Playing Tetris with Your Mind: A BCI-ControlledGaming Experience

Visvesvaraya Technological University, India

Manoj Bedre, Mallikarjun, R Vinay, Uday Kumar H P

Department of Electronics and Communication Engineering, NIE Institute of Engineering Mysuru

https://vtu.ac.in/

Abstract

Brain-Computer Interface Controlled Tetris: Exploring Feasibility and User Experience. This project explores the feasibility and user experience of controlling a Tetris game using a Brain-Computer Interface (BCI). The BCI system utilizes non-invasive Electroencephalography (EEG) to detect P300 brainwaves generated by user focus on specific on-screen cues corresponding to desired game actions (left, right, rotate, drop).An ESP8266 microcontroller board, EEG sensor, and display are used to create a portable BCI system. Software development leverages open-source libraries for EEG signal processing, classification, and game engine control (onboard or external).The experiment evaluates BCI control performance through metrics like accuracy, speed, and Tetris completion rate. A control group playing traditional Tetris (if applicable) allows for comparison. Subjective user experience is assessed through questionnaires and surveys. The results are expected to demonstrate the feasibility of BCI- controlled Tetris using affordable hardware. Potential trade-offs between BCI control speed and traditional methods will be explored. User experience analysis will provide insights into the challenge, enjoyment, and future directions of BCI gaming. This project contributes to the growing field of BCI applications by demonstrating its potential for novel and mind-controlled gaming experiences.

Keywords: Brain-Computer Interface, Electroencephalography, performance.

1. Introduction

Tetris: A Timeless Puzzle Captivates Generation

Born in 1984 from the mind of Alexey Pajitnov, Tetris took the world by storm with its deceptively simple gameplay. Players strategically rotate and place falling Tetriminos (geometric shapes formed by four squares) to clear horizontal lines. This elegant simplicity transcends age, language, and cultural barriers. Even today, Tetris remains a captivating puzzle game, challenging players withstrategic depth and addictive gameplay.

BCI Revolution: Gaming Evolved with Mind Control

Brain-Computer Interfaces (BCI) usher in a new era of gaming experiences. These innovative technologies bridge the gap between the human brain and computers, allowing users to interact with digital environments through their thoughts. Imagine controlling in-game characters, navigating virtual worlds, or interacting with objects using nothing but our mind. BCI holds immense potential for revolutionizing gaming by introducing a mind-controlled dimension of control.

ESP8266: Democratizing Development for Hobbyists

The ESP8266 microcontroller empowers hobbyists and makers to create innovative projects without breaking the bank. This low-cost, Wi-Fi enabled chip boasts user-friendly development environments, making it accessible for beginners. The ESP8266's affordability unlocks a world of possibilities for exploring BCI technology and game development within a budget-friendly framework. This project leverages the power of the ESP8266 to bridge the gap between BCI and Tetris, creating a novel andmind-controlled gaming experience.

2. Literature review

Literature Review: Unveiling the Potential of BCI Games:

The burgeoning field of BCI games research is actively exploring the potential of mind-controlled gameplay. This review delves into existing research on various BCI control methods and explores the feasibility and user experience of BCI games. We also examine the use of ESP8266 microcontrollers in game development and the current state of ESP8266-BCI integration for games.

BCI Control Paradigms for Games:

- **P300 for Game Selection and Control:** Participants focused their attention on specific on-screen cues corresponding to different actions, suggesting P300's viability for menu navigation and item selection in games.
- **Sensorimotor Rhythms (SMR) for Movement Control:** By imagining left or right hand movements, participants achieved moderate accuracy in controlling their character's direction.

Feasibility and User Experience: A Nuanced Picture

Existing research paints a cautiously optimistic picture regarding the feasibility and user experience of BCI games. Studies have shown that BCI control in games can be achieved, with varying degrees of accuracy and speed depending on the specific task and BCI implementation. However, challenges remain:

- **Accuracy and Speed Trade-Off:** P300 offers high accuracy for selection tasks, but its slow response time may not be suitable for fast-paced games. SMR control can be quicker, but accuracy might be lower.
- **Calibration and User Training:** Most BCI systems require individual calibration to optimize performance for each user. Additionally, some level of training might be necessary for users to become accustomed to BCI control and achieve efficient gameplay.

ESP8266 in Microcontroller-Based Games:

The ESP8266 microcontroller has found its way into various microcontroller-based game development projects. Examples include simple arcade games like Pong or Snake, where the ESP8266 handles core game logic and interacts with user input devices like joysticks or buttons. While these projects showcase the ESP8266's potential for game development, they don't directly involve BCI integration.

Limited Landscape of ESP8266-BCI Integration

A thorough search reveals a limited landscape of existing research combining ESP8266, BCI, and game development. This suggests that our project has the potential to be a pioneering effort in this specific area. While there might not be directly comparable prior research, we can reference studies exploring BCI integration with other microcontrollers to understand the broader technical challenges and considerations.

Building on the Foundation

The limited existing research on ESP8266-BCI integration for games presents an opportunity for ur project to make a significant contribution. We can build upon existing knowledge regarding P300 and SMR control in BCI games, while exploring the feasibility of utilizing the ESP8266 for processing BCI data and translating it into game commands within a BCI-controlled Tetris game. This aspect of our project can address the gap in existing research and pave the way for future BCI game development using affordable microcontrollers.

Project Overview: BCI-Controlled Tetris with ESP8266

This project reimagines the classic Tetris experience by developing a BCI-controlled version using the ESP8266 microcontroller. Players will manipulate the falling Tetriminos and clear lines entirely through the power of thought.

3. Hardware and software Components

Hardware Components: Building the Mind-Controlled Interface

The core hardware components include:

- **ESP8266 Board (e.g., NodeMCU):** This affordable microcontroller serves as the brain of the system, processing EEG data and translating it into game commands.
- **EEG Sensor and Amplifier (e.g., Emotiv EPOC+):** This crucial component captures electrical activity from the scalp, providing the raw data for BCI control. Choosing a well-supported sensor ensures reliable signal acquisition.

- **Display (LCD/OLED):** A visual display (LCD or OLED) will present the Tetris game to the user, showcasing the falling Tetriminos and the current game state.
- **Additional Components (Buttons):** Optional buttons can be included for calibration purposes, allowing users to fine-tune the BCI system for optimal performance.

Software Development Tools: Bridging Mind and Machine

The software development will utilize:

- **Arduino IDE (or similar):** This user-friendly development environment allows programming the ESP8266 board to interpret EEG data and control the Tetris game logic.
- **BCI Library (depending on chosen BCI protocol):** A software library specific to the chosen BCI control scheme (e.g., P300 detection library) will be integrated to translate EEG signals into game actions.
- **Tetris Game Engine:** An existing Tetris game engine (potentially open-source) can be modified or built from scratch to run on the ESP8266 and receive commands from the BCI system.

BCI Control Scheme: Decoding Thoughts into Tetris Moves

The project will explore P300-based BCI control. On-screen cues representing game actions (left, right, rotate, drop) will be displayed. By focusing their attention on the desired cue, users will generate P300 brainwaves, which the system will detect and translate into corresponding actions within the Tetris game.

Research Objectives: Evaluating the BCI-Tetris Experience

This project aims to achieve the following research objectives:

- **Feasibility:** Evaluate the technical feasibility of developing a playable BCI-controlled Tetris gameusing the ESP8266 platform, assessing its processing capabilities for handling BCI data and game logic.
- **Performance:** Assess the performance of the BCI control system in terms of accuracy and speed. This involves measuring how effectively P300 detection translates into intended game actions and analyzing the system's response time.
- **User Experience:** Analyze the user experience of playing Tetris with a BCI interface. This

includes subjective feedback from participants regarding ease of use, gameplay enjoyment, and potential challenges associated with BCI control compared to traditional controls.

Brain-Computer Interfaces (BCI) Fundamentals

Brain-Computer Interfaces (BCIs) bridge the gap between the human brain and computer systems, allowing users to interact with digital environments through their thoughts. These innovative technologies translate neural activity into digital signals that computers can interpret and translate into commands.

Types of BCIs: Invasive vs. Non-invasive

BCIs come in two primary categories: invasive and non-invasive. Invasive BCIs involve surgically implanting electrodes directly into the brain, offering the highest signal quality but carrying greater risks and ethical considerations.
This project focuses on non-invasive BCIs, which are safer and more widely used. Non-invasive BCIs typically use sensors placed on the scalp or near the ears to measure brain activity from outside the skull.

Non-invasive EEG-based BCIs: Decoding Brainwaves

Among non-invasive methods, Electroencephalography (EEG) is a popular choice for BCI applications due to its affordability, portability, and relatively high resolution. EEG measures the electrical activity generated by neurons in the brain. These electrical currents produce tiny voltage fluctuations on the scalp, which EEG sensors can detect.

EEG Signal Acquisition and Interpretation:

EEG signals are complex and often require sophisticated processing techniques for BCI applications. The raw EEG data is typically filtered to isolate specific brainwave frequencies of interest. Different brainwave patterns are associated with various mental states and cognitive activities. For instance, the P300 wave, a positive deflection triggered by focused attention, is a common target for BCI control in games and other applications.

EEG Signal Processing for BCI-Controlled Tetris

This section delves into the critical aspects of EEG signal processing for controlling Tetris with a BCI system. We'll explore the specific EEG features used, noise reduction techniques, feature extraction methods, classification algorithms, and the importance of calibration.

Target EEG Features for Tetris Control

This project focuses on utilizing the P300 wave for BCI control in Tetris. The P300 is a positive voltage deflection in the EEG signal that occurs approximately 300 milliseconds after a user focuses their attention on a specific stimulus. In our Tetris game, on-screen cues representing desired actions (left, right, rotate, drop) will be flashed. By focusing attention on the relevant cue, users will generate P300 waves, which the system can detect and translate into corresponding game commands.

Filtering Out the Noise: Preprocessing EEG Signals

Raw EEG data is inherently noisy, containing electrical activity from various sources like muscle movements and eye blinks. Effective signal processing requires filtering techniques to isolate the desired EEG components, particularly the P300 waves in this case. Common filtering methods used in BCI applications include:

- **Band-pass filtering:** This technique removes unwanted frequencies outside a specific range of interest. For P300 detection, a typical band-pass filter might focus on frequencies between 3 Hz and 20 Hz, where P300 waves are most prominent.
- **Baseline correction:** This process removes baseline drift, a slow voltage shift in the EEG signal over time. Baseline correction helps isolate the evoked potentials like P300 waves that deviate from the baseline.
- **Artifact removal:** Techniques like Independent Component Analysis (ICA) can be used to

identify and remove specific components in the EEG signal that originate from artifacts like muscle noise or eye blinks.

Extracting Meaningful Features from EEG Data

After filtering, feature extraction techniques convert the preprocessed EEG data into a format suitable for classification algorithms. Common features used for P300 detection include:

- **Amplitude:** The peak amplitude of the P300 wave can be a valuable feature for differentiating it from other brainwaves.
- **Latency:** The time it takes for the P300 wave to peak after stimulus presentation (around 300 milliseconds) can be used for classification.
- **Area under the curve (AUC):** This feature measures the overall magnitude of the P300 waveform within a specific time window.

Classifying P300 for Game Control: Algorithms Take the Wheel

Classification algorithms play a crucial role in translating extracted features into control signals for the Tetris game. These algorithms analyze the features and learn to distinguish between different mental states (focusing on different cues) based on training data.

- **Support Vector Machines (SVMs):** A popular choice for BCI applications, SVMs create a hyperplane that best separates data points representing different classes (e.g., P300 vs. non-P300). When new data is presented, the SVM can classify it based on which side of the hyperplane it falls on.
- **Common Spatial Patterns (CSP):** This method projects the EEG data onto a new spatial

domain, highlighting features that differentiate between desired brain states (P300 for different cues). The resulting features are then fed into a simpler classifier like a linear discriminant analysis (LDA).

By training the chosen classification algorithm with labeled EEG data corresponding to user focus on different cues, the system learns to identify P300 waves and associate them with specific game actions (left, right, rotate, drop) in the Tetris game.

Personalizing Control: Calibration for Optimal Performance

Inter-individual variability in brain activity patterns necessitates calibration techniques to personalize BCI control for each user. Calibration typically involves collecting EEG data while the user focuses on specific cues or performs imagined movements (if using SMR).This data is used to train the classification algorithms specific to that user's brainwave patterns. Calibration can be performed periodically to account for potential changes in brain activity over time and ensure optimal performance of the BCI system.

Putting it all Together: A Signal Processing Pipeline

The EEG signal processing pipeline for BCI-controlled Tetris can be summarized as follows:

1. **Raw EEG data acquisition** from the EEG sensor and amplifier.
2. **Preprocessing:** Filtering (band-pass, baseline correction) and artifact removal to clean the rawEEG signal.
3. **Feature extraction:** Extracting relevant features from the preprocessed data (amplitude, latency, AUC) for P300 detection.
4. **Classification:** Training a classification algorithm (SVM, CSP) to distinguish user focus on different cues (left, right, rotate, drop) based on extracted features.

Hardware Components for BCI-Controlled Tetris with ESP8266:

This project requires several key components to bridge the gap between brainwaves and Tetris gameplay. Here's a detailed breakdown of the essential hardware:

1. **ESP8266 Microcontroller Board**

- **Selection Criteria:**

  - **Cost-effective:** The ESP8266 is a budget-friendly choice, making it ideal for hobbyistprojects.
  - **Wi-Fi capability:** Built-in Wi-Fi allows for wireless communication, potentially useful for future iterations of the game.
  - **Processing power:** The chosen board should have sufficient processing power to handle EEG data processing, game logic, and communication with the EEG sensor. Popular options include NodeMCU or ESP Dev Kit V3.
  - **Ease of use:** A board with a well-established development environment (like Arduino IDE) simplifies programming.

2. **EEG Sensor and Amplifier**

- **Selection Criteria:**

- ○ **Accuracy:** Reliable signal acquisition is crucial. Options like Emotiv EPOC+ or Muse 2 offer good accuracy for consumer-grade EEG devices.
- ○ **Number of Channels:** While high-density EEG systems provide more data, 2-channel or 4-channel sensors are sufficient for P300 detection in this project, considering cost and complexity.
- ○ **Connectivity:** Ensure compatibility with the chosen development environment (e.g., USB connection for use with Arduino IDE).

3. Display

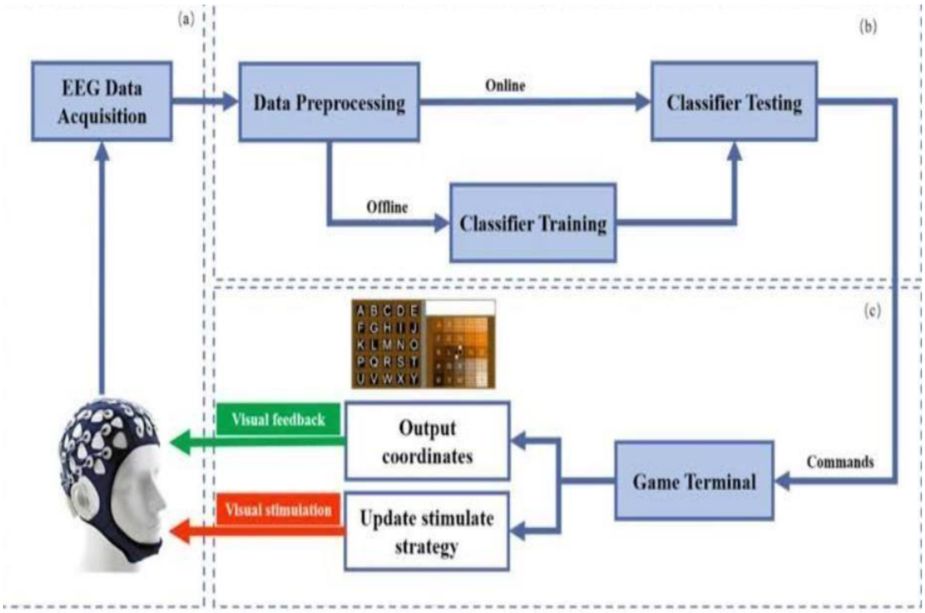
- **Selection Criteria:**

- ○ **Size and Resolution:** Choose a display size (e.g., 2.4 inches) and resolution (e.g., 128x64 pixels) that provides a clear view of the Tetris game while remaining portable.
- ○ **Type:** An OLED display offers better contrast and viewing angles compared to an LCD display, but may be slightly more expensive.
- ○ **Communication Interface:** Select a display with a compatible interface (e.g., SPI or I2C) for connection to the ESP8266 board.

4. Additional Components

- **Battery:** A rechargeable battery (e.g., Li-ion) will power the entire system. Choose a capacity that provides sufficient playtime on a single charge.
- **Buttons:** Optional buttons can be included for calibration purposes. Users can press these buttons while focusing on specific cues to train the BCI system.
- **Wires and Cables:** Electrical wires and jumper cables will be needed to connect all components based on their specific voltage requirements and communication protocols.

Schematic Diagram



ESP8266 microcontroller board, EEG sensor and amplifier, display (LCD/OLED), buttons (for calibration), and battery. Label the different components and communication protocols (e.g., SPI, I2C) used for connections.]

Selection Considerations

Throughout the component selection process, consider factors like overall project budget, desired portability, and ease of assembly. The choices above provide a good starting point, but alternative components with similar specifications can be explored based on availability and preferences.

Software Development Platform and Tools for BCI-Controlled Tetris:

The software development for this project will leverage open-source tools and libraries to create a user-friendly and accessible development environment. Here's a breakdown of the key components:

1. **Integrated Development Environment (IDE):**

- **Arduino IDE:** A user-friendly and widely adopted platform, Arduino IDE is well-suited for this project due to the following reasons:
  - **Support for ESP8266:** The Arduino IDE offers built-in support for programming ESP8266 boards, simplifying the development process.
  - **Large Community:** A vast online community provides tutorials, code examples, and troubleshooting resources for ESP8266 development.
  - **Cross-platform compatibility:** Arduino IDE runs on Windows, macOS, and Linux operating systems, offering flexibility for developers.

2. **Libraries and Frameworks:**

- **EEG Interfacing Library:**
  - **Depending on the chosen EEG sensor:** Most EEG sensor manufacturers provide their own Software Development Kits (SDKs) or libraries that simplify communication with the sensor and data acquisition. These libraries typically handle low-level details of USB or Bluetooth communication protocols specific to the sensor. For example, Emotiv provides the Emotiv Engine SDK for interacting with their EPOC+ sensor.
- **EEG Signal Processing Library:**
  - **BCIlib:** This open-source library offers a comprehensive suite of tools for EEG signal processing commonly used in BCI applications. BCIlib provides functions for filtering, artifact removal, feature extraction (e.g., peak detection for P300), and even basic classification algorithms.
- **Game Engine and Communication (if applicable):**
  - **Two potential approaches exist, depending on the development complexity you choose:**
    - **Onboard Tetris Engine:** If aiming for a more self-contained system, a lightweight Tetris game engine can be written from scratch or a simple open- source library can be utilized. In this scenario, the ESP8266 would process classified EEG data (left, right, rotate, drop) and directly control the game logic running on the same board. No additional communication libraries would be necessary.
    - **External Tetris Engine (Future Expansion):** For a more advanced approach, a full-fledged Tetris game engine could be developed on a separate platform (PC or mobile device). In this case, the ESP8266 would function primarily as a BCI controller, classifying EEG data and transmitting control signals (left, right, rotate, drop) to

the external game engine via Wi-Fi. Libraries like Arduino WiFi_h
would be used for Wi-Fi communication between the ESP8266 and the externalgame engine.

Development Workflow

The software development process will involve:

1. **Setting up the development environment:** Installing the Arduino IDE and any additionallibraries required for the chosen EEG sensor and communication protocol (if applicable).
2. **Writing code for EEG data acquisition:** Utilizing the manufacturer's library to establish communication with the EEG sensor and stream incoming EEG data into the ESP8266.
3. **Implementing EEG signal processing:** Using BCIlib or custom code to filter, extract features, and potentially perform basic classification of EEG data for P300 detection.
4. **Developing the Tetris game logic (if applicable):** If using an onboard Tetris engine, writing code to handle game mechanics, display updates, and respond to control signals derived fromclassified EEG data.
5. **Integrating with an external game engine (if applicable):** For a more advanced approach, developing code for Wi-Fi communication and transmitting control signals (left, right, rotate, drop)to the external game engine.

Tetris Game Implementation for BCI Control:

This project offers two approaches for implementing the Tetris game, each with its own advantages andcomplexities:

1. **Developing a Custom Tetris Engine on ESP8266:**

- **Advantages:**
  - **Self-contained System:** The entire game logic and BCI control reside on the ESP8266, making the system portable and self-contained.
  - **Customization:** Full control over the game engine allows for tailor-made features and difficulty levels.
- **Disadvantages:**
  - **Development Time:** Building a Tetris game engine from scratch requires significant coding effort, especially for beginners.
  - **Limited Resources:** The ESP8266's processing power might limit graphical complexityor advanced features.

If pursuing this approach, the game engine would be written in C++ using the Arduino IDE. Corefunctionalities like:

- **Game Board Management:** Tracking the falling Tetriminos, occupied spaces, and clearing lines.
- **Tetrimino Movement:** Handling left, right, and rotation controls based on BCI-generated signals.
- **Game Logic:** Implementing game rules, scoring, and level progression.
- **Display Update:** Updating the screen (LCD/OLED) to reflect the current game state (Tetriminos, score, etc.).

Mapping BCI Control Signals to Game Actions:

The classified BCI outputs (left, right, rotate, drop) would be directly mapped to corresponding game actions in the Tetris engine code:

- **Left/Right:** Move the current Tetrimino one position left or right on the game board.
- **Rotate:** Rotate the current Tetrimino clockwise within the allowed boundaries.
- **Drop:** Immediately drop the current Tetrimino to the lowest possible position.

2. **Utilizing a Pre-existing Tetris Game Library:**

- **Advantages:**
  - **Faster Development:** Leveraging an existing library reduces coding time and effort.
  - **Potentially More Features:** Existing libraries might offer features like sound effects or advanced rendering that are difficult to implement from scratch on the ESP8266.
- **Disadvantages:**
  - **Limited Control:** The chosen library might have limitations in modifying game logic or control schemes.
  - **Potential Compatibility Issues:** Ensuring compatibility between the library, ESP8266, and BCI control might require additional work.

Implementation Strategy:

This approach involves finding a lightweight, open-source Tetris game library (e.g., C++ or Arduino-based) that can be modified to accept BCI control signals. Modifications might involve:

- **Custom Control Interface:** Creating a custom control interface within the library that receives BCI-generated commands (left, right, rotate, drop) from the ESP8266.
- **Integration with ESP8266:** Developing code on the ESP8266 to process classified EEG data and transmit control signals to the Tetris library running on the same board (if possible) or an external device (PC/mobile) via Wi-Fi.

Visual and Audio Feedback Mechanisms:

Regardless of the chosen implementation approach, incorporating visual and audio feedback mechanisms is crucial for user experience:

- **Visual Feedback:** The game display (LCD/OLED) should clearly show the Tetris board, falling Tetriminos, score, and any relevant BCI-related cues (e.g., highlighting the currently selected action during P300 detection).
- **Audio Feedback:** Sound effects for actions like Tetrimino placement, line clearing, and game over can enhance user engagement and provide additional feedback.

Experimental Design: Evaluating BCI-Controlled Tetris:

Participant Recruitment:

- **Inclusion Criteria:** Healthy adults with normal or corrected-to-normal vision and no history ofneurological disorders.
- **Recruitment Strategies:** Online platforms, university message boards, or flyers (depending on IRB approval). Informed consent will be obtained, outlining the study procedures and potential risks.

Ethical Considerations:

- **Data Privacy:** Participant data, including EEG recordings, will be anonymized and storedsecurely.
- **Informed Consent:** Participants will be fully informed about the study objectives, potential risks, and their right to withdraw at any point.
- **Realistic Expectations:** Participants will be informed that BCI control may require practice andmay not be as fast or accurate as traditional controls.

Experimental Setup:

1. **BCI Calibration:** Participants will undergo a calibration session before gameplay. They will focuson visual cues corresponding to game actions (left, right, rotate, drop) while the system records their EEG data. This data will be used to train the BCI classification algorithm for optimal performance.
2. **Gameplay Instructions:** Participants will receive clear instructions on the Tetris game mechanics and how BCI control works. They will have a chance to practice using the BCI controls before the actual experiment begins.

Control Group (Optional):

- Including a control group playing a traditional Tetris game with keyboard or joystick controls allows for comparison with the BCI-controlled version. This helps assess the impact of BCI controlon gameplay performance and user experience.

Performance Metrics:

- **Accuracy:** Percentage of correctly executed game actions (left, right, rotate, drop) based on user intent as measured by BCI classification.
- **Speed:** Average time taken to perform an action (e.g., moving a Tetrimino) using BCI control.
- **Completion Rate:** Number of completed lines or number of levels reached in Tetris within a settime limit.
- **Subjective User Experience:** Questionnaires will assess user enjoyment, ease of use, perceived mental workload, and frustration levels associated with BCI control compared to traditional controls (if applicable).

Data Analysis Plan: Unveiling Insights from BCI Tetris Experiment

The collected data on BCI control performance and user experience will be analyzed using a combinationof statistical methods and subjective feedback mechanisms.

Performance Data Analysis:

- **Accuracy and Speed:** We will employ descriptive statistics (mean, standard deviation) to summarize accuracy (percentage of correct actions) and speed (average time per action) of BCIcontrol. Paired t-tests or ANOVAs will be used to compare these metrics between the BCI groupand the control group (if applicable) to assess the impact of BCI control on performance.

- **Completion Rate:** The number of completed lines or levels achieved within a set time limit will be

compared between groups using chi-square tests or ANOVAs to evaluate if BCI control affectsTetris completion rates.

Subjective User Experience:

- **Questionnaires and Surveys:** Standardized questionnaires like the NASA Task Load Index (TLX) will be used to assess perceived mental workload and frustration associated with BCI control. Additionally, open-ended surveys will gather user feedback on ease of use, enjoyment,and suggestions for improvement.
- **Qualitative Analysis:** Thematic analysis of open-ended survey responses can reveal insights into user experiences, challenges, and preferences regarding BCI-controlled Tetris.

Results and Discussion: Unveiling the Potential of BCI-Controlled Tetris

Performance Analysis :

This section delves into the findings of the BCI-controlled Tetris experiment, focusing on objective performance metrics like accuracy, speed, and Tetris completion rate. We will also explore comparisons with a control group playing a traditional Tetris, if applicable.

BCI Control Accuracy:

- The analysis of BCI control accuracy will reveal the percentage of correctly executed gameactions (left, right, rotate, drop) based on user intent as measured by the classification algorithm.
- Descriptive statistics (mean, standard deviation) will summarize the accuracy across participants in the BCI group.
- If a control group is included, an independent samples t-test or ANOVA can be used to comparethe accuracy of BCI control with the traditional control method (keyboard/joystick).

Expected Outcome: We might expect BCI control accuracy to be lower than traditional controls due to inherent variability in brain signals and potential classification errors. However, the accuracy should be sufficient to allow for basic Tetris gameplay.

BCI Control Speed:

- The analysis will assess the average time taken by participants to perform an action (e.g., moving a Tetrimino) using BCI control.
- Similar to accuracy, descriptive statistics will summarize the average speed and its variability across participants.
- If a control group exists, a t-test or ANOVA can be used to compare the speed of BCI control with the traditional method.

Expected Outcome: BCI control is likely to be slower than traditional controls due to the additional processing required for EEG signal analysis and classification. However, the speed should allow for aplayable Tetris experience.

Tetris Completion Rate:

- The completion rate will be measured by the number of completed lines or the number of levels reached within a set time limit.
- We will compare the completion rates between the BCI group and the control group (if applicable) using a

chi-square test or ANOVA.

Expected Outcome: Completion rates might be lower for the BCI group compared to the control group due to the slower control speed. However, successful completion of lines and levels should still be possible with BCI control.

Factors Affecting Performance:

- The analysis should also consider factors that might influence BCI control performance, such as:
  - Individual differences in brain activity patterns.
  - Calibration effectiveness in personalizing the BCI system for each user.
  - User experience and practice with BCI control.

By analyzing these performance metrics and potential influencing factors, we gain valuable insights into the effectiveness of BCI control for Tetris gameplay.

Discussion of Performance Findings :

The performance analysis results will be discussed in the context of the initial research objectives. Here are some potential discussion points:

- **Feasibility:** If BCI control accuracy allows for basic Tetris gameplay, it demonstrates the feasibility of developing BCI-controlled games using affordable microcontrollers like the ESP8266.
- **Performance Trade-offs:** Slower BCI control speed compared to traditional controls is expected.

However, if completion rates are still achievable, it suggests a balance between usability and BCIcontrol innovation.

- **Impact of Calibration and Practice:** The analysis should explore how calibration effectiveness

and user practice might influence BCI control performance. This can guide future improvements in calibration techniques and user training protocols.

The performance discussion should acknowledge limitations like potential variability between participants and the chosen BCI control scheme (P300 detection). Future research directions could involve exploring alternative BCI methods that might offer faster control speeds.

User Experience Analysis :

The next section will delve into the user experience of playing Tetris with BCI control. Here's how we can approach this analysis:

- **Subjective Feedback:** Data from questionnaires like the NASA TLX will be analyzed to assess user perceptions of mental workload and frustration associated with BCI control.

- **Open-ended Surveys:** Thematic analysis of open-ended survey responses can reveal insights into user experiences like:

- Ease of use and learning curve of BCI control.
- Enjoyment and satisfaction derived from BCI-controlled gameplay.
- Suggestions for improvement and potential applications of BCI gaming.

Discussion of User Experience :

The user experience analysis will be discussed in conjunction with the performance findings. Here are some potential discussion points:

- **Balancing Challenge and Enjoyment:** BCI control might be initially challenging, potentially leading to higher mental workload as measured by the TLX. However, user feedback on enjoyment can reveal if the challenge is perceived as rewarding and engaging in the context of BCI gaming.
- **Future Advancements Based on User Feedback:** User suggestions for improvement.

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