BrainSnake: Exploring Mode of Interaction in a Cooperative Multi-brain BCI Game Based on Alpha Activity

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Abstract—**This paper describes the design, development and evaluation of BrainSnake, a cooperative multi-brain closely-coupled brain-computer interface (BCI) game based on alpha activity. BrainSnake uses communication to address common shortcomings of BCI as an interaction modality. A within-subject study was performed to understand the value of communication in a BCI setting by putting players in both a "co-present" and "remote" condition. Results draw a complex picture of player experience but indicate that participants attributed more control over the snake character and less frustration to the co-present condition. Moreover, there was a preference for balancing communication and BCI input while playing the game. Recommendations for future design of cooperative multi-brain BCI games are derived.**

***Keywords*—*brain computer interface*; *game design*; *multimodal interaction*; *user experience*; *communication*.**

I. INTRODUCTION

In recent years, Brain-Computer Interfaces (BCIs) have been investigated as an input modality for user interfaces in recreational human-computer interaction (HCI), such as art [1] and games [2] [3]. At present, multi-brain BCI games enable multiple users to work towards the completion of cooperative or competitive tasks [4] [5]. However, BCI as an input modality still comes with a number of issues preventing it from becoming mainstream, such as delays in inputs, bad signal recognition, long training time, and cumbersome hardware [4]. Nevertheless, research on User Experience (UX) in games provides cumulative evidence that the use of (multi-brain) BCI as an interaction modality has considerable potential for the gaming community [3]–[6].

Research suggests that multi-player game setups may be preferred over single player mode with regard to fun and motivation [5]. However, to the best of our knowledge, no attention has been devoted to how people experience communication in multi-brain BCI games and how in-game communication should be implemented. This is due to the fact that Electroencephalography (EEG) recordings are easily disturbed by facial expressions, speech and bodily movements [4], limiting the scope of efficient modes of communication. This poses a challenge to BCI game designers.

We invite BCI researchers and game designers to view shortcomings of BCI in a new light. [6] makes a case for considering shortcomings of BCI in traditional BCI applications as in-game tasks and challenges from a game design point of view [6] [7]. One way to overcome these shortcomings is by using BCI as a complementary control modality. An example of such a BCI implementation is AlphaWoW, a variant of the popular videogame World of Warcraft, which calculates power in the alpha frequency (8-12 Hz) of the brain to control the shape-shifting ability of certain playable characters: when the user experiences stress, such as under in-game battle conditions, there is little alpha activity, and the character changes into a powerful bear form. Once the user starts to relax, alpha activity increases and the character reverts back to its natural elf shape [6]. However, such an implementation of a BCI is passive, i.e., the user is not directly controlling the game with brain activity. One of the easiest ways to control alpha activity is by closure of the eyes, however this introduces a counterintuitive control mechanism: alpha activity is increased when the subject closes their eyes, and by doing so, they give up visual feedback. Moreover, it takes a few seconds to induce higher alpha activity and for the system to detect it [4], preventing BCI players from playing fast-paced games.

Nonetheless, alpha activity is still worth exploring, since retrieving alpha band frequency is comparably uncomplicated without (extensive) training and it only requires a few electrodes for signal acquisition. Hence, inspired by Nijholt et al., we explore alternative ways of using BCI as a game input modality aimed at overcoming common shortcomings of alpha activity. For this, we propose "BrainSnake", a game with a novel design that uses both verbal player interaction and eye closure as main gameplay mechanics. Additionally, we investigate how the presence of direct communication, or the lack thereof, may affect playability and user experience of a multi-brain BCI game.

Section II of this article illustrates the design and implementation of BrainSnake and its novel interaction modality based on alpha activity. Section III describes the design and execution of a user study in which players evaluated BrainSnake under different inter-player communication conditions. Results of the user studies are reported and discussed in Section IV. Finally, in Section V, conclusions are drawn and recommendations for future designs of (alpha-based) BCI games are given.

II. GAME DESIGN

BrainSnake is based on the popular game "Snake", in which a snake character made up of dots has to collect pieces of

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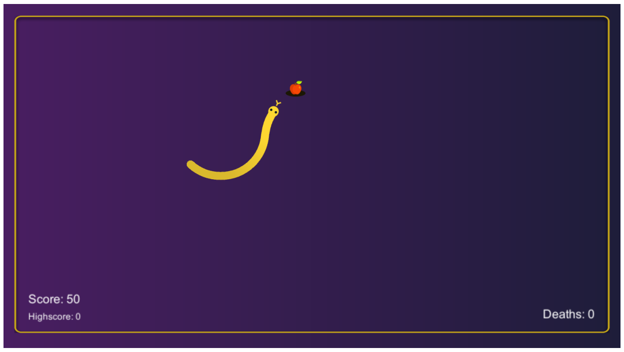


Figure 1. Screenshots from the final version of BrainSnake.

food on the screen whilst avoiding its own tail. The body of the snake grows by one dot for each piece of food collected, gradually increasing the difficulty of the game. Game over occurs when the snake eats its own tail (or hits one of the screen borders). BrainSnake adopts a similar gameplay in which two players have to collect apples by sharing control over the snake character. Both players control the snake avatar using their brain activities to turn either left or right. The complementarity-based control [8] was expected to elicit cooperative activities typical of closely-coupled games (e.g., “working out strategies together”) which may be affected by the presence of communication (or lack thereof) [9]. Fig. 1 shows the graphical interface of the game, showing the snake avatar in yellow and collectable apples in red. Moreover, the current score, high score and the amount of deaths is visible in the bottom corners of the screen.

A. Gameplay and Interaction

The interaction of BrainSnake is designed to compensate three main limitations of alpha activity as an input modality. Firstly, alpha activity is most suitable for being used as a binary input despite being measured on a continuous scale, since it is difficult to regulate. Secondly, inducing and detecting alpha activity requires time, which results in a delay of a few seconds [4]. Thirdly, in order to induce alpha activity effectively, the subject has to close their eyes.

In the classic Snake game, the player has to choose, real-time, between “no action”, “turn left” and “turn right” in order to direct the snake. This type of input combined with the delay in detecting alpha activity and lack of visual feedback over the game, would be likely to affect the playability of the game negatively and make players frustrated. To overcome this, BrainSnake featured a social component. Two players played the game together so that, whenever one player closed their eyes to induce alpha activity, the other player could act as the feedback provider communicating the state of the game to their partner. Game controls were designed such that, if there is no input from either player, the snake will move forward in its direction. One of the players can take ‘control’ over the snake by increasing their alpha activity. When this happens, the snake stops moving and goes into a “rotation mode”. Depending on which player took control, the snake’s head will rotate either left or right to a 90 degrees angle, as visualized in Fig. 2, in steps of 0.5 degrees per frame. When the controlling player opens their eyes - and reduces their alpha activity - the snake will be “released” and move forward again. When a player takes control over the snake, the alpha activity of the other player will be neglected and will have no influence on the gameplay. Additionally, the game uses audio assistance as another modality to indicate when the snake rotates, eats an apple, or when it dies. In contrast to the classic snake games, when the snake hits one of the borders of the screen, it bounces back instead of dying, reducing the overall difficulty of the game.

This interaction mechanism overcomes the earlier mentioned limitations of alpha-based BCI as (i) the binary (high or low) input is split over two players, (ii) the delay in response can be corrected by the other player (in the form of feedback) and (iii) there is an additional pair of eyes for the players to help them keep track of the state of the game. Additionally, this setup allowed to further stress the complementarity cooperative game pattern of BrainSnake: while it is possible to play the game without communication and rely on acoustic feedback only, even when the player’s eyes are closed, talking to each other is expected to make the gaming experience more enjoyable [9].

B. Implementation

The implemented BCI system consisted of three subcomponents for EEG-data acquisition, data pre-processing and game visualization. For the data acquisition a BioSemi Active 2 [10] was used to buffer the raw EEG signals of 7 channels [C3, Cz, C4, P3, P4, O1 and O2] using a 7 to 12 Hz temporal filter to record the alpha waves. OpenVibe [11] was used to pre-process the data into a numeric representation of the alpha activity of the player. Lastly, the binary classification of the alpha activity (high or low) as well as the game visualization were done with the Unity game engine [12].

High or low alpha activity is detected by means of the incoming data-signal from OpenVibe. The signal was duplicated and filtered with an infinite impulse response filter to reduce

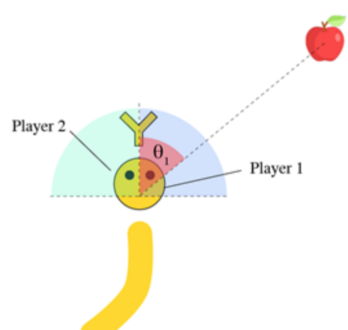


Figure 2. Players have joint control over the snake, one player rotates the snake’s head left and the other player rotates it right. Rotation happens in steps over time (θ_1) till a 90 degree angle is reached, after which the snake will rotate back to its original position. Rotation continues till the player ‘releases’ the snake.

noise; it was then analysed alongside with the raw samples to determine high and low alpha activity according to a static, pre-determined threshold. When the filtered signal reached the threshold (for a certain amount of samples), the subject was classified as having high alpha activity, triggering the rotation mode in the game. By contrast, when the raw signals stayed below the threshold for a certain amount of time, the alpha activity was classified as low.

III. METHOD

A. Study Design

A within-subject experimental design was devised to investigate how players experienced different modes of communication in a BCI setup. This included two experimental conditions: (i) a "co-present setup", in which the two players were located next to each other, allowing them to communicate face-to-face while playing; and (ii) a "remote" set-up, in which the players were physically separated from each other by a wall and prohibited from communication. Fig. 3 illustrates the experimental setup of both conditions. Each participant experienced both conditions. The order of completion was counterbalanced. A within-subject design was chosen to allow participants to make well-informed comparisons between both modes of interaction. Player experience was assessed quantitatively using the Game Experience Questionnaire (GEQ) [13] once after each condition. Next to this, a semistructured interview was conducted at the end of the experiment to capture player experience qualitatively. Topics discussed in the interview included the seven core dimensions of the GEQ, user experiences regarding the different modes of interaction, difficulties encountered while playing BrainSnake, as well as user suggestions regarding improvements of inter-player communication.

B. Participants

A total of 12 participants (ten male, two female) aged 18 to 28 (M = 23.5, SD = 2.939) were recruited to take part in the experiment. Participants were all students from the University of Twente recruited through convenience sampling. Six pairs were formed with the intention of pairing up participants who did not know each other prior to the experiment. This was done to prevent relationship bonds from biasing the game experience of our participants.

C. Procedure

Prior to the experiment, participants were briefly introduced to their partner and asked to fill in a demographic questionnaire, including questions about their previous experience with games and BCIs. Moreover, participants were briefed on the experiment and instructed what was required from them in order to play the game. The participants were then equipped with a BioSemi cap and set up for a short individual training session. During training, the game is played in single-player with the snake only able to rotate in one direction. Once both participants reached enough confidence with the BCI, the multiplayer version of the game was introduced in one of the two experimental settings. In the remote condition, a partition wall was placed between the two players and earphones were used to ensure that no verbal communication would occur between the two players. Each game session lasted eight minutes and was followed by an administration of the GEQ. After both conditions were played, the BCI equipment was removed from each participant who was then asked to take part in an individual, audio recorded 20-minute interview aimed at further investigating dimensions from the GEQ as well as their personal experiences with the game in each condition.

D. Ethics

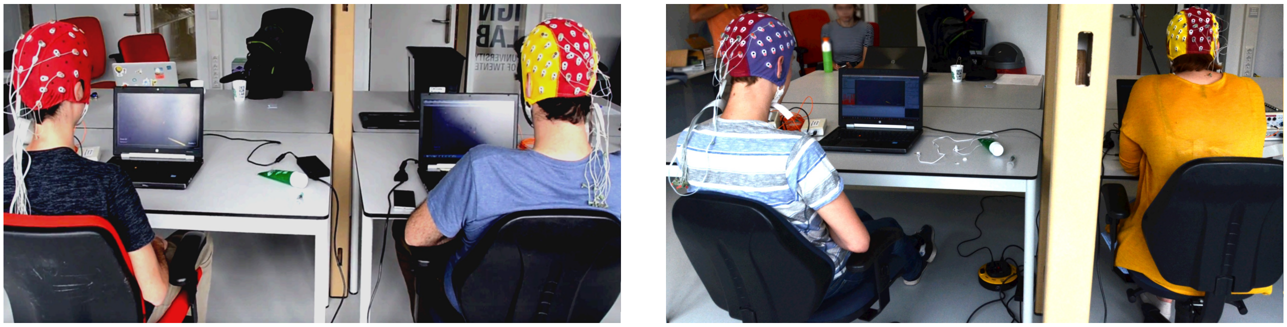
All participants were asked to sign an informed ethical consent form prior to the experiment. Participants were informed that they would be required to wear EEG equipment and that the data collected would be anonymised and only be used for research purposes. Moreover, participants were asked for consent to have their interview sessions audio recorded. This research was approved by the ethics committee of the University of Twente. No funding is received for this research.

E. Measurements

The GEQ consists of three modules: a core module which measures game experience on seven components calculated from 33 items: Immersion, Flow, Control, Positive and Negative Affect, Frustration, and Challenge. The remaining two modules, the social presence module (three components calculated from 17 items: Psychological Involvement - Empathy, Psychological Involvement - Negative Feelings, Behavioural Involvement) and the post-game module, assess psychological and behavioural involvement of the player with other social entities, and how players felt after they stopped playing, respectively. The post-game module was not included in this study because it is targeted at assessing naturalistic, rather than experimental gaming. All items of the GEQ are measured on a five-point Likert scale with answers ranging from 0 to 4. The GEQ was filled in by the participants after each condition. The interview schedule was partly inspired by the GEQ, covering six of the seven dimensions of the core module of the questionnaire. The dimension of Immersion was left out intentionally because immersiveness was not an aim of the developed game. Moreover, the interview schedule was targeted at exploring the communication between players and the suitability of either mode of communication for cooperative or competitive game settings.

IV. RESULTS & DISCUSSION

Internal consistency reliability was assessed for the relevant GEQ modules using Cronbach's alpha, the core module (co-present condition α = .807, remote condition α = .886) and the social presence module (co-present condition α = .856, remote condition α = .919). For the semi-structured interviews, a coding scheme was developed following a grounded theory approach to identify patterns, contrasts and similarities in participants' responses [14]. The coding scheme was informed by the measured constructs of the GEQ. Pattern-based inspection



(a) (b)

Figure 3. Experimental setup for the co-present (a) and remote (b) condition.

was then performed based on the Cooperative Performance Metrics (CPMs) proposed by El-Nasr et al. [8]. As BrainSnake was designed following patterns typical of closely-coupled games [9], it was expected to raise a need for communication between the two players, reflected in CPMs such as "helping one another" and "working out strategies together" [8].

Results suggest that mode of communication did influence all the investigated aspects of player experience, although the obtained results draw a complex picture: player experience was affected, amongst other things, by individual differences and the level of harmony between players. This is also reflected in the high standard deviations of the GEQ core scores in Fig. 4. Similar results were obtained for the social presence module, as shown in Fig. 5. In the co-present condition, where direct verbal communication was allowed, participants tended to feel more psychologically and behaviourally involved with their partners. However, the obtained scores for the social presence components show great individual differences, whereas the results obtained from the semi-structured interviews give a more complete picture of how participants experienced playing BrainSnake and the interaction with their partners. In the remainder of this section, the results from the interviews are discussed.

A. Control

Eight participants explicitly indicated that they had a higher perceived control in the co-presence condition. Only one of the participants felt more in control in the remote condition, naming the lack of pressure from having to engage in communication with an unfamiliar person as a potential factor for this. P5-1: *"I was doing my thing, and let him do his thing, and it kinda worked better"*. It should also be noted that three of the participants felt that their partner was more in control of the character than they were, and that they were feeling overpowered by the other's level of control on the snake. P5-2: *"I felt that's because she kept turning, I could not turn… somehow, because she kept doing it, it was overpowering"*. This could be accounted as an instance of the *Got in each other's way* CPM [8] in which one player's actions slow down the other's.

B. Flow

Seven participants stated having experienced more flow in the co-present condition. Participants attributed the experience of flow to either i) the presence of their partner in the co-present condition, ii) being able to focus more on themselves and their actions in the remote condition, iii) the increasing skills level in the second game session (regardless of the experimental condition). The flow of one participant was actually compromised due to the increasing frustration throughout the course of the experiment. Despite the fact that the same written definition of flow was provided during each interview, the variety of responses suggests that each participant provided an answer according to their own mental model and personal concept of flow. As it turns out, the concept of flow is difficult to understand and might be more suitable for indirect assessment in subsequent research.

C. Frustration

Nine participants felt more frustrated in the remote condition. Two participants felt frustrated due to the absence of communication options in the remote condition. P5-2: *"I felt more frustrated because I couldn't verbally communicate with the other player"*. However, lack of control over the game character was named as the main source of frustration. P6-1: *"I felt like the system is just not picking up enough of what I want to do"*. This is in line with earlier research on user frustration due to malfunctioning control systems in HCI. For instance, Reuderink, Nijholt and Poel (2009) succeeded in inducing frustration in players of an adapted Pacman game by manipulating the user input and visual output of the game. Results obtained from the current study confirm the paramount importance of well-functioning game controls for minimising user frustration in HCI in general, and for BCI games in particular.

D. Challenge

A number of participants perceived both conditions as equally challenging, albeit for different reasons. Lack of communication in the remote condition added challenge for some, as one could not rely on their partner for the timing of the controls. P3-1: *"You can't work with each other, you can't*

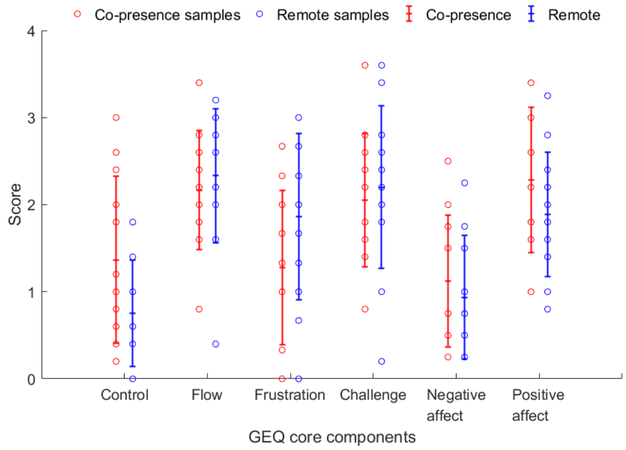


Figure 4. GEQ core component scores. High standard deviations are visible due to the individual game experiences of the participants.

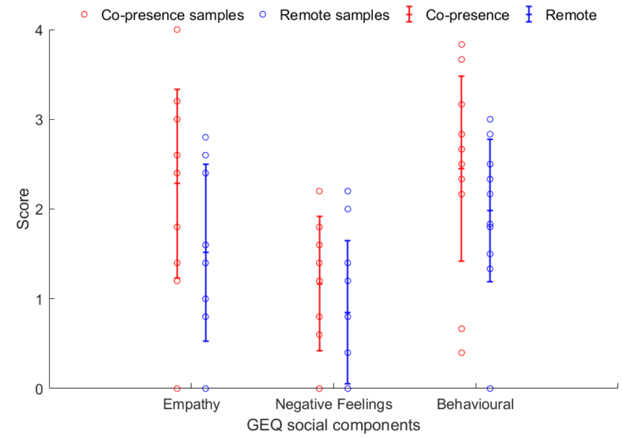


Figure 5. GEQ social component scores. Similar to the core components, high standard deviations are visible.

talk...”. For others, managing communication while playing was regarded as more challenging since verbal communication distracted participants from entering a state of relaxation. P1-2: *“I felt more challenged in the first round because you had to communicate and actually motivate each other and talk to each other”*. One of the participants mentioned that having to rely on communication added challenge because their partner was not “in sync” with them. P5-2: *“Because we had completely different ways of planning, then the communication made it really hard”*. Others pointed out how not being able to communicate added the challenge of having to rely on intuition to anticipate the other player’s moves. P1-1: *“The challenge was understanding the other player”*.

E. Positive & Negative Affect

Overall, BrainSnake was well-received by the participants. Eight participants showed enthusiasm towards the BCI control mechanism, while four stated that they appreciated the cooperative nature of the game. P1-2: *“I liked the way you could play the game with another player. So you actually had to work together”*. Two participants stated that they enjoyed the added challenge of having to rely on intuition to anticipate their partner’s move in the remote condition. P3-2:*“I preferred the one where we were not allowed to talk to each other ‘cause I think that’s more challenging to get the feeling of what the other is doing”*. When asked what they did not like about BrainSnake, five participants pointed out the earlier mentioned delay in detecting alpha activity and three participants indicated that they did not like having to close their eyes to perform a game action. P4-2: *“(...) that is not really what a player enjoys generally. You want to be able to track what you’re controlling.”*

F. Effect of communication on alpha based BCI

Ultimately, responses from around half of the participants suggest that there may have been a trade-off between communicating with a partner and being able to regulate levels of relaxation and focus in order to control the character. These participants stated that either communication made it harder for them to regulate their alpha activity, or that it would be preferable to keep communication to a minimum in order to keep one’s mental state stable. P1-2: *“I was a bit more distracted in the first round, because you have to talk to each other and you can’t only concentrate on what you’re doing on the screen”*. This could be accounted as another instance of the *Got in each other’s way* CPM, although this could likely be influenced by individual differences. For instance, a few players seemed concerned about getting a high score and even the CPM of *worked out strategies* which involved keeping communication with their partner to a minimum. P6-1: *“We spoke about strategies, how to achieve the most points in the game. During the game, we tried to keep the communication to a minimum. I tried it, to not distract my partner when he had to go into relaxation”*. Another participant, admittedly unfamiliar with gaming, only enjoyed playing BrainSnake in the co-present condition thanks to the communication component.

G. Limitations

One noteworthy limitation of the current study is the fact that participants were exposed to a cooperative game while being questioned about a hypothetical competitive game setting in the subsequent interview. Similarly, participants were offered only one form of communication during the game sessions, namely direct verbal communication, but subsequently they were asked about their preferences for hypothetical alternative forms of communication. Participants’ statements regarding their preferences for either mode of communication for a competitive or cooperative game setting and their preferences for a specific form of communication have to be interpreted with caution. The inspection of CPMs was also performed based on user interviews rather than by analysing recorded gaming sessions, which made it difficult to identify metrics such as *laughter or excitement together* and *got in each others’ way*. Future studies should consider investigating the effect of communication modalities on players’ experience

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with novel BCI mechanisms in more detail, for instance by analysing recorded gaming sessions.

V. CONCLUSION

The current study exemplifies how game design allows users to play fast-paced BCI games using alpha activity, addressing common limitations associated with this input modality. Evaluation of the communication component of BrainSnake shows that most participants attributed more control over the snake character and less frustration to the co-present condition, albeit for different reasons. Moreover, most participants found playing in co-presence more enjoyable, while many felt that the lack of communication in remote added frustration and/or challenge to the game. Nonetheless, a few participants reported enjoying the extra challenge of not being able to communicate in the remote condition. Multiple participants suggested that there could be in fact a trade-off between direct communication and alpha based BCI, and players who self-reportedly worked well with each other worked out strategies which involved minimal use of communication in order to maintain focus. After having played BrainSnake, participants expressed their own ideas on alternative ways of communication (e.g., in-game visual and auditory cues) that could be implemented to enhance cooperation while compromising alpha activity as little as possible. Conceivably, the counterintuitive control mechanism of eye closure was received with mixed feelings: despite the fact that a few participants were intrigued by the interactive potential of this game mechanism, many regarded it as a main source of frustration.

Ultimately, BrainSnake was well-received and we suggest that novel gameplay mechanisms and dynamics departing from traditional gameplay should continue to draw genuine interest in the BCI game community. While individual and contextual differences in the way players experienced BrainSnake make drawing general conclusions difficult, the development of BrainSnake and insights from our participants' responses are of potential interest to those involved in the design and development of BCI games. In conclusion, the following recommendations are made:

- When using alpha waves or other BCI-paradigms as input modality for games, it is worth to think about creative compensations for its limitations as this can result in interesting new interaction modalities. For example, future work should look into assistive game mechanisms, such as one player having control over the movement of a character, while another player controls its speed or the direction of the camera [15]. This may potentially lead to improved game performance and enhanced immersion.
- Results indicate that closely-coupled cooperative BCI games based on alpha activity benefit from subtle, less intrusive ways of communication between players, while face-to-face verbal communication may disrupt one's levels of focus or relaxation causing players to get in each other's way more often. Future work should focus on extending this knowledge into other BCI-paradigms as well as exploring less intrusive ways of communication. For example, previous research shows that tactile feedback can be useful when the visual channel is highly loaded by a complex task [16] [17]. This may also benefit communication in BCI games.
- On the contrary, the use of direct verbal communication could be of potential interest for competitive BCI games based on alpha activity as, for example, verbal communication may allow for strategic manipulation of the opponent. Novel interaction modalities that allow to interfere with the opponent's ability to control the game are conceivable and worth investigating in the future.

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