Kessel Run - A Cooperative Multiplayer SSVEP BCI Game

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Abstract. Digital game research has been rapidly growing with studies dedicated to game experience and adopting new technologies. Alongside, research in Brain-Computer Interfaces (BCI) is growing in game applications. Besides technical shortcomings, BCI research in gaming can also be lacking due to challenges such as poorly designed games that do not provide a fun experience to its players.

In this paper we present a novel multiplayer Steady-State Visually Evoked Potential (SSVEP) game - *Kessel Run* - with BCI-focused cooperative mechanics, drawing attention to the impact of game design in the user experience.

Twelve participants played Kessel Run using a 2-electrode cap and rated their experience in a questionnaire. The SSVEP performance was lower than expected, with an average classification accuracy of 55% and maximum of 79% at a 33% chance level. Despite low performances, players still reported a state of Flow, felt behaviorally involved and empathized with each other, finding it enjoyable to play the game together.

Keywords: Multi-Brain Brain-Computer Interfaces · Games
Steady-State Visually Evoked Potentials

1 Introduction

Initially, Brain-Computer Interfaces' (BCIs) primary goal was to restore communication for the physically challenged. Applications include moving a wheelchair [1], spelling through a device [2], among others. However BCI devices are progressively becoming smaller and more affordable. Easy-to-use Electroencephalography (EEG)-based BCI headsets such as the Emotiv EPOC or the NeuroSky®'s MindWave have appeared in the market, leading to their usage outside the medical field and towards healthy user industries, like entertainment. In particular, the gaming industry is embracing BCI as an acceptable interaction modality given its potential to enhance user experience by offering something that current interaction modalities do not [3].

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Among the BCIs implemented for games, the first trend was to adapt previously made games conceived for traditional inputs. Classic games like Pacman [4], Pinball [5] or Tetris [6] were successfully used to demonstrate the application of BCIs in gaming. The rest are original, newly-developed games but these are usually proofs of concept and often do not take into account proper game design, an important requirement for every user that intends to play. Because BCI depends so much on what control paradigm is used, the interaction may vary and game developers must understand the characteristics of a specific BCI in order to design game mechanics that take advantage of its interaction. Multiplayer games, even though extremely popular in the gaming community [7], are not a very common genre in BCI games with only a few examples existing [8–11].

Gürkök et al. tried to build a BCI game framework from their research experiences in both the BCI and games communities [12]. They mentioned that "challenge", "fantasy" and "sociality" made a difference in BCI games, increasing users' motivation to play, and briefly described the ways BCI games can satisfy each of these motivations. Controlling a BCI can be challenging by itself, as it is an imperfect recognition technology. It requires players to show continuous effort and even repeat their actions until they are understood by the BCI. Nevertheless, a game should offer challenges that match the player skills in order to provide Flow [13]. Games also let players do things that they usually cannot do in real life. In a virtual world, the feeling of presence can be achieved by having a good correspondence of player actions to in-game actions. Some people enjoy playing computer games not necessarily for the challenge or the fantasy but just to be with others. Spending time with friends and seeing their reactions and expressions are huge motivations to play games socially [13]. Any multiplayer BCI game can also provide such an interactive environment. Players may cooperate or compete using BCI and they can share their experiences, such as difficulties or enjoyment with control, while playing the game.

Our game, Kessel Run is introduced as a multiplayer BCI game to breach the gap between fun games and BCI games. There is a need to create original BCI games that follow good game design practices and introduce mechanics that best suit the control paradigm. A large amount of developers consider "ease of playing the game" and "exciting application" as some of the most important elements of games [3]. Our goal was to create a BCI game that could be played outside the laboratory, with a short training period and that was as exciting as a non-BCI game. Since multiplayer games are a popular genre among gamers and sociality is one of the largest motivations to play, we chose to develop a 2-player game that can be played socially with a friend.

This paper is divided in the following sections: Sect. 2 introduces the BCI game developed and its mechanics according to a set of derived game design rules. Section 3 explains the experimental set-up, procedure and data analysis carried out, leading to Sect. 4 in which the players' performance and user experience is discussed. Finally we present our conclusions for this study in Sect. 5.

2 Kessel Run

In this section we will explore the methodologies used in the design, development and implementation of our BCI game. We start by introducing the good game design rules that were implemented throughout our game, before briefly introducing the game itself - *Kessel Run* -, its goals and simplified gameplay. After, we give an explanation on Kessel Run's BCI-focused multiplayer mechanics and the different game elements introduced, along with some considerations about our BCI paradigm selection. Finally, we approach the technical side of Kessel Run's implementation, going over our software choices and their integration.

2.1 Game Design Requirements

In this study our goal is to design a BCI-specific game that is able to provide a fun experience for its players. In order to achieve this, we derived a set of rules and concepts from good design theories applied in BCI games, mostly from Csikszentmihalyi's Flow theory [14] and Salen & Zimmerman's Paradox of Control [15]. While the Flow theory describes the immersion in a game as a state in which the player is actively engaged and where his skills match the challenge level of the game (the Flow Zone), the Paradox of Control assumes that in a state of Flow the player must feel in control of the events, while at the same time feeling the possibility of losing control due to his own failure. Together, these essentially state that in order to achieve Flow the player has to feel both in control of his skills and challenged by the game.

Based on the Flow components noted by [14] and summarized by [16], we formulated a set of requirements that must be fulfilled in order to achieve a good game design:

- The game must feature a clear goal.
- The game must have clear rules.
- The game must challenge the players' skills.
- The game should be controlled by the BCI paradigm.

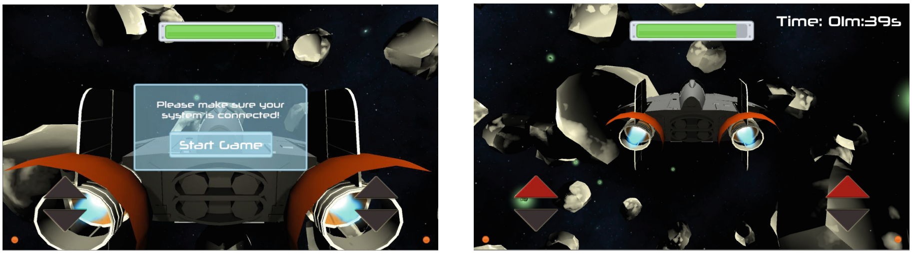
In addition, it is also necessary to take into consideration the fact that Kessel Run is a cooperative multiplayer game. Several attempts have been made to identify the building blocks and the essential components of collaborative games. Wendel et al. [17] have combined and augmented previous guidelines with the purpose to stimulate the development of social skills such as team-work, communication, and coordination during game play. Some of the most important components that can be used in the design of cooperative games are a common goal/success, collaborative tasks, inter-dependent roles among players and communication.

Based on the components identified by [17], we add the list of requirements to achieve the desired interaction between players in a cooperative game:

- The players must have a common success.
- The game must feature collaborative tasks.
- The players should have inter-dependent roles.
- The game should allow for communication between the players.

2.2 Kessel Run

Kessel Run is the computer game developed for our experimental purposes. Built on the cross-platform game engine Unity 5®[1], the game world contains a moving spaceship navigating through an asteroid field (Fig. 1). Being a 2-person multiplayer game, the players' goal is to survive a 2 min space race by cooperating with one another, losing only the smallest possible amount of fuel in the process. The steering of the spaceship is shared by both players (each player controls one of the propellants' movement), and therefore cooperation is needed in order to win the game. To win the game, the spaceship needs to last the entire 2 min race without losing all fuel, which decreases every time the ship is hit by an asteroid. The game is lost if fuel is zero before the race ends.



(a) Start game with a connection warning (b) Gameplay

Fig. 1. Screengrabs from the Kessel Run computer game.

2.3 Game Mechanics

In Kessel Run we looked into building a game that is designed specifically for BCI control and can also provide an exciting experience for its players. Guided by the requirements introduced in Sect. 2.1, in Kessel Run we applied a set of elements, rules, and interesting mechanics that we will now describe.

Elements. To keep Kessel Run interesting for its players, it is necessary to include elements that make it not only enjoyable, but also that aid in deriving meaning from the game's sets of rules and goals. The elements described can be seen in Fig. 2.

The **Asteroids** can be found floating around space and are meant to satisfy the need for challenge in the players' skill, since these damage the spaceship and reduce fuel. Asteroids are spawned at random locations around the player's perimeter at every frame of the game, and have different sizes and rotations.

The **Fuel Power Ups** are scattered randomly around space, but are more scarce and much smaller than asteroids. By gathering fuel power ups the players

[1] Unity 5®, from Unity Technologies - https://unity3d.com.

are able to keep their fuel level high and therefore win the race. However, because these are small and rare, gathering them is not trivial.

Besides these in-game elements, several on-screen components were added to Kessel Run. The **Fuel Bar** indicates the amount of fuel left on the spaceship, while the **Timer** shows how much time is left until the race ends and the players win. There is also the players' **Control Panel**, which displays two arrows that turn red when the player moves in that respective direction. As we will explain later, the players must cooperate in order to steer the spaceship properly and therefore the Control Panel helps them visually understand the other player's movement, while also keeping both aware of their options in terms of spaceship movement.

In a more practical perspective, the **Connectivity Indicator** is always present for each player under his Control Panel and indicates whether or not the BCI software is acquiring data and connected to the game. This provides a sanity check and prevents any experimental mistakes. The indicator is orange when the system is not connected, and turns green when it is fully operational.

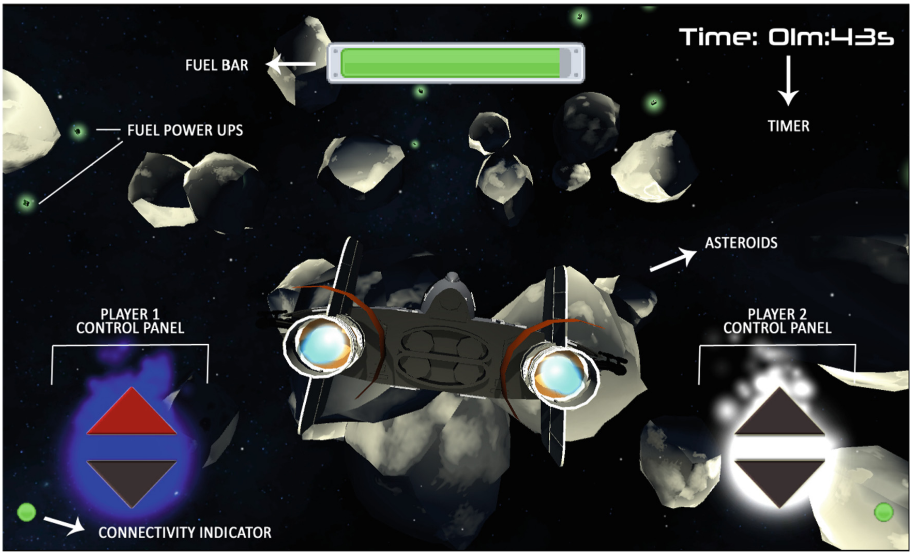


Fig. 2. Kessel Run - multiplayer BCI game in which players must cooperate with each other to navigate through an asteroid field. Several on-screen elements indicate players' status such as time left to win the game, fuel level, and an indicator of software connectivity.

Lastly, we also introduced the possibility for one player to take control of the entire spaceship by himself ('***Take Over***' command). Players can only take over when a red button periodically appears at the screen bottom, and the first player to press it takes over the spaceship for a total of 5 s. When one player takes over he is able to control the spaceship alone, although being restricted to only going up or down, making the second player unnecessary for playing the game. This functionality is intended to stimulate players' competitive behavior and was introduced as a way to offer choices in the gameplay.

Rules. The game must be governed by a set of rules which the players make use to achieve their goal and win the game. In Kessel Run, these rules are translated into the restricted movement of the spaceship and on the fuel points system, as well as the timer of the race itself.

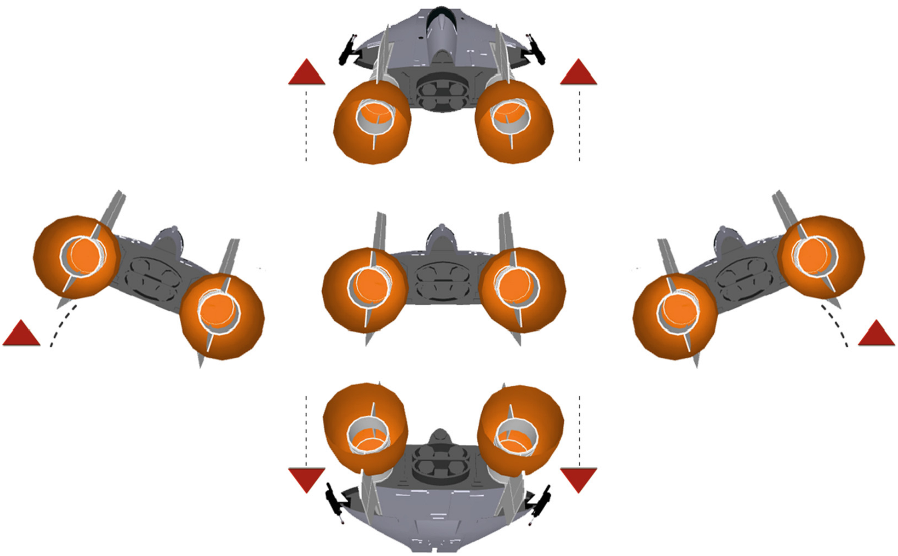


Fig. 3. Game mechanics in the spaceship movement. Each player controls the direction (up or down) of one propellant. If both players move their respective propellers up (or down), the ship moves in that direction. Otherwise, the wing rotates in the selected direction (e.g. left propellant rotates to the right when player goes up).

As mentioned previously, each player is only able to manipulate one side of the spaceship. As a result both have to work together in order to steer the ship in the desired direction. Since each player controls their respective ship's propellant, they each have only two possible movements: up or down. We chose to restrict this motion for two reasons; while being restrained would force the players to work together and create a more fun game, it also reduces the degrees of freedom for the BCI. Because each player only has three choices (steer up, down, or stay in the same place), this simplifies the classification process which we will introduce later on.

Although the players are individually restricted, together they can combine the two movements to steer the spaceship in different directions (see Fig. 3).

Since each player only controls one propellant, if he chooses to move alone the spaceship will be tilted in its respective side. Otherwise, if both chose to go in the same direction they can move the entire ship, or tilt at a higher degree when going on opposite directions. This allows for a higher range of motion and permits space scouting for fuel power ups and the dodging of asteroids.

A point system is a frequent rule implemented in several games. Here, points are disguised as fuel. The race starts with 100% fuel, and every time the ship is hit by an asteroid (by not dodging efficiently) fuel decreases by 5% of the initial value. The only chance players have of regaining fuel is by passing a Fuel Power Up, which increases fuel by another 5%. If the ship reaches 0% fuel at any given time, then the game is over and the players lose. On the other hand, if players manage to keep fuel above 0% until the 2-min timer ends, then the race is won.

In Kessel Run, as in many games, the points system serves two purposes: while they clarify the game's goal (number of points must be above zero to win), they also provide further challenge in the game; players can chose whether they simply want to beat the game, or improve their score. Providing these types of choices in the game helps keeping the players in the Flow Zone since the difficulty can be adjusted to the player's needs.

2.4 Paradigm Selection

When dealing with BCI games, the paradigm selection must be carefully considered. Some paradigms might prove more useful for BCI gaming than others. Paradigms may be more accurate, have a higher sense of control, or simply offer higher speed or more dimensions of control. Furthermore, all paradigms will have their own potential as well as limitations with respect to the paradox of control. This leaves us with the task of selecting the best paradigm for achieving an occurrence of the paradox of control.

Among the three types of paradigms (active, passive and reactive [3]), we opted to use a reactive paradigm because these have relative low illiteracy rate (89% of the users are able to get an 80% accuracy or higher after only a short training [18]) and can be used without requiring long training sessions. Moreover, using the Steady-State Visually Evoked Potentials (SSVEP) paradigm in Kessel Run provides a continuous control since the BCI detects user's intention for as long as he attends the stimuli (flickering lights). The SSVEPs requires little to no training, have low illiteracy rates [19] and more importantly, when placing external LEDs for SSVEP stimulus the space on the computer screen is no longer occupied with BCI and is free to be solely dedicated to the game. Before proceeding it is important to note that SSVEP also has downsides. Having the player concentrate on stimuli constantly can become very tiresome and uncomfortable to the player [12], particularly for the SSVEP paradigm as it features a constant flickering and could potentially break immersion in the game [20]. We attempt to counteract these downsides by making each game last a relatively small amount of time.

After selecting our paradigm, we must implement it as a game controller. For our game two red solid LED lights are placed on the top and bottom's midline of each player's screen for the up and down directions, respectively. Using external LEDs as visual stimuli avoids the limited number of frequencies of use due to monitor's refresh rate. The flickering is done at 15 and 12 Hz, detected on the 10–20 system's Pz or/and Oz electrodes, and using Canonical Correlation Analysis (CCA) as a detection method [21].

The CCA algorithm is implemented in MATLAB® and used in real-time during the game. The algorithm uses blocks of 80 samples for each iteration on acquired data. Since the sampling frequency is 512 Hz for our system, a player's decision is made every 0.15 s, offering a very smooth control.

Before each play session, the player's algorithm settings are defined empirically by selecting which electrode combination (Pz and/or Oz) and CCA threshold offers a better performance.

2.5 Software Integration

We now review the technical implementation of our multiplayer game. In the previous sections we have mentioned already two of the core softwares used to build our system: Unity 5® and MATLAB®.

After developing the game in Unity and implementing the BCI paradigm in MATLAB, we are left with two pieces of software that are not specifically designed to interact with each other. Furthermore, MATLAB is scarcely used as a real-time processing tool due to being slower than compiled code [22], and does not have a library to acquire data from the BCI device used.

Because of its flexibility and ease of integration with other software, we chose BCI2000®[2] for acquiring EEG data, connecting to Unity and MATLAB at the same time (and interacting with its different scripting languages), and controlling the crucial aspects of the experiment (e.g. start of acquisition, data markers and saving).

One BCI2000 session only acquires signals from one BCI system at a time; this means that for a multiplayer game such as Kessel Run, we are in need of at least 2 computers. In our set-up, we chose to have 3: the 2 players have dedicated computers that are in charge of acquiring, processing, and sending their signals to a separate PC where the game is running (Fig. 4). The communication between the player's and the game's computers was done via UDP (*User Datagram Protocol*). In our experiment, the UDP messages being sent from BCI2000 are related to the player's decision in the game: go up, down, or stay in the same position. Unity sends messages back to BCI2000 regarding the game status: beginning and end of game, and whether it was lost or won, which are then marked on the saved data.

There are two advantages of using BCI2000. First is the possibility to integrate different software components and orchestrate the data acquiring and processing. Secondly, because BCI2000 is a modular program, it is very easy to switch between BCI devices for data acquisition without the need to adapt the remaining game system. While in the present work we report using Biosemi

[2] BCI2000®, from Schalk Lab - http://bci2000.org/.

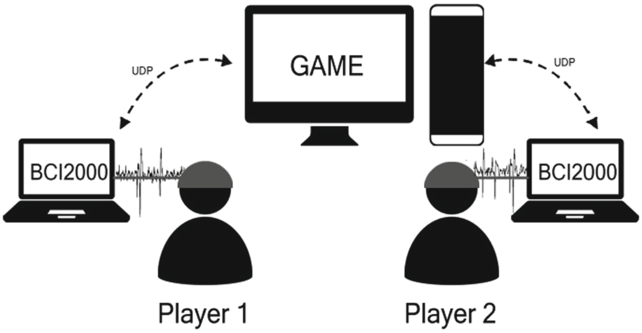


Fig. 4. UDP connection scheme: each player's computer processes the incoming brain signals, translates them into game actions, and sends them to the dedicated computer game. The computer game returns game information for marking the saved data.

ActiveTwo system for EEG data acquisition, we have tested Kessel Run with portable devices such as the Emotiv EPOC with success.

3 Methods and Materials

We invited participants to play Kessel Run in order to test if our BCI multiplayer game is capable of creating an enjoyable user experience for its players and if the SSVEP paradigm is a reliable way to control it.

3.1 Participants

All participants that volunteered to take part in this experiment were university students. We asked all participants to bring a friend, and if no friend was available they were teamed up with another participant. Participants were 12 subjects (5 female) aged 22 to 31 years old (mean age = 23.8 years old) that participated in pairs for a total of 6 game sessions. All participants reported daily computer usage. Half of the participants had no earlier experience with BCI at all, while the other half had interacted with a BCI at least once. All subjects read and signed an Informed Consent Form, verified and approved by the Ethics Committee. No subjects suffered from any neurological, psychiatric or other relevant diseases unadvised to the participation in the experiment.

3.2 Materials

EEG signals were acquired using a Biosemi ActiveTwo system[3] on a dedicated recording PC for each participant. All signals were acquired at a 512 Hz sampling rate, and two active Ag-AgCl electrodes for EEG (Pz and Oz) were placed according to the international 10–20 system.

[3] Biosemi ActiveTwo - http://www.biosemi.com.

The experiments were performed in a quiet darkened laboratory environment. The set-up consisted of 3 computers: two for the EEG data acquisition, processing and recording, and one for the participants to play the game. A table with comfortable chairs was placed in the room center, and participants were seated facing each other as seen in Fig. 5. By seating this way players could see each other and interact during gameplay while focusing on the game without too strong head movements. Two pairs of red SSVEP LED lights (10 cm × 10 cm) were mounted on the top and bottom's midline of each player's 1920 × 1080, 60 Hz monitor.

Fig. 5. Two participants shortly after beginning playing Kessel Run. (Color figure online)

3.3 Procedure

Before playing the game, every participant filled in a demographic questionnaire that also inquired about their gaming habits and previous BCI usage. After being explained the content of the experiment, the EEG caps and electrodes were placed on each participant. A good connectivity was ensured by applying electrolyte gel until all electrode offsets were lower than ±20 mV. A short SSVEP session of 80 s was recorded for offline performance analysis and participant's CCA parameter definition (threshold and EEG channels used). In this session, participants were asked to look at the top and bottom LED light, and at the center of the screen every 5 s, while their EEG data was acquired using BioSemi's software, ActiView.

Participants were given time to learn the game before playing eight rounds of Kessel Run. After they played the game, every participant filled questionnaires on Game Experience and Social Presence adapted from the Game Experience Questionnaire developed by IJsselsteijn et al. [23,24]. The first module assesses game experience as scores on six components: Challenge, Competence, Flow, Tension/Annoyance, Positive and Negative Affect. The social presence module investigates psychological and behavioral involvement of the player with other social entities, in this case the co-located person playing the game with them [24]. This module consists of three components: Behavioral Involvement, Psychological Involvement - Empathy and Psychological Involvement - Negative Feelings. An extra item was added to the social presence module to assess players' intentions to cooperate with one another: 'I felt inclined to work together with the other'. For both questionnaires the items were presented on a scale of agreement from 0 to 4, in which 0 - 'not at all', 1 - 'slightly', 2 - 'moderately', 3 - 'fairly' and 4 - 'extremely'.

3.4 Data Analysis

All data was analyzed under MATLAB® and R software environment for statistical computing.

Participants' SSVEP performance was evaluated using the training session recorded during the experiment. Raw EEG signals from the back of the head (Pz and Oz) were selected and trials of 80 samples were extracted for the three conditions: looking at 12 Hz (bottom) light source, at 15 Hz (top) light source, and at the center of the computer screen. Each trial was then subject to CCA with sine and cosine reference signals at 12 and 15 Hz. Upon visual inspection the best electrode(s) and an empirical correlation threshold were set for each participant, and classification for each condition followed. No preprocessing was performed in order to minimize real-time computing costs. The resulting trials were classified into game actions according to the maximum of CCA's correlations. If the highest correlation (of the two possible values for each frequency) exceeds the participant's threshold, the decision is set to the corresponding frequency - 12 or 15 Hz -, meaning that the player goes either up or down. If the threshold isn't met, the decision to stay in the center is chosen.

For Kessel Run's game experience, each item's scores were grouped according to their respective user experience components: Challenge, Competence, Flow, Tension/Annoyance, Positive and Negative Affect. For the Social Presence questionnaire, items were grouped in three components: Behavioral Involvement, Psychological Involvement - Empathy and Psychological Involvement - Negative Feelings. After grouping, mean and standard deviation were derived from participant scores for both modules. For the single item *'I felt inclined to work together with the other'* only the frequency of responses and mean score were determined.

4 Results

We now present the results obtained from the experiment described in the previous section, in which participant pairs were asked to play our BCI game - Kessel

Run - and rate it according to its game and social experience. Along with our findings, we derive some comments and discuss the meaning for each result.

4.1 Performance

Of the initial 12 participants, two (one pair) were excluded only from performance analysis due to changes in the experimental setup.

Table 1. SSVEP performance descriptives from CCA classification (33% chance level).

	$\bar{X}(\sigma)$	Max	Min
Overall	55.3 (14.1)	78.9	34.1
12 Hz	62.7 (12.6)	85.6	47.8
15 Hz	37.8 (19.5)	80.0	20.0

Generally speaking, SSVEP performance was lower than expected. Overall classification (i.e. the 3 class decision between choosing the 12 or 15 Hz stimuli, or choosing not to move by looking at the PC's center) was 55% on average, reaching a maximum 79% (Table 1). Most participants obtained a performance above 50% (see Fig. 6), although a few remain under the it. We identified two key factors that influence these low performance values: darkness of the room, and participant detection of the used frequencies.

In order to obtain a good quality SSVEP it is necessary to isolate its visual stimuli from other light sources, usually done by darkening the experimental room to reinforce stimuli brightness. Although all of our experiments were performed under a darkened laboratory, ambient light was still present due to window gaps (visible in Fig. 5) which caused a reduction in LED brightness and consequent loss in performance.

On the other hand, a good quality SSVEP relies also on the brain's capacity to react to repetitive flickering at a certain frequency. From Fig. 6 we can note that subject's performance for the 12 Hz frequency (light blue bars) is consistently higher than at 15 Hz (yellow bars) and that its maximum (86%) and mean (63%) performance are also the highest of the three classes, meaning that participants could more easily produce SSVEPs when focusing on the 12 Hz light source but had difficulty recognizing the 15 Hz source, dragging the overall performance down. This difference in performance is likely due to the fact that the 12 Hz frequency is within the dominant alpha range. Because the 15 Hz source was generally harder to classify, the overall BCI performance is lowered and participants could either control both or only one of the spaceship's directions. Hakvoort et al. [25] too found that subject's precision in a CCA-based detection method differs according to frequencies used. Similar results were also found in [26].

Moreover one can expect that during game play the detection performance is even lower because the BCI and the game both use the visual channel. The

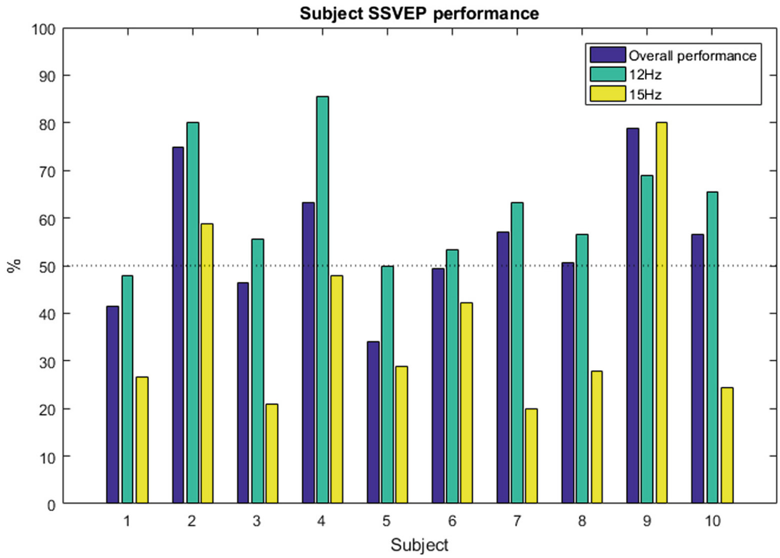


Fig. 6. SSVEP performance per subject. Light blue and yellow bars correspond to the percentage of trials correctly classified as looking at 12 and 15 Hz, respectively. Dark blue bars indicate the CCA's overall performance classifying if the subject is looking at the 12, 15 Hz light source, or not looking. (Color figure online)

different SSVEPs are induced by flickering lights above and below the screen. In order to issue a BCI command the player has to visually focus on the corresponding flickering light instead of the game. But due to the fast dynamics of the game the player also needs to focus on the video game. This results in a rapid switching of focus and no time for the SSVEP to reach a steady state in the EEG signal.

Although there might have been some misjudgment on our behalf on the SSVEP frequency selection, we observed that despite low BCI performance the players were able to adapt their game strategy, placing their head in different positions for better SSVEP detection (closer to the LED light, for example) or focusing on using only one of the controls (usually the 12 Hz) to play the game. Their adaptation could result in a feeling of higher control than what is anticipated by their classification performance, which is based solely on the recorded training session, and cause a reduced impact on the user experience.

4.2 Game Experience

To evaluate Kessel Run's user experience as a digital game we grouped responses from the Game Experience questionnaire (GEQ) into key components and results are summarized in Fig. 7.

Most likely due to low BCI performance, participants only felt slightly competent ($\overline{competence} = 1.1$) to play the game. Interestingly enough, we observed

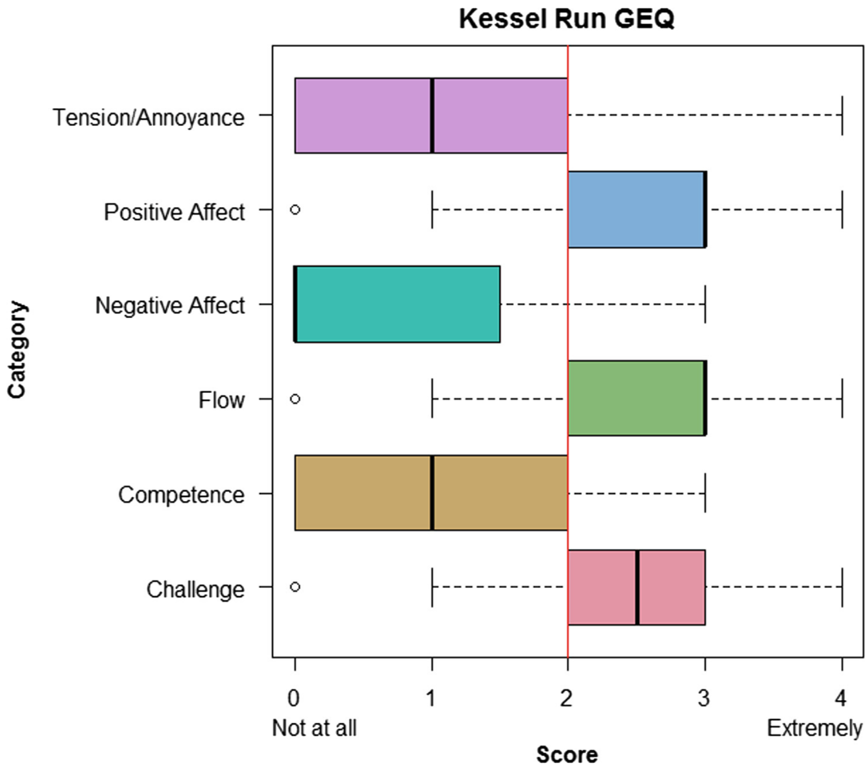


Fig. 7. Boxplot for the answers on the Game Experience questionnaire, for each of the six components: Challenge, Competence, Flow, Tension/Annoyance, Positive and Negative Affect.

that participants were able to adapt while playing Kessel Run even when not in full control of the BCI, as mentioned in the previous section. Teams often opted to move the spaceship in only one of their controllable directions in order to play together. Otherwise when one player had a better BCI performance, the other would be elected "captain" and would order directions for the spaceship to move next. These strategies helped create a greater bond between players and lead to a predominantly positive affect during the game ($\overline{pos.affect} = 2.5/\overline{neg.affect} = 0.8$). Moreover, they also lead to greater feel of immersion ($\overline{Flow} = 2.6$) during the game and a moderate to fair sense of challenge ($\overline{challenge} = 2.3$). When considering the questionnaires scores we can conclude that Kessel Run is an overall enjoyable game, specially when taking into account the participant's Flow scores, suggesting a good employment of the good design requirements appointed previously.

There is, of course, room for improvement in Kessel Run's enjoyment and the BCI paradigm selection seems to play an important role in the game's playability due to its Competence scores. It would be advantageous to substitute SSVEP with another equally or more intuitive paradigm such as motor imagery, because this paradigm is based on induced activations and not on evoked responses could provide a more intuitive and fun experience.

4.3 Social Presence

The summary of the Social Presence questionnaire (SPQ) results aggregated by component is shown in Fig. 8.

For the Behavioral Involvement component, all items had positive scores (mean above 2). This component included six items with mean scores ranging from 2.4 to 3.1 ($\overline{b.involvement} = 2.7$). This component measures the degree to which players feel their actions to be dependent on their co-players actions. Results suggest that players considered their actions fairly dependent on the other's actions, e.g. mean (*'What the other did affected what I did'*) = 2.8.

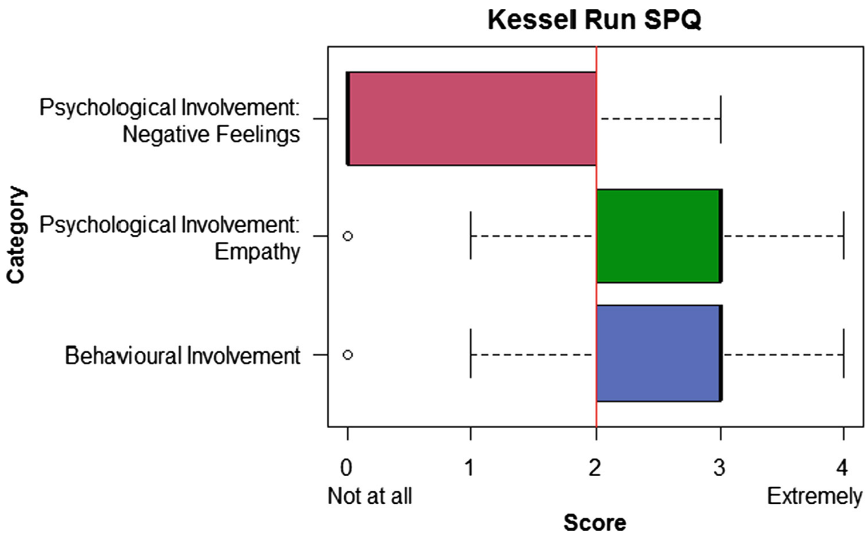


Fig. 8. Boxplot for the answers on the Social Presence questionnaire, for each of the three components: Behavioral Involvement, Psychological Involvement - Empathy and Psychological Involvement - Negative Feelings.

In the Psychological Involvement - Empathy component, all but one items had a mean score over 2 ($\overline{empathy} = 2.3$). Of all the six items included in this component, *'I admired the other'* was the only one with a negative mean score (mean = 1.0 'slightly'). This may be due to the fact that players only felt slightly competent playing the game and didn't feel their co-players to be much more competent controlling the BCI. The remaining five items had mean scores ranging from 2.3 to 2.8. Players empathized with each other: mean (*'I empathized*

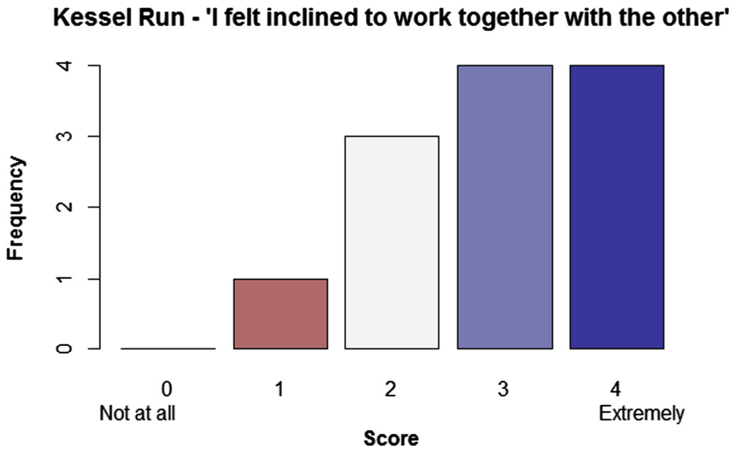


Fig. 9. Frequency bar plot of answers to the item *'I felt inclined to work together with the other'.*

with the other') = 2.6 and found it fairly enjoyable to be with the other: mean (*'I found it enjoyable to be with the other'*) = 2.8.

For the Psychological Involvement - Negative Feelings component, the overall mean score was negative (mean under 2). Players only slightly indicated negative feelings towards the other ($\overline{neg.feelings}$ = 0.9). This component included five items with mean scores ranging from 0.3 to 1.6. Players didn't feel jealousy: mean (*'I felt jealous about the other'*) = 0.3 or revengeful towards the other player at all: mean (*'I felt revengeful'*) = 0.4. On the other hand, players felt moderately influenced by the other's moods: mean (*'I was influenced by the other's moods'*) = 1.6.

The question *'I felt inclined to work together with the other'* was added to the questionnaire as a measure of intention to cooperate among the players. Results show that the majority of players (8 out of 12) gave the item a score of 3 or 4, agreeing 'fairly' or 'extremely' with the sentence (see Fig. 9). The mean score for this item was 2.9, which means that overall, players felt 'fairly' inclined to work together with the other player. These results suggest that Kessel Run met the requirements proposed in Sect. 2.1 for good cooperative game design.

5 Conclusions

In this paper we have presented a novel BCI game, Kessel Run, developed with the intention of breaching the gap between fun games and BCI games. We developed Kessel Run as a multiplayer BCI game by following good game design practices and implementing mechanics that suited the SSVEP control paradigm, as well as taking into account the sociability aspect between players. Our goal is for Kessel Run to be played outside the laboratory, and as such we implemented it using flexible software that supports multiple BCI devices, using only 2 EEG electrodes and with a short training period required.

The game is a space exploration race, in which the 2 players must cooperate with one another in the steering of a spaceship in order to dodge asteroids and survive for 2 min in space without losing all fuel. For the ship steering, cooperative mechanics that are suited for the BCI paradigm were implemented.

Kessel Run was played by 12 participants and rated for game experience and social presence. We grouped questionnaire responses into their key items and evaluated player SSVEP performance.

While SSVEP might not be a reliable paradigm to control the Kessel Run game (only a maximum of 79% accuracy for a 33% chance level was achieved), some changes could be made in future game iterations in order to improve its performance. Using a checkerboard pattern instead of a simple flickering LED square could have given stronger SSVEPs responses [19]. We could also resort to machine learning algorithms to improve SSVEP classification, but these might have higher computation costs and could potentially be slower, which is the reason they were not used in this project. In contrast, using motor imagery instead of the SSVEP paradigm could lead to a more intuitive and perhaps reliable control, although at the expense of longer training sessions and possible BCI illiteracy [18].

Regarding Kessel Run's game experience and overall successfulness in the application of good game design practices, we looked into the reported user experience to find that despite SSVEP's low performance, Flow was still achieved as players felt challenged by the game (see Fig. 7). We believe that following the design requirements in Kessel Run helped in creating an enjoyable and positive experience to its players.

As a multiplayer game between two co-located players, we looked into the social presence felt while playing Kessel Run, investigating psychological and behavioral involvement (see Fig. 8). In general, players considered their actions fairly dependent on the other's actions. In a cooperative game, this behavioral involvement results from the game having collaborative tasks and players having inter-dependent roles, design requirements established in Sect. 2.1. The majority of players indicated in fact they felt fairly to extremely inclined to work together with the other (see Fig. 9), as should be in a collaborative game. Players empathized with the other and found it fairly enjoyable to play the game together, even though they did not particularly admire the other. Negative feelings were generally very low with players only reporting they were slightly influenced by the other's moods but didn't feel jealous or revengeful towards the other player at all.

Despite its shortcomings in the BCI performance, with this work we intend to draw attention to the importance of good game design in BCI games. BCIs are a naturally challenging way of control and therefore require extra care when applied to gaming. By developing unique game mechanics and taking the user experience into consideration we expect to encourage the creation of new multiplayer games in the BCI gaming field.

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References

1. Choi, K., Cichocki, A.: Control of a wheelchair by motor imagery in real time. In: Fyfe, C., Kim, D., Lee, S.-Y., Yin, H. (eds.) IDEAL 2008. LNCS, vol. 5326, pp. 330–337. Springer, Heidelberg (2008). https://doi.org/10.1007/978-3-540-88906-9_42
2. Guan, C., Thulasidas, M., Wu, J.: High performance P300 speller for brain-computer interface. In: IEEE International Workshop on Biomedical Circuits and Systems. IEEE (2004)
3. Ahn, M., Lee, M., Choi, J., Jun, S.: A review of brain-computer interface games and an opinion survey from researchers, developers and users. Sensors **14**(8), 14601–14633 (2014)
4. Reuderink, B., Nijholt, A., Poel, M.: Affective pacman: a frustrating game for brain-computer interface experiments. In: Nijholt, A., Reidsma, D., Hondorp, H. (eds.) INTETAIN 2009. LNICST, vol. 9, pp. 221–227. Springer, Heidelberg (2009). https://doi.org/10.1007/978-3-642-02315-6_23
5. Tangermann, M., Krauledat, M., Grzeska, K., Sagebaum, M., Blankertz, B., Vidaurre, C., Müller, K.-R.: Playing pinball with non-invasive BCI. In: NIPS, pp. 1641–1648 (2008)
6. Pires, G., Torres, M., Casaleiro, N., Nunes, U., Castelo-Branco, M.: Playing Tetris with non-invasive BCI. In: IEEE 1st International Conference on Serious Games and Applications for Health (SeGAH), pp. 1–6. IEEE (2011)
7. Spil Games: State of Online Gaming Report. Spil Games (2013)
8. Hjelm, S.I., Browall, C.: Brainball-using brain activity for cool competition. In: Proceedings of the First Nordic Conference on Computer-Human Interaction (NordiCHI), Stockholm, Sweden, p. 9 (2000)
9. Bonnet, L., Lotte, F., Lécuyer, A.: Two brains, one game: design and evaluation of a multiuser BCI video game based on motor imagery. In: IEEE Transactions on Computational Intelligence and AI in Games, pp. 185–198 (2013)
10. Gürkök, H., Nijholt, A., Poel, M., Obbink, M.: Evaluating a multi-player brain-computer interface game: challenge versus co-experience. Entertain. Comput. **4**(3), 195–203 (2013)
11. Maby, E., Perrin, M., Bertrand, O., Sanchez, G., Mattout, J.: BCI could make old two-player games even more fun: a proof of concept with "connect four". In: Advances in Human-Computer Interaction (2012)
12. Gürkök, H., Nijholt, A., Poel, M.: Brain-computer interface games: towards a framework. In: Herrlich, M., Malaka, R., Masuch, M. (eds.) ICEC 2012. LNCS, vol. 7522, pp. 373–380. Springer, Heidelberg (2012). https://doi.org/10.1007/978-3-642-33542-6_33
13. Sweetser, P., Wyeth, P.: GameFlow: a model for evaluating player enjoyment in games. Comput. Entertain. **3**(3), 3 (2005)
14. Csikszentmihalyi, M.: Flow: The Psychology of Optimal Experience. Harper Perennial, New York City (1990)
15. Salen, K., Zimmerman, E.: Rules of Play: Game Design Fundamentals. MIT Press, Cambridge (2004)

16. van Veen, G.: Brain invaders-finding the paradox of control in a P300-game through the use of distractions. Master's thesis, University of Twente, The Netherlands (2013)
17. Wendel, V., Gutjahr, M., Göbel, S., Steinmetz, R.: Designing collaborative multiplayer serious games: escape from Wilson Island - a multiplayer 3D serious game for collaborative learning in teams. Educ. Inf. Technol. **18**(2), 287–308 (2013)
18. Guger, C., Daban, S., Sellers, E., Holzner, C., Krausz, G., Carabalona, R., Gramatica, F., Edlinger, G.: How many people are able to control a P300-based Brain-Computer Interface (BCI)? Neurosci. Lett. **462**(1), 94–98 (2009)
19. Vialatte, F.-B., Maurice, M., Dauwels, J., Cichocki, A.: Steady-state visually evoked potentials: focus on essential paradigms and future perspectives. Prog. Neurobiol. **90**(4), 418–438 (2010)
20. van de Laar, B., Gürkök, H., Plass-Oude Bos, D., Poel, M., Nijholt, A.: Experiencing BCI control in a popular computer game. IEEE Trans. Comput. Intell. AI Games **5**(2), 176–184 (2013)
21. Tello, R.M.G., Muller, S.M.T., Bastos-Filho, T., Ferreira, A.: A comparison of techniques and technologies for SSVEP classification. In: 5th ISSNIP-IEEE Biosignals and Biorobotics Conference: Biosignals and Robotics for Better and Safer Living (BRC), pp. 1–6 (2014)
22. BCI2000 Wiki (2017). http://bci2000.org/wiki/User_Reference:Matlab_MEX_Files
23. IJsselsteijn, W., De Kort, Y., Poels, K.: The game experience questionnaire: development of a self-report measure to assess the psychological impact of digital games (2013, manuscript in preparation)
24. De Kort, Y., Poels, K., IJsselsteijn, W.: Digital games as social presence technology: development of the social presence in gaming questionnaire (SPGQ). In: Proceedings of PRESENCE, pp. 1–9 (2007)
25. Hakvoort, G., Reuderink, B., Obbink, M.: Comparison of PSDA and CCA detection methods in a SSVEP-based BCI-system. Technical report TR-CTIT-11-03, Centre for Telematics and Information Technology University of Twente (2011)
26. Allison, B.Z., McFarland, D.J., Schalk, G., Zheng, S.D., Jackson, M.M., Wolpaw, J.R.: Towards an independent brain-computer interface using steady state visual evoked potentials. Clin. Neurophysiol. **119**(2), 399–408 (2008)