University of Geneva

Interaction Multimodale et Affective

Cheesy Math

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September, 2023

Contents

1 Introduction

In the exciting world of gaming, developers continuously strive to create immersive experiences that captivate players and keep them on the edge of their seats. Our project is an exciting runner game featuring a character named Mousy. In this game, players take control of Mousy, collecting cheese and answering easy math questions while navigating a course filled with obstacles.

The main objective of our project is to explore how humans perform in solving basic math problems when they are engaged in a video game compared to when they focus solely on math puzzles. To accomplish this, we've designed a two-player runner game where players collect cheese and tackle math problems. Before starting the game, one player answers math questions and once the game begins, the same player encounters similar math questions while playing the game. Our goal is to analyze the differences in math-solving performance in these two contexts: during the game with distractions and multitasking versus a focused math puzzle-solving scenario. Our assumption is that the difference between the performances will be interesting.

Beyond the typical gameplay experience, we are particularly interested in exploring the physiological responses of players as they navigate through the game's increasing difficulty levels. An intriguing aspect of our project is our use of the "Flow" emotional model, where we adjust the character's speed based on the players' heart rate. To achieve this, we plan to utilize electrocardiogram (ECG) data to monitor the players' heart rate (HR).

To capture and enhance the player experience, we utilize inputs like smartphone accelerometer data for movement, laptop touchpad interactions for jump, and heart rate measurements through Bitalino and OpenSignal to change the speed of the character. The game outputs sound through speakers, displays visuals on monitors, and provides vibration feedback in the mobile version using smartphone sensors.

Our project aims to report on the differences in math problem-solving performance before and during the game, taking into account the impact of distractions and multitasking, as well as any variations in performance between genders. By exploring the relationship between gaming, math, and emotions, we hope to contribute valuable insights to the world of educational and entertainment technology.

2 Game

In our project, we developed a captivating and educational game called "Cheesy Math," which offers players an engaging and challenging experience while simultaneously testing their math skills. This game revolves around the adventures of our protagonist, Mousy, as she navigates through a perilous industrial environment. The primary objective of Cheesy Math is to collect as many cheese items as possible while correctly answering a set of 10 math questions. Players assume control of Mousy and must guide her through the treacherous terrain filled with various obstacles. To progress in the game and achieve a high score, players must correctly answer 10 math questions. This feature not only entertains players but also helps us to study how the quality of human performance in solving easy math problems differs when players focus solely on math puzzles versus when playing a video game.

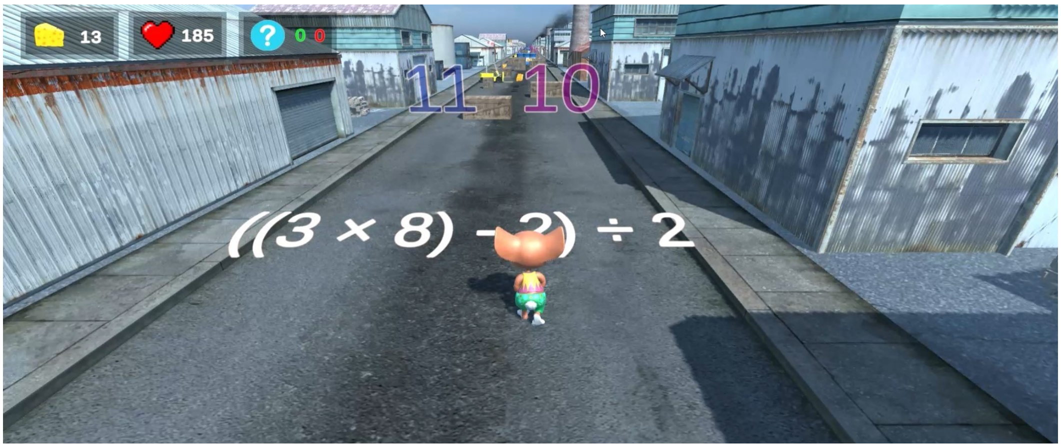

Figure 1: Mousy's Adventure Amidst Obstacles and Mathematical Challenges in 'Cheesy Math' Game.

The game environment consists of both fixed and dynamic obstacles. Fixed obstacles include boxes and barrels strategically placed throughout Mousy's path, while dynamic obstacles such as forklifts and stone bars add an element of unpredictability to the game. Colliding with these obstacles will result in a reduction of Mousy's health, adding an element of risk and excitement to the gameplay.

What sets Cheesy Math apart from many other games is its unique twist on difficulty adaptation. Rather than using traditional methods to adjust the game's challenge level, we have implemented another approach based on the heart rate (HR) changes of one of the players during gameplay. The game monitors the player's HR using an ECG sensor, and as the player's heart rate increases or decreases, the game's difficulty dynamically adjusts accordingly. This innovative feature adds an extra layer of excitement and immersion, making Cheesy Math a truly one-of-a-kind gaming experience.

We developed Cheesy Math using the Unity3D game engine with C# programming for the gameplay elements. In the creation of "Cheesy Math," we employed online assets for environmental design, character animations, and graphics, all of which have been diligently documented and referenced in our report. [1]Additionally, we utilized Python programming to analyze the ECG signals from the player, allowing us to seamlessly integrate the real-time heart rate monitoring into the game.

3 Research Question

The central research question of this study is: **How does playing video games affect human performance in solving easy math problems?**

To investigate this question, we designed an experiment where one player was tasked with answering 10 math questions in one minute before and during the gameplay. The questions presented a moderately challenging pace, with only six seconds allotted for each question. The objective was to measure any differences in math-solving performance between these two contexts: before engaging in the game and while actively playing it.

An underlying assumption in our research is that the player's math-solving performance during the game would likely be less accurate compared to when they were not playing. This hypothesis is rooted in the notion that the act of gaming introduces multitasking and distractions that could hinder cognitive performance.

In our game, the character, Mousy, is controlled by two players. Player one is the primary operator who has visibility of the game screen, answers the math questions, and manages Mousy's actions, such as jumping. Additionally, player one communicates instructions to player two for Mousy's lateral movements using a smartphone accelerometer. This unique gameplay dynamic introduces a potential source of noisy data, as it combines math problem-solving with real-time coordination and communication between the two players.

To address the potential influence of this noisy data on our study, a supervisor was assigned to observe and record player one's answers to the math questions while they guided player two during the game. This supervision not only ensures data accuracy but also serves to identify any interaction errors that may arise from the collaboration between the two players.

4 Adaptability

In our pursuit of creating an engaging gaming experience, we implemented the concept of **Flow** as an emotional model. Flow represents a state of optimal engagement and immersion in an activity, where the individual experiences a sense of complete absorption and enjoyment. To achieve this state in our game, Cheesy Math, we utilized Flow as a guiding framework to enhance player engagement.

One of the key aspects of Flow is the dynamic balance between the player's skills and the challenge level presented by the game. To achieve this balance, we leveraged real-time heart rate (HR) monitoring to adjust the game's difficulty dynamically. Tian Y et al. [3] demonstrated in their research that HR tends to vary at different levels of difficulty, with higher HR correlating with increased challenge. To implement this concept in Cheesy Math, we first established a baseline HR for player one by calculating the mean HR (based on ECG signals of 150 Seconds) before the game began. This baseline HR provided us with a reference point to gauge the player's physiological response to the game's challenges.

During gameplay, we continuously monitored player one's HR and assessed fluctuations from the established baseline. When the HR deviated from this baseline, we dynamically adjusted the character's speed in response. Specifically, for each window size of 10 seconds, if the player's HR dropped below the baseline, indicating a decrease in arousal or engagement, we increased the character's speed to intensify the gameplay experience. Conversely, if the HR exceeded the baseline, indicating heightened arousal, we moderated the character's speed to alleviate potential stress and maintain a more balanced emotional state.

5 Heart Rate Measurement

In our research, the measurement of heart rate (HR) played a pivotal role in dynamically adjusting the gameplay experience. To capture the HR data of player one, we utilized the Bitalino device in conjunction with the corresponding software, OpenSignals. The Bitalino device, as depicted in Figure 2, features three electrodes designed to collect electrocardiogram (ECG) signals. For our setup, we placed the red electrode on the left-hand wrist, the black electrode on the right-hand wrist, and the white electrode on the left side of the belly. This configuration allowed us to capture accurate ECG data, which was instrumental in monitoring the player's heart rate throughout the gameplay.

Figure 2: Bitalino is a Toolkit to be Used in a Laboratory or to Create Prototypes and Applications Using Physiological Sensors. [2]

To ensure the precise collection of ECG data, we configured the Bitalino device settings in the OpenSignals app as illustrated in Figure 3. We selected the "raw" signal type, opted for a high sampling rate of 1000Hz, and activated the Lab Streaming Layer (LSL) in the settings page and integration tab. These settings were crucial for obtaining high-quality and real-time HR data.

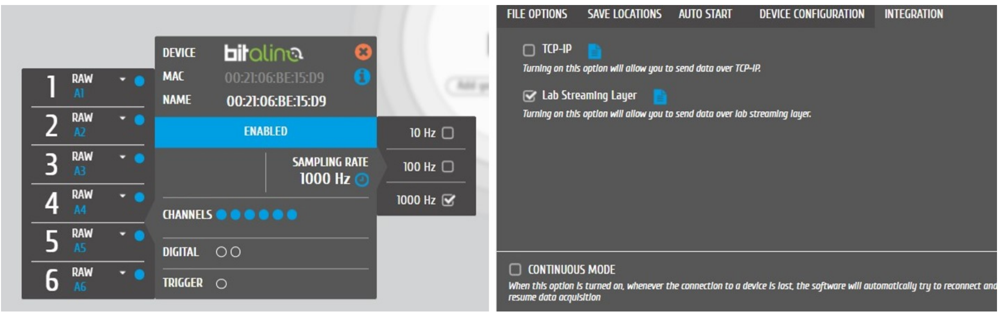

Figure 3: Configuring Opensignals Settings for Accurate ECG Signal Reception and Transmission.

To seamlessly integrate the HR data into our game, we developed a Python script that acted as an intermediary between the Bitalino device and our game engine. This script made use of the **pylsl** library, which allowed us to establish a connection and facilitate the transfer of HR data from the Bitalino device to our game.

```python
# Make Connection with Bitalino

### Define the MAC-address of the acquisition device used in OpenSignals
os_stream = resolve_stream("name", "OpenSignals")
# Create an inlet to receive signal samples from the stream
inlet = StreamInlet(os_stream[0])


# Make Connection with Unity3D
host, port = "127.0.0.1", 25001
sock = socket.socket(socket.AF_INET, socket.SOCK_STREAM)
sock.connect((host, port))
```

Figure 4: Utilize *StreamInlet* and *resolve_stream* functions from the *pylsl* Library in Python to Transfer the ECG Signal from OpenSignals to Unity3D.

To ensure that the HR data was successfully transmitted to our game, we employed the **biosppy** library to extract the player's heart rate from the ECG signals. This extraction process involved the application of signal processing techniques and algorithms to discern the HR values, ensuring that the data accurately represented the player's physiological state during gameplay.

```python
# ECG signal processing using biosppy library and extract Heart Rate
HR = ecg.ecg(signal=ECG_list, sampling_rate=1000., show=False)["heart_rate"]

# Compute HR mean for each window
HR_mean = np.round(np.mean(HR), 2)
```

Figure 5: Utilize *ecg* Function from the *biosppy* Library in Python to Extract HR Values from the ECG Signals.

Biosppy computes heart rate (HR) from an ECG signal using a modified Pan-Tompkins QRS complex detection algorithm. The process begins with ECG signal preprocessing, including filtering and differentiation to emphasize QRS complexes. The squared and integrated signal is then thresholded to identify potential R-peaks. A peak selection process within local windows identifies the most prominent peaks as R-peaks. Subsequently, the RR intervals between successive R-peaks are calculated, and HR is obtained by converting the average RR interval to beats per minute (BPM). This automated procedure in Biosppy provides an efficient and accurate means of HR extraction from ECG data, even in the presence of noise.

6 Modalities

Our project relies on a range of essential equipment to facilitate various aspects of our research and game development. To measure the heart rate of player one, we employ the Bitalino device in conjunction with the OpenSignal app, ensuring precise data capture for our physiological analysis. The game itself is constructed and executed through the versatile Unity 3D application, running seamlessly on a dedicated laptop. To control the dynamic movements of our in-game character, Mousy, we harness the power of a smartphone, with the Unity Remote application serving as the bridge that enables intuitive and responsive gameplay control.

Inputs:

- **Laptop Touchpad:** The touchpad of the laptop serves as an input device, enabling players to trigger character jumps within the game.
- **Smartphone accelerometer Sensor:** Utilizing the accelerometer sensor of a smartphone, players have precise control over Mousy's character movements within the virtual world. The motion sensor enhances player interaction and immersion.
- **Bitalino Heart Rate Monitor:** We employ the Bitalino device to measure the heart rate of player one during gameplay. This heart rate data is a crucial input used to dynamically control the character's speed within the game, contributing to the real-time adaptation of gameplay challenges.

Outputs:

- **Sound Effects:** To enhance player engagement, our game incorporates a variety of sound effects. These include distinct audio cues for colliding with obstacles, providing correct or incorrect answers to math questions, approaching boundaries, and experiencing crashes. These audio elements add a multisensory dimension to the gaming experience.
- **On-Screen Scores:** Player scores and progress are displayed directly on the game screen, providing immediate feedback on their performance and mathematical aptitude.

- **Haptic Feedback (Mobile Version):** In the mobile version of our game, players receive tactile feedback through vibrations when encountering obstacles or collisions. This feature intensifies the immersive experience and heightens player awareness of in-game events.

This combination of input and output components, alongside the equipment mentioned earlier, forms a comprehensive ecosystem that allows us to collect real-time physiological data, create an engaging gameplay environment, and provide immediate feedback to players.

7 User Test

The user test procedure was carried out systematically to gather data on both cognitive and physiological aspects of player engagement in Cheesy Math:
Player one commenced by tackling 10 math questions within a 150-second time frame, evaluating their cognitive abilities. Following this, the Bitalino device's electrodes were properly placed on Player One's body to accurately measure their heart rate. The Bitalino device was then powered on and connected to the OpenSignals application for heart rate data recording. OpenSignals settings, as explained in the heart rate measurement section, were configured for optimal data collection.

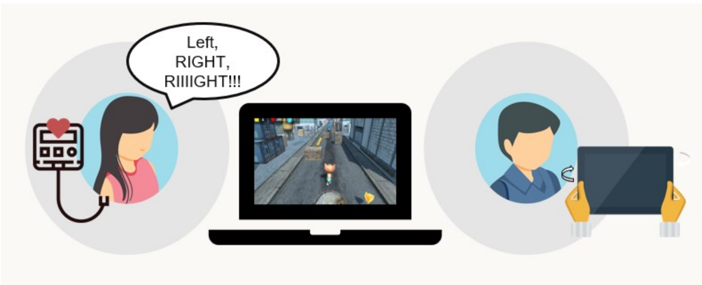

Figure 6: Only Player One Can See the Screen and Command Player Two to Move Mousy.

Player One initiated ECG signal collection by clicking "Start" in the OpenSignals app. A Python script, bitalinoBaselineAcq.py, was executed to calculate the mean heart rate value for Player One, establishing a baseline. The acquired mean heart rate was set as the baseline in the BitalinoUnity.py script, serving as a reference for dynamic gameplay adjustments. The Unity Remote App was launched on an Android smartphone and connected to the laptop via USB cable, enabling responsive character control. With Unity3D running, the game commenced as Player One clicked "Start" in the OpenSignals app to capture real-time ECG signals. The BitalinoUnity.py script facilitated real-time communication between the Bitalino device and the Unity game.

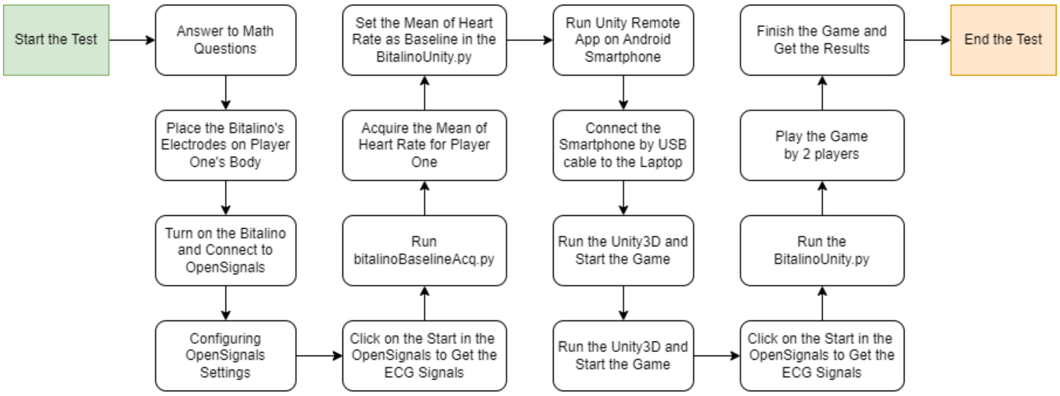

Figure 7: Diagram Illustrating the Process of User Test of Cheesy Math

Two players engaged in gameplay, controlling the character Mousy, while the game adjusted based on Player One's heart rate fluctuations. Once the game concluded, results were compiled, and data related to performance and physiological responses were collected for analysis. This structured approach ensured the precision of our user test while capturing both cognitive and physiological dynamics during gameplay.

8 Results

We conducted our user test with a group of six participants, comprising three men and three women. This balanced representation allowed us to obtain a comprehensive set of data, encompassing a range of individual responses and experiences. In this section, we present the results of our experiment, shedding light on how different participants interacted with the game and how their physiological responses varied.

The provided data pertains to Player One's performance before the start of the game and their response to 10 math questions, their performance in answering math questions during the game, the results observed by the supervisor, the level of communication error between two players, and the number of times the character's speed, "Mousy," changed relative to Player One's heart rate during the game, using a comparative 10-second interval compared to the baseline.

Table1: Performance Results for Women

Participant ID	Baseline of HR	Performance Before the Game		Performance During the Game		Supervisor Observations		Error	Collected Cheeses	Number of Speed Changes
		Correct	Wrong	Correct	Wrong	Correct	Wrong			
WP1	75.76	10	0	8	2	8	2	0	47	4
WP2	87.33	10	0	9	1	7	3	2	12	3
WP3	85.72	10	0	8	2	7	3	1	19	6

Table2: Performance Results for Men

Participant ID	Baseline of HR	Performance Before the Game		Performance During the Game		Supervisor Observations		Error	Collected Cheeses	Number of Speed Changes
		Correct	Wrong	Correct	Wrong	Correct	Wrong			
MP1	79.46	10	0	5	5	5	5	0	53	12
MP2	85.74	10	0	6	4	8	2	2	44	10
MP3	75.55	9	1	4	6	5	5	1	65	10

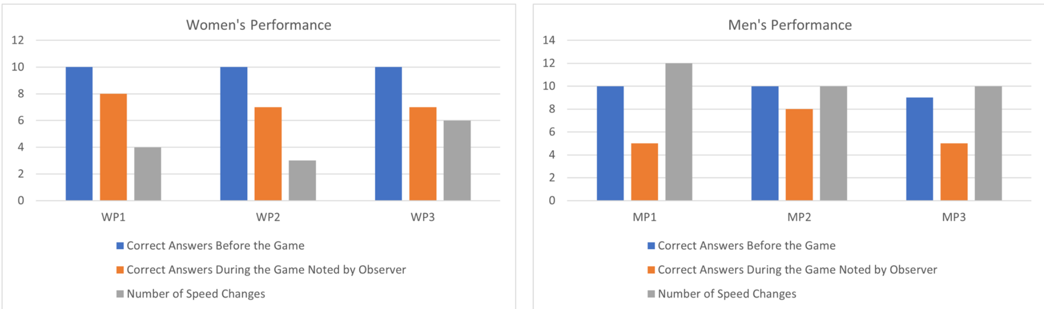

Diagram 1: A Diagram to Illustrate the Performance Results for Women and Men

9 Observations

Based on the results we have observed:

1. Participants exhibited a considerable drop in in-game performance (values recorded by the supervisor) compared to their performance before starting the game. In some instances, this drop was even as much as a halving of performance, which can be considered as bad as randomly selecting answers. This can indicate the severe effects of factors that cause distraction within the game for the player, as well as the impact of multitasking during gameplay, which has reduced the player's performance.

2. The Heart Rate fluctuation and consequently, the changes in Mousy's speed, were less pronounced among female participants compared to male participants. This may be due to the fact that female players may not take the game very seriously or that their physiological system undergoes fewer changes during gameplay. Additionally, the greater fluctuations in character speed observed among male players during gameplay may contribute to increased difficulty in responding to math questions. These speed variations could introduce added challenges, potentially affecting their math problem-solving capabilities.

3. The average heart rate (HR) obtained as the baseline before the game varies among the participants in the user test. This diversity in baseline HR values suggests that individuals have distinct physiological responses.

4. The quantity of cheese items collected by female players was lower than that of male players, while the rate of correct answers provided by female players during gameplay was higher. This observation might be attributed to female players prioritizing the solving of math questions more than collecting cheese items.

10 Future work

Our current research has opened avenues for further exploration and refinement in several directions. Expanding our participant pool to include a more diverse range of players would provide richer data for more robust inferences. This broader sampling would help us understand how physiological responses and performance interact across different demographics. In terms of gameplay content, future work could involve changing the nature of challenges, such as exploring riddles or shape combinations. This variation could shed light on how different cognitive demands impact both performance and physiological responses, extending the applicability of our approach across various game genres.

Monitoring the heart rate of player two would deepen our understanding of cooperative gameplay dynamics, allowing us to explore how both players' physiological states evolve during collaborative play. This data could reveal patterns of interaction and coordination that influence the gaming experience. Additionally, introducing experimental conditions like reversing the controller's left and right directions could further investigate the effects of cognitive load and physiological arousal on player performance. This modification in gameplay mechanics might provide insights into the adaptability of our real-time adjustment system to varying levels of challenge and cognitive demand.

11 Conclusion

In this project, we sought to answer the central research question: "How does playing video games affect human performance in solving easy math problems?" To investigate this, we designed an experiment where players answered math questions before and during gameplay in the Cheesy Math game. Our assumption was that the cognitive performance of players during the game would likely be less accurate due to the introduction of multitasking and distractions. Our game featured a unique two-player setup, where Player One controlled the character, Mousy, and answered math questions while Player Two assisted with lateral movements using a smartphone accelerometer. This collaboration introduced the potential for noisy data. To address this, a supervisor recorded Player One's math answers and monitored gameplay for interaction errors. We also implemented the concept of "Flow" as an emotional model, adjusting gameplay difficulty based on real-time heart rate data to enhance player engagement.

Our observations revealed a significant difference in performance before and during the game, directly addressing our research question about how video games impact math problem-solving. Players performed noticeably worse during the game compared to their pre-game performance, indicating that gaming introduces cognitive challenges and distractions that hinder math-solving abilities. We also observed differences in heart rate responses and gameplay performance between genders. Female players exhibited less heart rate fluctuation and collected fewer in-game items but provided more correct answers during gameplay. In conclusion, our research provided insights into the complex relationship between gameplay, physiological responses, and gender-related differences in performance. Our findings contribute to a better understanding of player engagement dynamics and the potential for real-time adaptation in game design. Future work could involve expanding the participant pool, varying game content, monitoring Player Two's heart rate, and experimenting with reversed controller inputs to further explore these dynamics. Ultimately, our study highlights the importance of considering both cognitive and physiological aspects in game design and user experience evaluation.

References

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[3] TIAN, Y., BIAN, Y., HAN, P., WANG, P., GAO, F., AND CHEN, Y. Physiological signal analysis for evaluating flow during playing of computer games of varying difficulty. *Psychol* (2017).