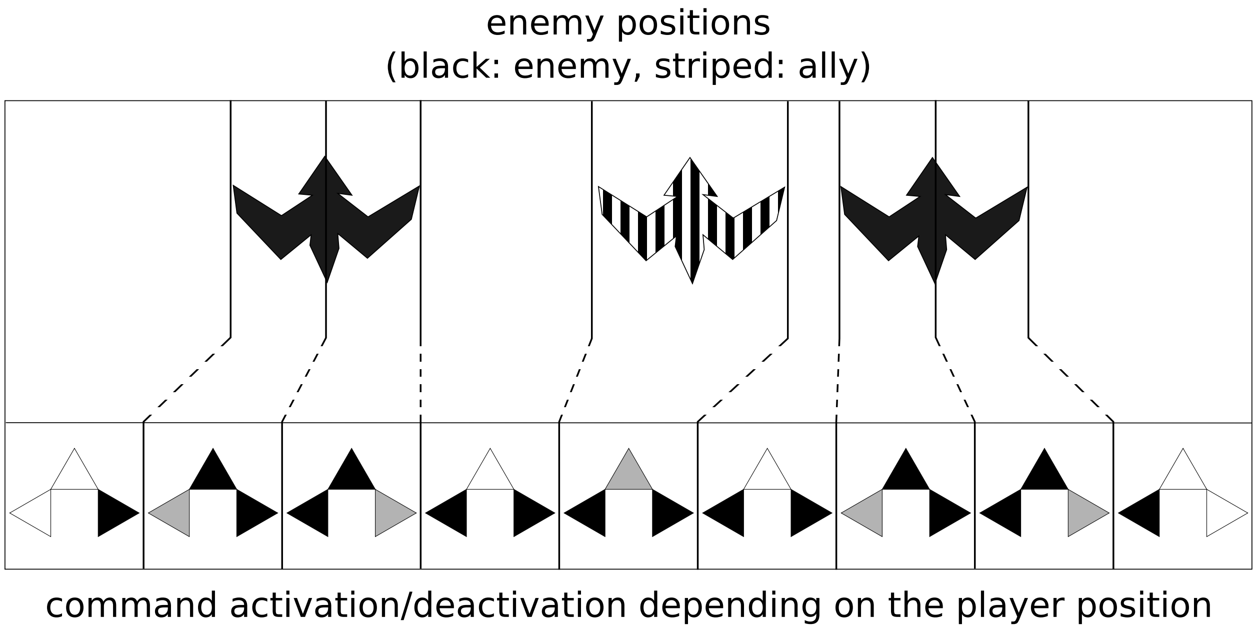


Fig. 2: Controller Configurations: Blacks figures represent enemies, Striped figure is the allied ship. The model is in scale to the real game. On the bottom, the three arrows represent the possible states of the three SSVEP Commands relative to the players position: black=active, grey=inhibited (in *CTRL_A* and *CTRL_AB*), white=disabled (in *CTRL_B* and *CTRL_AB*), grey and white commands act as normal in *CTRL_B* and *CTRL_A* conditions respectively.

would require disabling specific commands. These commands are disabled by suppressing the flickering of the corresponding targets. Therefore, results obtained from the respective classifiers are also discarded. There are two situations in which a command is disabled. One takes places when the user-controlled ship reaches the edge of the screen. Indeed, being at the leftmost (or rightmost) spot of the environment makes impossible to move further. Thus, the command associated with the illegal movement is disabled. The other case happens when there is no ship in front of the players. This should mean that although they are physically able to shoot by activating the cannon target, this action will never result in any change to the environment. In this situation, this target is disabled by not activating its flickering.

3) Implementation of the analog contextual controller: As the rules of the game allows the system estimating which commands are, with high-probability, unwanted - false positives, the effect of these commands can be weighted, in such a way that the user is less likely to activate

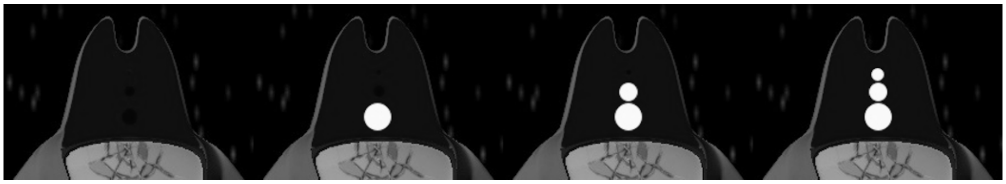


Fig. 3: Illustration of progression of feedback level on the “cannon” target. At the left the feedback shows level 0 and at the left level 3.

them. One of the unwanted actions in this particular game is shooting the allied spaceships. Thus, in the game conditions in which this feature is enabled, the rate of fire is slowed down while the player is in front of an ally. Thus, under this condition, the user can activate the target, but its behavior within the game context will increase the time necessary to shoot down the allied ship. Another game behavior is activated when the player is placed in front of an enemy. In this situation, the logical target to activate is the cannon in order to shoot. Therefore, the system inhibits the behavior of the movement targets by slowing down the movement of the user’s spaceship caused by their activation. Thus, this assistance facilitates focusing on the enemy by making it more difficult to move away from it. The slowdown is progressive, meaning that it is strongest when the player is aligned with the middle of the enemy ship and decreases towards the sides.

4) Co-located feedback: In [13] a mental state feedback was introduced into a SSVEP-based BCI. The feedback provided was reported useful by the users but some of them also indicated that the process of checking the feedback level had also as an effect that they lost focus on the flickering target when a mental state feedback is provided while controlling an SSVEP-based application. The primary task is to focus their attention on the flickering target in order to activate the commands. A secondary and optional task consists in checking the mental state feedback to verify the system responsiveness. In this work, we have implemented a co-located feedback showing the user’s concentration level at each of the flickering targets. This feedback presented was showed within the graphics as three circles inside of each target, as shown in Figure 3.

At any given time the feedback level could be 0, 1, 2 or 3 - represented by progressively illuminating the three circles. A value of 0 shows no concentration at all, while a value of 3 means that the SSVEP response is high enough to activate the command. Putting the feedback indicator in the middle of the flickering object makes the primary task implicit while the user performs the secondary task. While users focus on the mental state feedback they will be also directly concentrated on the middle of the flickering target. The feedback levels were derived from the LDA (Linear Discriminant Analysis) classifier output. The value used for the feedback level was the distance of the currently classified vector to the separating hyperplane of the LDA. This distance was normalized (by dividing it by an estimated maximum distance) to obtain a real value between 0 and 1, which was later transformed to a integer value between 0 and 3. Further detail of the feedback estimation can be found in [13].

B. Apparatus

The data was acquired by a g.Tec USBamp EEG device. EEG was acquired on eight channels, mostly in parietal region: O1, Oz, O2, Iz, POz, Pz, CPz and Cz. The signal was sampled at 512 Hz and the device's internal 4th order Notch filter with range between 48 Hz and 52 Hz and wide band pass filter between 1 Hz and 100 Hz, sampled at 512 Hz, were used to eliminate environmental noise. During the training and the different trials, users were placed in a comfortable chair with their eyes about 60 cm from the computer screen. The screen used was the laptop display of a 15" Macbook pro. The computer was risen so its top edge was on level with the user's eyes. A photo of a subject playing the game can be seen on Figure 1a. Signal acquisition and processing was done by the OpenViBE [25] software.

C. Signal processing

The three commands were activated by focusing on three separate flickering objects oscillating at 5 Hz, 6 Hz and 7.5 Hz, respectively. Each flickering object was treated separately and was associated to an LDA classifier using features described later in the paragraph. For each frequency, the eight EEG channels were separated by two fourth-order CSP (Common Spatial Pattern) spatial filters into two groups of eight reconstructed channels. These two groups represented the best linear combinations of the original channels that maximize the response for the stimulated frequency and its first harmonic. Estimation of the CSP filters was done according to the method described in [26].

The power levels at frequencies of the flickering targets and their first harmonics were calculated by filtering the EEG signal in a narrow band (0.7 Hz) around the target frequency. The signal was divided into epochs of 1 s each and an epoch was created every 100 ms. The signal in each epoch was then squared, averaged over the whole epoch, and finally, a natural logarithm of the value was computed. The final values were used as features for the classifier. In this regard, each of the three classifiers received vectors consisting of two features.

D. Training

A short training was required in order to compute the coefficients for the CSP spatial filters and to train the LDA classifiers. During the training phase the user's spaceship was displayed on the middle-bottom position of the screen. One of the four possible instructions was shown in the middle of the screen: LEFT, RIGHT, CANNON, MIDDLE. MIDDLE condition was used to obtain values for the moments where user is not looking at any particular target, but still has the ship in his visual field. The user was then instructed to look at the indicated target, or to the middle of the spaceship. Once the message disappeared, all three targets on the ship began to flicker for 7 s. After this time, a short break followed (1.5 s) and a new instruction appeared. This process was repeated until each of the targets was requested five times. The whole training lasted around 4 min. None of the participants reported any eye fatigue due to the training procedure. The values from the training session were used to compute the LDA classifiers. Each classifier used vectors from epochs when the user was looking at the target it was classifying as target vectors and all of the others as non-targets.

E. Procedure

After the training, all of the users played four rounds of the game, each in a different controller condition. The order of these conditions was counterbalanced. Each round consisted of four enemy waves as described in Section III-A. After each of the trials, participants completed NASA_TLX questionnaires. Besides, GEQ was also provided after completing the *CTRL_0* and *CTRL_AB* conditions. At the end of the game, they were asked to rate the assistance provided in the different conditions and to report any suggestions.

IV. RESULTS

The influence of the two kinds of contextual controller provided (Binary and Analog) has been evaluated by employing a variance analysis (ANOVA) with two within-subjects variables.

	SCORE (pts)	HITS_E	HITS_A	KILLS_B (trials)	TIME (s)
BINARY	A: 3270 P: 3333 p= .88	A: 21.5 P: 24.2 p= .14	A: 5.9 P: 8.3 *p= .019*	A: 1.8 P: 2.2 *p= .02*	A: 25.0 P: 18.9 *p= .01*
ANALOG	A: 2854 P: 3750 *p= .001*	A: 21.3 P: 24.4 *p= .008*	A: 7.2 P: 7.0 p= .79	A: 1.7 P: 2.2 *p= .04*	A: 23.0 P: 20.8 p= .32

TABLE I: Influence of analog and binary contextual controller (A: Absent, P: Present)

Differences among the four experimental conditions (*CTRL_0, CTRL_A, CTRL_B* and *CTRL_AB*) have been evaluated with Student t-tests, to analyze the best inclusion criteria of an SSVEP contextual controller.

A. Performance results

As can be seen in Table I, the ANOVA of performance measurements indicated a positive influence of the Analog control in SCORE ($F(1,11)=18.6$; $p=.001$), the number of HITS_E ($F(1,11)=10.4$; $p=.008$) and KILL_B ($F(1,11)=16.5$; $p=.002$). Regarding the Binary control, its positive influence was significant for KILL_B ($F(1,11)=6.6$; $p=.02$) and TIME ($F(1,11)=7.89$; $p=.01$), however its influence was negative for HITS_A ($F(1,11)=7.5$; $p=.02$).

Therefore, the analog control increases the users' capacity of performing the game task accurately, in terms of the number of space-ships that users could hit and the number of trials in which they successfully destroyed both enemies, which in turn increased the score achieved. The binary control was also positive in terms of improving the rapidity. However, this kind of control affected the accuracy negatively by increasing the number of shots at allies.

As shown in Figure 4, differences among conditions indicated that performance was higher with the *CTRL_AB* controller than without any kind of assistance (*CTRL_AB-CTRL_0*). Thus, the score achieved (*CTRL_AB-CTRL_0*=958 pt., $t_{11}=1.9$, $p=.07$), the number of enemy hits (*CTRL_AB-CTRL_0*=5.8, $t_{11}=3.1$, $p=.01$) and the trials with both enemies destroyed (*CTRL_AB-*

	NASA_TLX	TEMP DEMAND	PERFORMANCE
BINARY	A: 50.4	A: 47.5	A: 56.8
	P: 45.7	P: 38.1	P: 55.0
	p=.09	*p=.02*	p=.72
ANALOG	A: 50.5	A: 48.1	A: 60.6
	P: 45.6	P: 37.5	P: 51.2
	p=.01	*p=.02*	*p=.04*

TABLE II: Influence of analog and binary contextual controller (A: Absent, P: Present) on workload

CTRL_0=0.9, t_{11}=3.63, *p=.004*) were higher. Besides, the time taken to destroy the first enemy got reduced (*CTRL_AB*-*CTRL_0*=8.3 s, t=-3.6, *p=.004*). However, the number of allies' hits was higher in *CTRL_AB* than in *CTRL_0* without a significant difference. As can be seen in Figure 4, conditions with only one type of assistance (*CTRL_A* or *CTRL_B*) did not significantly improve performance achieved in *CTRL_0* condition. Indeed, performance results (HITS_E, KILLS_B, TIME) showed a significant improvement in most of the cases when both types of assistance were provided together in relation to conditions with only one type.

B. Subjective reports of workload, game engagement and perceived assistance

As can be seen in Table II, the overall NASA_TLX index was influenced positively for both types of context controllers (Binary: F(1,11)=3.2, *p=.09*; Analog: F(1,11)=9.3, *p=.01*), although being significant only for the analog one. Thus, the overall workload was reduced with the assistance introduced in the SSVEP controller by modifying the effect of the command activation in the game. Results in the components of workload have indicated that this positive influence was mainly due to a reduction of perceived temporal demand and to an improvement of perceived performance. Analog type of contextual controller influences significantly both factors (Temporal Demand: F(1,11)=6.4, *p=.02*; Performance: F(1,11)=5.3, *p=.04*), while binary controller had a significant influence only in the Temporal Demand (F(1,11)=6.8, *p=.02*). As shown in Figure 4e, the reduction in the overall workload relative to the one obtained in *CTRL_0* condition was already significant in *CTRL_A* (*CTRL_A*-*CTRL_0*: 5.1, t_{11}=2.4, *p=.03*), and therefore in *CTRL_AB* (*CTRL_AB-CTRL_0*: 10.3, t_{11}=2.7, *p=.02*). As for Temporal Demand, this reduction was significant in the three conditions (*CTRL_A-CTRL_0*=15, t_{11}=2.5, *p=.02*; *CTRL_B-CTRL_0*=-14, t_{11}=2.9, *p=.06*; *CTRL_AB-CTRL_0*=20, t_{11}=3.0, *p=.01*).

Game engagement (GEQ index rated on a five Likert scale) was very similar in *CTRL_0* (M=2.5, SD=0.4) and *CTRL_AB* (M=2.47, SD=0.5) conditions. Thus, there were no significant differences between average results of its components.

Participants reported that both type of contextual controllers were of some help (Analog: M=4.4, SD=1.7; Binary: M=4.1, SD=2.1) but without significant difference between conditions.

Despite of simplifying the game, the assistance of disabling commands made by the binary controller was reported to impact negatively in the perceived system responsiveness. Indeed, one participant indicated that the changes in the commands availability (flickering switching between on and off) had distracted his attention and might have made him activate wrong commands.

As for the analog control, it seems that its positive effect was due to also to its transparency. Indeed, four participants did not realise its existence.

V. Discussion

The evaluation performed in this pilot experiment has provided further insight about the feasibility of including a contextual controller in an SSVEP-based BCI application. In particular, a modality of continuous feedback and two ways of contextual assistance implemented within computer game have been evaluated.

In contrast with results obtained on a previous attempt of including feedback within an SSVEP mimesis controller [13], performance and subjective participants' reports have highlighted that positioning of the feedback inside the stimuli was better perceived than adding feedback as an additional source of information (in [13] the feedback was included as an morphing outline of the stimuli or by moving parts of an animated controller).

Outcomes obtained from the human evaluated factors have indicated that the best approach is based on weighting the controls effect (analog control) rather than disabling them altogether (binary control). It seems that the positive influence of the assistance in performance and mental workload is related to the assistance transparency, that is to say, to the extent to which the assistance does not disrupt the perceived system responsiveness. Additionally, participants also reported that when a command was switched off by the binary control they found it more frustrating when the system did not respond to their intentions, as the game was supposedly simplified. Though ad-hoc and preliminary, this aspect may be the cause of the non positive effect of the assistance included through the binary controller in certain human factors.

Moreover, the SSVEP controller has not overloaded typical mental workload of the user interface (within a range from 43 to 53). Results for the four analysed conditions were quite similar to those values encountered in previous studies for BCI games ([27], [28]). Indeed, participants' workload (NASA TLX index) measured after playing at different Pacman game levels without a BCI was found in [29] within a range from 26 to 69. This outcome could lead to conclude that the inclusion of BCI as an additional input modality for applications issued for general audience is not an unreachable goal.

Results of game engagement levels were close to those encountered in previous studies about BCI games ([27], [28]). This shows the feasibility of developing games for people limited to this kind of interaction modality. However, in line with workload, engagement results have also made evident that integrating this type of input with typical interaction modalities is necessary for general public applications, games in particular.

VI. Conclusion

There is a common agreement within research studies aimed to bring the use of BCI controllers to applications developed for a wide audience, about the necessity of improving human computer interaction techniques usually employed in these systems. With the aim of increasing responsiveness and reliability of SSVEP controllers, a new kind of controller integrated with the application context has been proposed.

Previous attempts in the design of these interfaces have already considered the integration of SSVEP controllers within the context of a game to improve immersion and the inclusion of feedback cues associated with controls activation to increase the degree of perceived responsiveness. Aiming to design an SSVEP controller in terms of usability, this study describes the design of a controller completely adapted to a proof-of-concept game and with a feedback conceived to maintain users' focus on the controller. This last aspect was highlighted in a previous study as a possible source of performance reduction.

As a step forward and following typical techniques already employed for developers of graphical user interfaces and immersive games, two mechanisms adapted to the application context have been developed by providing a high level assistance to the BCI controller. Disabling controls or changing its effect depending on the actions being performed by users during their interaction are common techniques used to share the control between the system and the user, and they have been proved to improve interface usability in terms of easiness of use and performance. In line with these studies, the research presented here has also shown the viability of integrating similar techniques into an SSVEP controller and shown the improvement achieved in terms of different human factors.

Within game applications, BCI interfaces are being included as an additional source of control that allows creating new paradigms of interaction which are not linked, and limited, to motor actions. For example, in a typical role play game an SSVEP controller presented as a small patch in the corner of the screen could be used to activate/deactivate certain guidance/powers without losing track of what is going on in the game and without delaying other actions being made through typical controls. That is to say, they would be able to bring interaction within a game beyond the use of traditional controls that consist in pushing buttons or moving a joystick, via enriching the communication flow between users and applications not limiting it by motor abilities. However, with this purpose in mind, BCI controls may be analyzed in terms of usability and should be also properly included within the game context. Usability of these systems is strongly related to mental workload, that is to say, the control itself should not reduce attention resources involved with the game tasks. Following approaches of previous studies,the possible benefits of a shared BCI controller has been evaluated not only in terms of performance but also attending to workload metrics.

Preliminary results obtained through an experiment conducted by using the proposed proof-of-context game have confirmed the hypothesis of the benefit in terms of workload reduction and performance improvement of a context-dependent controller. The experimental design used has also allowed to highlight that assistance based on modulating the effects of actions has had its main influence in increasing game performance in terms of accuracy. The main influence of assistance based on disabling unnecessary controls has shown its main influence in responsiveness through time measure. Both types of assistance have positively contributed to mental workload reduction. The level of game engagement has also proved the neutral perception of these controllers, providing certain insights into the feasibility of integrating such an SSVEP controller in a traditional game computer without altering end users' engagement.

REFERENCES

[1] A. Lécuyer, F. Lotte, R. Reilly, R. Leeb, M. Hirose, and M. Slater, "Brain-computer interfaces, virtual reality, and videogames," *Computer*, vol. 41, no. 10, pp. 66 –72, Oct. 2008.

[2] D. Plass-Oude Bos, B. Reuderink, B. Laar, H. Gürkök, C. Mühl, M. Poel, A. Nijholt, D. Heylen, and D. S. Tan, *Brain-Computer Interfacing and Games*. Springer London, 2010, pp. 149–178.

[3] F. Lotte, "Brain-computer interfaces for 3D games: hype or hope?" in *Proceedings of the 6th International Conference on Foundations of Digital Games*. New York, NY: ACM, 2011, pp. 325–327.

[4] A. Nijholt, D. Tan, G. Pfurtscheller, C. Brunner, J. del R. Millán, B. Allison, B. Graimann, F. Popescu, B. Blankertz, and K.-R. Müller, "Brain-computer interfacing for intelligent systems," *IEEE Intell. Syst.*, vol. 23, no. 3, pp. 72–79, May 2008.

[5] B. Allison, T. Luth, D. Valbuena, A. Teymourian, I. Volosyak, and A. Graser, "BCI demographics: how many (and what kinds of) people can use an SSVEP BCI?" *IEEE Trans. Neural Syst. Rehabil. Eng. : a publication of the IEEE Engineering in Medicine and Biology Society*, vol. 18, no. 2, Apr. 2010.

[6] B. Blankertz, M. Tangermann, C. Vidaurre, S. Fazli, C. Sannelli, S. Haufe, C. Maeder, L. E. Ramsey, I. Sturm, G. Curio, and K. R Mueller, "The Berlin brain-computer interface: Non-medical uses of BCI technology," *Frontiers in Neuroscience*, vol. 4, no. 00198, 2010.

[7] A. S. Royer, M. L. Rose, and B. He, "Goal selection versus process control while learning to use a brain–computer interface," *J. Neural Eng.*, vol. 8, no. 3, p. 036012, 2011.

[8] C. J. Bell, P. Shenoy, R. Chalodhorn, and R. P. N. Rao, "Control of a humanoid robot by a noninvasive brain–computer interface in humans," *J. Neural Eng.*, vol. 5, no. 2, p. 214, 2008.

[9] G. Vanacker, J. del R. Millán, E. Lew, P. W. Ferrez, F. G. Moles, J. Philips, H. Van Brussel, and M. Nuttin, "Context-based filtering for assisted brain-actuated wheelchair driving," *Intell. Neuroscience*, vol. 2007, pp. 3–3, Jan. 2007.

[10] A. S. Royer, A. J. Doud, M. L. Rose, and B. He, "EEG Control of a Virtual Helicopter in 3-Dimensional Space Using Intelligent Control Strategies," *IEEE Trans. Neural Syst. Rehabil. Eng.*, vol. 18, no. 6, pp. 581–589, Dec. 2010.

[11] F. Lotte, A. van Langhenhove, F. Lamarche, T. Ernest, Y. Renard, B. Arnaldi, and A. Lécuyer, "Exploring large virtual environments by thoughts using a brain–computer interface based on motor imagery and high-level commands," *Presence-Teleop. Virt.*, vol. 19, no. 1, pp. 54–70, Feb. 2010.

[12] F. Galán, M. Nuttin, E. Lew, P. W. Ferrez, G. Vanacker, J. Philips, and J. del R. Millán, "A brain-actuated wheelchair: Asynchronous and non-invasive brain–computer interfaces for continuous control of robots," *Clin. Neurophysiol.*, vol. 119, no. 9, pp. 2159–2169, 2008.

[13] J. Legény, R. V. Abad, and A. Lécuyer, "Navigating in virtual worlds using a self-paced SSVEP-based brain–computer interface with integrated stimulation and real-time feedback," *Presence-Teleop. Virt.*, vol. 20, no. 6, pp. 529–544, Dec. 2011.

[14] J. J. Wilson and R. Palaniappan, "Analogue mouse pointer control via an online steady state visual evoked potential (SSVEP) brain–computer interface," *J. Neural Eng.*, vol. 8, no. 2, p. 025026, 2011.

[15] F. Lotte, Y. Renard, and A. Lécuyer, "Self-Paced Brain-Computer Interaction with Virtual Worlds: A Quantitative and Qualitative Study "Out of the Lab"," in *4th international Brain Computer Interface Workshop and Training Course*. Graz, Austria: Graz University of Technology, 2008.

[16] C. Mühl, H. Gürkök, D. Plass-Oude Bos, M. Thurlings, L. Scherffig, M. Duvinage, A. Elbakyan, S. Kang, M. Poel, and D. Heylen, "Bacteria Hunt: A multimodal, multiparadigm BCI game," *Journal on Multimodal User Interfaces*, vol. 4, no. 1, pp. 11–25, Mar. 2010.

[17] H. Cecotti, “A self-paced and calibration-less SSVEP-based brain-computer interface speller.” *IEEE Trans. Neural Syst. Rehabil. Eng.*, vol. 18, no. 2, pp. 127–133, Apr. 2010.

[18] I. Sugiarto, B. Allison, and A. Gräser, “Optimization strategy for SSVEP-based BCI in spelling program application,” in *Proceedings of the 2009 International Conference on Computer Engineering and Technology*, vol. 1. Washington, DC: IEEE CS, 2009, pp. 223–226.

[19] C. Kapeller, C. Hintermüller, and C. Guger, “Augmented control of an avatar using an SSVEP based BCI,” in *Proceedings of the 3rd Augmented Human International Conference*. New York, NY: ACM, 2012, pp. 27:1–27:2.

[20] K.-K. Shyu, P.-L. Lee, Y.-J. Liu, and J.-J. Sie, “Dual-frequency steady-state visual evoked potential for brain computer interface,” *Neuroscience Letters*, vol. 483, no. 1, pp. 28–31, Oct. 2010.

[21] P.-L. Lee, J.-J. Sie, Y.-J. Liu, C.-H. Wu, M.-H. Lee, C.-H. Shu, P.-H. Li, C.-W. Sun, and K.-K. Shyu, “An SSVEP-actuated brain computer interface using phase-tagged flickering sequences: A cursor system,” *Annals of Biomedical Engineering*, vol. 38, pp. 2383–2397, 2010.

[22] H. Segers, A. Combaz, N. Manyakov, N. Chumerin, K. Vanderperren, S. Huffel, and M. Hulle, *Steady state visual evoked potential (SSVEP) - based brain spelling system with synchronous and asynchronous typing modes*. Springer Berlin Heidelberg, 2011, vol. 34, pp. 164–167.

[23] H. S. G., “Development of NASA-TLX (task load index) : Results of empirical and theoretical research,” 1988.

[24] J. H. Brockmyer, C. M. Fox, K. A. Curtiss, E. McBroom, K. M. Burkhart, and J. N. Pidruzny, “The development of the game engagement questionnaire: A measure of engagement in video game-playing,” *J. Exp. Soc. Psychol.*, vol. 45, no. 4, pp. 624–634, Jul. 2009.

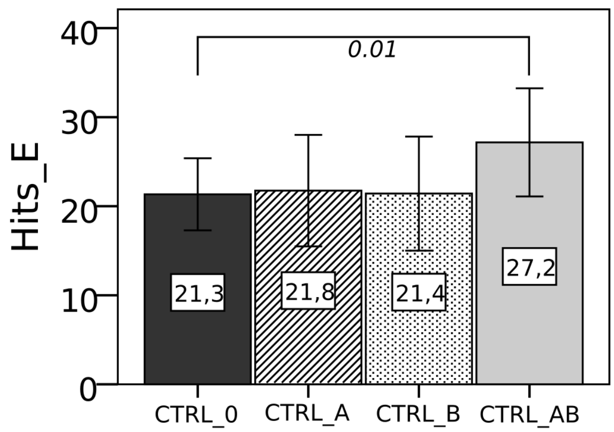
[25] Y. Renard, F. Lotte, G. Gibert, M. Congedo, E. Maby, V. Delannoy, O. Bertrand, and A. Lécuyer, “OpenViBE: An open-source software platform to design, test, and use brain–computer interfaces in real and virtual environments,” *Presence-Teleop. Virt.*, vol. 19, no. 1, pp. 35–53, Apr. 2010.

[26] B. Blankertz, R. Tomioka, S. Lemm, M. Kawanabe, and K.-R. Müller, “Optimizing spatial filters for robust EEG single-trial analysis,” *Signal Processing Magazine, IEEE*, vol. 25, no. 1, pp. 41 –56, 2008.

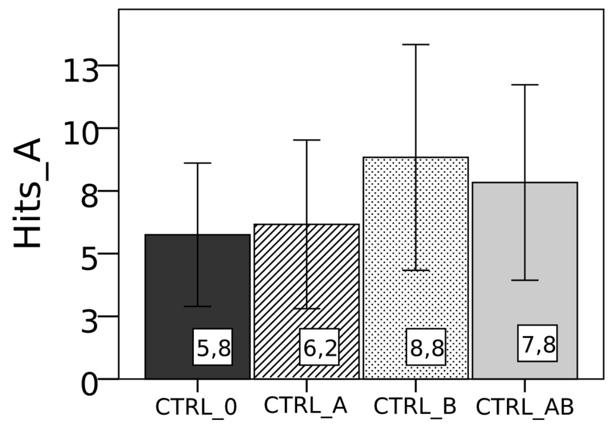
[27] H. Gürkök, D. Plass-Oude Bos, B. L. van der, F. Nijboer, and A. Nijholt, “User experience evaluation in BCI: Filling the gap,” *International Journal of Bioelectromagnetism*, vol. 13, no. 1, pp. 54–55, Jul. 2011.

[28] R. Vilimek, T. Zander, and C. Stephanidis, *BC(eye): Combining Eye-Gaze Input with Brain-Computer Interaction*. Springer Berlin Heidelberg, 2009, vol. 5615, pp. 593–602.

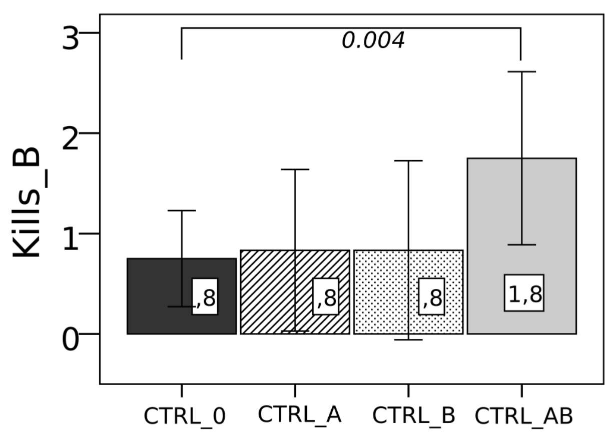
[29] A. Girouard, E. Solovey, L. Hirshfield, K. Chauncey, A. Sassaroli, S. Fantini, R. Jacob, T. Gross, J. Gulliksen, P. Kotzé, L. Oestreicher, P. Palanque, R. Prates, and M. Winckler, *Distinguishing Difficulty Levels with Non-invasive Brain Activity Measurements*. Springer Berlin Heidelberg, 2009, vol. 5726, pp. 440–452.



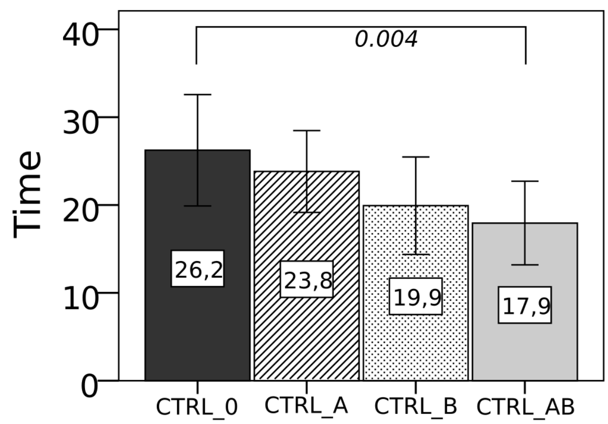
(a) Enemy Hits



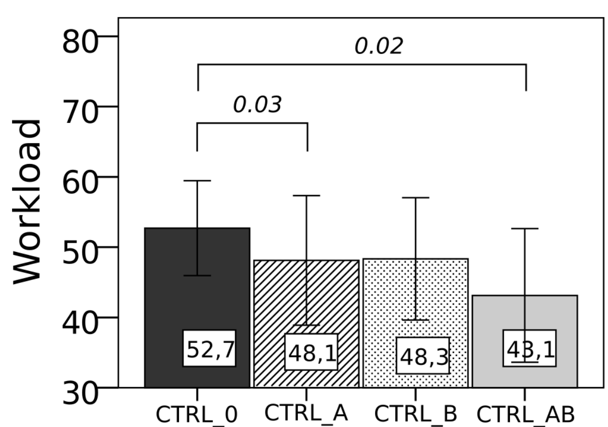
(b) Allied Hits



(c) Both Enemies destroyed



(d) Time to shoot first enemy



(e) Overall workload

Fig. 4: Average value of selected performance metrics and workload for the four experimental conditions (CTRL_0, CTRL_A, CTRL_B, CTRL_AB)