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Master's Thesis
Academic Year 2021

Developing Players' Sense of Agency by Physiological Sensor in Game-Play: Design Approaches of Dynamic Difficulty Adjustment

Keio University
Graduate School of Media Design

Ziyue WANG

A Master's Thesis
submitted to Keio University Graduate School of Media Design
in partial fulfillment of the requirements for the degree of
Master of Media Design

Ziyue WANG

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Abstract of Master's Thesis of Academic Year 2021

Developing Players' Sense of Agency by Physiological Sensor in Game-Play: Design Approaches of Dynamic Difficulty Adjustment

Category: Design

Summary

Games are entertaining due to its interactive nature and the occasional requirement of a certain level of skill to complete them. However, this can also potentially lead to frustration since there is no way for a game to truly understand the player's behaviours in game-play. Sometimes the mistakes is happened because of carelessness. However, The more likely reason is the player cannot make game character move the way they want it to. The study approach to develop player's sense of agency with avatar by haptic feedback on the controller. The trigger condition of feedback depends on player's physiological data. We propose a controller design with a actuated button which can generate haptic feedback to player as a dynamic difficulty adjustment system. We also detect the user's electrodermal activity (EDA), heart rate and acceleration data via embedded sensors in a game controller and use the gathered signals to detect their cognitive load level in real-time. The actuated button will be activated in an appropriate load level. An experiment was designed to observe how players performed at different levels of difficulty when using controller with actuated button. We try to evaluate whether this feedback helps to improve the player's sense of agency with the game character. And the experiment also helps to analyse the characteristics of the player's physiological data at different levels of difficulty. Results indicates a correlation between haptic feedback and sense of agency.

Keywords:

game difficulty, sense of agency, physiological sensor, entertainment, haptic

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Chapter 1
Introduction

1.1. Gaming Culture

Video games began to emerge as a commercial entertainment medium in the 1970s and became the basis of a major entertainment industry in Japan, the United States and Europe in the late 1970s. [1] After the two years following the 1983 recession, the video game industry experienced over two decades of growth, becoming a 10 billion dollar industry and competing with the television and film industry as the most profitable visual entertainment industry in the world. with online and smartphone games becoming popular worldwide, game is becoming not only game itself, but also a cultural symbol.

In 1983, the video game magazine Video Games Player stated that video games "are as much an art form as any" other field of entertainment.[1] Various studies have shown that it has had a profound impact on society, with negative views suggesting that it restricts the physical and mental development of young people; video games have become a common form of entertainment in people's lives.

Video game culture is a worldwide new media subculture formed by video gamers. As video games have exponentially increased in popularity over time, they have had a significant influence on popular culture. Video game culture has also evolved with Internet culture and the increasing popularity of mobile games. Many people who play video games identify as gamers, which can mean anything from someone who enjoys games to someone passionate about it. As video games become more social with multiplayer and online capability, gamers find themselves in growing social networks. Playing video games can both be entertainment as

1 "Video Games Player 1983 Golden Joystick Awards". Video Games Player. United States: Carnegie Publications. 2 (1): 49–51. September 1983

well as competition, as the trend known as electronic sports has become more widely accepted.

However, in recent years, many people around me have gradually stopped playing games, or their time playing games has gradually decreased. Some are because of the pressure of work and no extra time for playing games, and some turn their entertainment to live broadcast or short video, which is a better way to use fragmented time for entertainment.

1.2. Accessibility in Games

1.2.1 Time and Energy Demand

Individual and external influences push and pull on the amount of gaming. Shi et al. [2] gives a reason of some influences. In this study, some participants indicated that they stop playing game and try other activities which also offer the sense of challenge likes video games, such as making some food or dancing.

Nowadays, people's work is generally based on mental work and it is very intensive. In China, there is an expression called 996, which means working at 9am and leaving at 9pm every day, six days a week. And Japanese society has had a culture of work overtime for many years. Not only is the work intense, but the work is also very stressful.

Although playing game can make people get rid of work, it can just offer temporary relief from their negative emotions. Game should not be a way to address the problems they were facing. In Shi's study [2], someone thought at this moment, game "likes a drug" and "made them feel worse". If you think about the game and its progress, you'll be in a bad state of mind, which will affect your work.

Hellström et al. [3] examined the relation between gaming-time, motives to play, and negative consequences due to playing MMORPGs. The result showed that spending much time on game playing leads to negative consequences.

1.2.2 Game Difficulty

The difficulty of the game has been a hot topic of discussion for countless players. Many players have had the experience of giving up on a game because it was too difficult to play, or to understand.

In the 70's and 80's when arcade games were prevalent, the "difficulty of the game" was directly linked to the revenue of the arcade. [1] At that time, developers designed difficulty options for games, but unfortunately most players did not have the power to choose. The arcade halls would often quietly crank up the difficulty of the games to more efficiently earn the coins that players purchased.

In the subsequent Nintendo Family Computer era, due to the low storage limit of cartridges, the only way to make players feel they were getting their money's worth out of a game was to increase the difficulty of the limited game content to increase the player's play time, and the games of this period were almost always very difficult. That is why the word called "Nintendo hard".[2]

As technology has evolved, video games have become more popular and user-friendly, with more playable elements, more content and more diverse game systems. But the fact is that games now have extremely deep game systems and informative story, But it is this fullness of content that comes crashing down on the player and makes it daunting to fully digest all the game content for a while.

1.3. Game Companies' Effort to Attract New Players

1.3.1 Design New Hardware

Nintendo is a great example of this. They are always thinking of ways to bring a new gaming experience to players with new forms of gaming. To counter PlayStation Portable from SONY, Nintendo released the *Nintendo DS*[3] in 2004. Dual screens, touch, voice recognition, wireless connectivity with a more affordable price tag of 15,000 yen, it still looked relatively attractive.

The main feature of the new handheld was the touch screen design, targeting

2 WHAT IS "NINTENDO HARD"? https://web.archive.org/web/20110223221444/http://bnbgaming.com/2011/02/08/what-is-nintendo-hard/

3 Nintendo DS https://www.nintendo.co.jp/ds/

blue ocean users with a heterogeneous experience. As a result, Nintendo held "Touch!DS" events in Tokyo, Osaka, Nagoya, Fukuoka and Sapporo throughout November,[4] attracting a large number of young women who don't normally get into gaming.

DS is still aimed at the blue ocean market, with the launch of *nintendogs*[5] on 21 April attracting a large number of users, with the ability to interact with the cute pet on screen through screen touch, when ordinary electronic pets had no such appeal at all, and instantly demonstrating the vastness of the blue ocean market. *Brain Age: Train Your Brain in Minutes a Day!*[6], which was released on May 19, appealed to the non-gamer community of all ages.

Wii[7] has managed to open up the market to light gamers and many non-gamer user groups using a proven and inexpensive motion sensing game solution. It could partially accommodate traditional games and had software Wii Sports as well as Wii Play for show the Functionalities of everything. And later on *Nintendo Switch*[8], with the explosion of Ring Fit Adventure and so on, attracted a large number of new players.

1.3.2 Tapping into Female Gamer Market

In the 1990s, female gamers were a minority. However, female participation in gaming is increasing. According to an Entertainment Software Association survey, women players in the United States increased from 40% in 2010 to 48% in 2014. [4]

In Japan, the first "Otome Game" was "Angelique" released by Koei Tecmo Games in 1994. Around 2002, the term "Otome Game" started to spread, and with it, a variety of Otome Games were released. In 2008, a series of "Otome Games" were released, and many of them became Widely acclaimed. In 2011,

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4 `https://dengekionline.com/data/news/2004/9/10/0e34a36fefb9f5b949de44169e658246.html`

5 Nintendogs `https://www.nintendo.co.jp/ds/adgj/`

6 `https://www.nintendo.co.jp/ds/andj/`

7 `https://www.nintendo.co.jp/wii/`

8 Nintendo Switch `https://www.nintendo.co.jp/hardware/switch/`

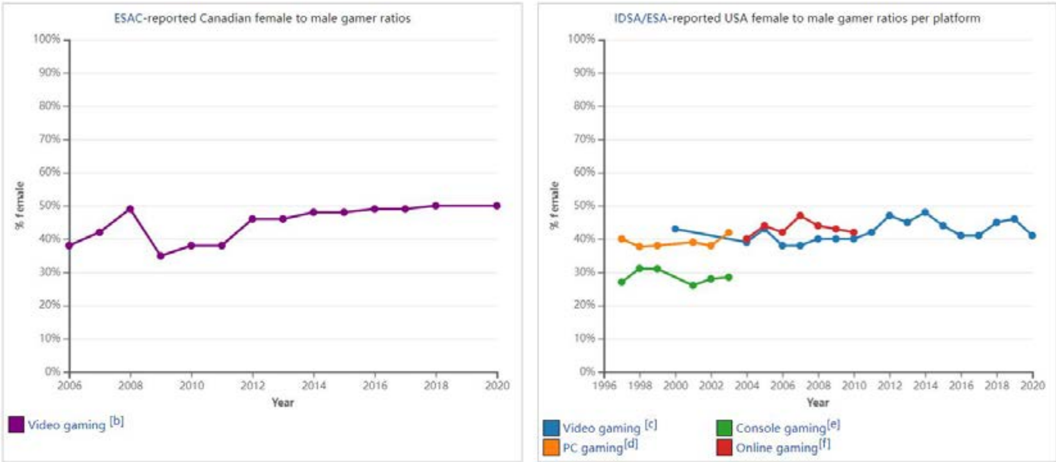


Figure 1.1 USA and Canadian female to male gamer ratios

the market size exceeded 14 billion yen, and not only games, but also goods, TV animations, movies, stage productions, and other media mixes have been made. [5]

1.3.3 Dynamic Difficulty Adjustment

The value of dynamic difficulty adjustment system is that it allows a wider players - from the professional players to the novices - to set the game experience in the "not too hard to overcome, but appropriately challenging and urgent ". This zone is also the zone where "player proficiency in game skill increases fastest" and "players are most likely to get into a state of flow".

The dynamic difficulty adjustment(DDA) system has two types: Short-term Thinking and Long-term results.[9]

Short-term DDA mainly ensures that players don't get lucky or unlucky all the time. It appears not to change the overall game difficulty, and more about making sure that the player does not experience long strings of luck (good or bad) from the game's random number generators (RNG).

9 More Than Meets the Eye: The Secrets of Dynamic Difficulty Adjustment `https://www.gamedeveloper.com/design/more-than-meets-the-eye-the-secrets-of-dynamic-difficulty-adjustment`

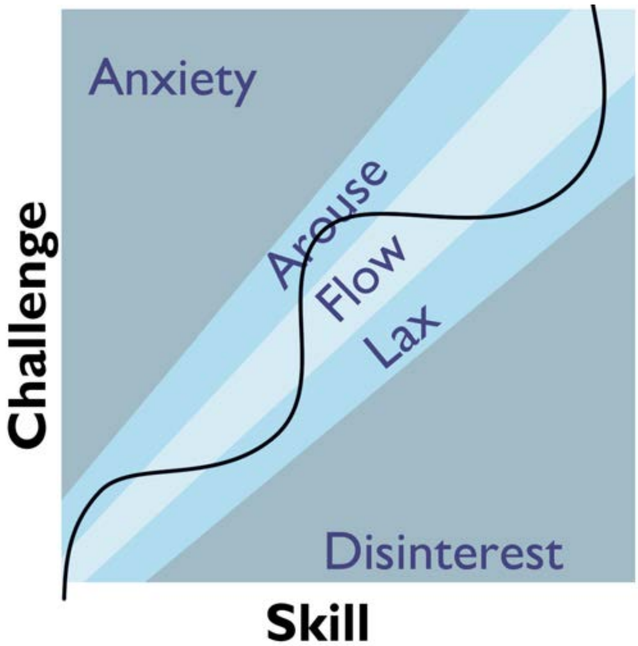


Figure 1.2 Game flow

The goal of the long-term DDA is to have the entire game world upgrade as the player performance. If the player plays well all the way through, the game will become high level and the difficulty will be corrected upwards, while if the player stumbles, the game will be lower level and the difficulty will be corrected downwards. "Resident Evil" have had DDA system from *Resident Evil 4*.[10]

During the course of the game, the system will give the player a rating (a hidden value, there are always 16 levels from 0 to 15) based on the player's performance in real time. Factors that affect this hidden value are: the player's hit rate, the frequency of damage taken, the number of enemies the player has killed, the number of continues, etc.; factors that affect this hidden value are: the enemy's strength, the enemy's attack power, the enemy's desire to attack, the location of the enemy, the player's attack power, the difficulty of the QTE, etc.

10 Resident Evil 4 https://store.steampowered.com/app/254700/Resident_Evil_4/

1.4. Sense of Agency

This experience of controlling one's own actions and, through them, the course of events in the outside world is called 'sense of agency'. It forms a central feature of human experience; however, the brain mechanisms that produce the sense of agency have only recently begun to be investigated systematically. Sense of agency refers to the feeling of controlling one's own actions and, through them, events in the external world. [6]

When a person takes the initiative to do something, he only feels that he is completing a task, but is not aware of the exact operational process of doing it. As an example, this sense of agency often occurs when one is sitting in the driver's seat and the driver completes a series of actions such as waiting for a red light, turning, changing lanes, etc., These operations do not make one think deeply about the process of the action.

Modern people spend a lot of time interacting with machines every day, whether for work or entertainment. However, people often don't spend much time thinking about how the interaction will work. Often, these interactions are ignored because the HCI designer has gone to great lengths to remove the rigidity from the interaction. User experience is at the heart of interface design, and this is where sense of agency comes in.

The process of playing the game itself works on the same principle. The player interacts with the characters in the game through their own control of the handles or keyboard and mouse. The player's ability to make the character act in the way he or she wants determines the experience.

1.5. Research Goal

When a player feels a game is too difficult, sometimes it is not because he thinks the game's mechanics too complex for him to calculate the best solution, but rather because the player cannot establish a good sense of agency with the game's characters. The lack of agency results in the player not being able to get the game's characters to act the way he wants them to.(Figure 1.3)

Therefore, increasing the player's sense of agency in controlling the character

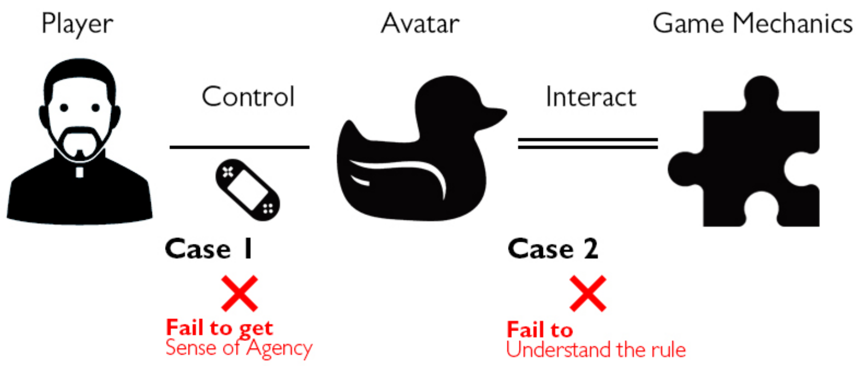


Figure 1.3 The reason making player feel difficult

is also a way to moderate the level of difficulty. To reach the goal, this thesis provides the following contributions:

- We designed a platform game with dynamic difficulty adjustment system.
- We designed and made a controller which can detect user's physiological data. An actuated button is also designed to make haptic feedback to player.
- We evaluated the sense of agency by the performance in gameplay and result of NASA-TLX questionnaire.
- We found that the game and controller system develop the sense of agency between the player and the character, and provide a new gaming experience for the player.

1.6. Thesis Structure

The paper consists 5 chapters. Chapter 1 provides the background which is needed to explain for the thesis. Chapter 2 introduces the research which is related to our work. Chapter 3 discusses the game difficulty problem and goal setting of our project, prototype design and user test for concept design. Chapter 4 presents

2 experiments to evaluate the design system developed in Chapter 3. Finally Chapter 5 provides a summary of the whole research.

Chapter 2
Related Works

2.1. Video Gaming

A video game or computer game is an electronic game that involves interaction with a user interface or input device, such as a joystick, controller, keyboard, or motion sensing device, to generate visual feedback. This feedback is shown on a video display device, such as a TV set, monitor, touchscreen, or virtual reality headset. Video games are often augmented with audio feedback delivered through speakers or headphones, and sometimes with other types of feedback, including haptic technology.[1]

2.1.1 Challenges in Action Games

The genre of games mentioned are defined by the core gameplay of the game (how the player interacts with the game) rather than visual or narrative. [7] For example, a racing game has a track as its main level and the player needs to complete the track as fast as possible as its goal. Therefore, either a normal racing game or a game with an animal racing theme can be classified as a racing game. [8]

Of course, not all games can be clearly categorised. Sometimes the genre classification can be vague and there can be a lot of subjectivity in classification. A individual game can belong to several game categories at once.

Action games in particular are a type of video game that emphasises the player's physical challenges and hand-eye coordination. Action games generally have a simple plot and can be played mainly by familiarising oneself with the operation.

1 https://en.wikipedia.org/wiki/Video_game

[8] Such as "Monster Hunter"[2] and "Bayonetta"[3].

The Monster Hunter series has never focused on plot, and it wasn't until Monster Hunter World that it began to increase the proportion of plot, but it remains a small percentage of the plot. Bayonetta doesn't even use cutscene for most of the plot, but simple still-frame images with voice acting. However, in contrast, the action systems in both games are very deep, with Monster Hunter having 14 different kinds of weapons. each with a separate action system and special mechanics. Bayonetta having a pioneering 'Witch Time' and 'Holding' system to complement the action elements, in addition to the basic action game mechanics system.

Action games are one of the first and most common type of games. The game provides an environment in which the player must control the character and react to changes in the environment, such as moving, jumping, attacking, etc. to achieve the goal designed in the game. The important thing is to design the whole game process exciting and smooth. With the gameplay, content becomes more complex and varied.

2.1.2 Player Classification

Bartle Taxonomy of Player Types

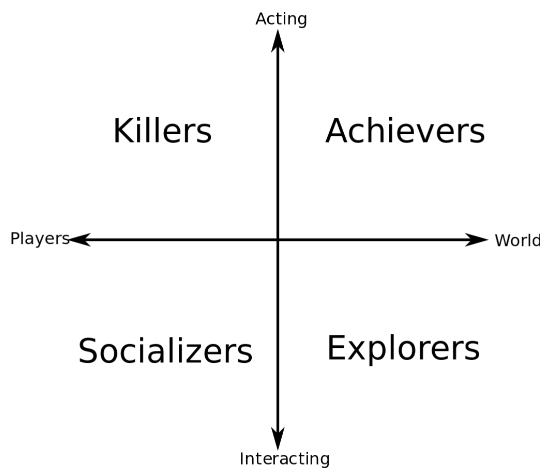
The Bartle taxonomy of player types is a classification of video game players based on a 1996 paper by Richard Bartle [9] according to their preferred actions within the game. The classification originally described players of multiplayer online games (including MUDs and MMORPGs), though now it also refers to players of single-player video games.

Bartle divides players into four categories.

- `Achievers:` A focus on attaining status and achieving preset goals quickly and/or completely. Achievers want elite status, and the ability to show it off.

2 `https://www.capcom.co.jp/monsterhunter/rise/`

3 `https://www.nintendo.co.jp/bayonetta/`



(Source: Bartle Taxonomy of Player Types [9])

Figure 2.1 Bartle Taxonomy of Player Types

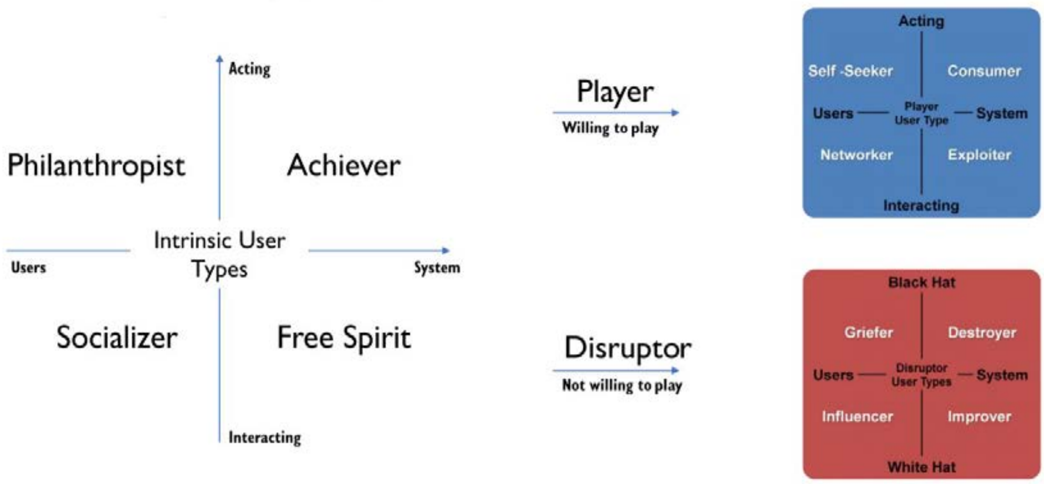
- `Explorers:` A focus on exploring and a drive to discover the unknown. Explorers want to go where no one else has gone and know what no one else knows.
- `Socialisers:` A focus on socialising and a drive to develop a network of friends and contacts. It doesn't matter what they do, as long as they do it with friends.
- `Killers:` A focus on winning, rank, and direct peer-topper competition. It's all about "beating" another human.

Player classification is critical to both the analysis of physiological data and the analysis of player behaviour. Even if two players are given the same experimental data, the meaning of the data may change if they are different player types. If a player is Socialisers, he/she may not be interested in the design of the level and have no desire to 'Acting' when playing the game we designed.

The HEXAD Gamification User Types

The HEXAD gamification user types are attempting a segmentation of users based on their receptivity to varying gamification strategies. The underlying model is based on research on human motivation, player types, and years of practical design experiences. This model presents the first typology to classify users of gamified systems, enabling clustering them based on intrinsic and extrinsic motivational factors. The HEXAD model is comprised of the following six gamification user types: Socializers, Free Spirits, Achievers, Philanthropists, Players, and Disruptors. [10]

The study points to the existence of players not willing to play games. They do not care about their performance in the game and have no desire to keep playing. Therefore, their measured physiological data at different levels of difficulty may not yield significant results.



(Source: The HEXAD gamification user types [11])

Figure 2.2 HEXAD gamification user types

Game Player Motivations

Adapted from Bartle, the four quadrants–immersion, achievement, cooperation and competition–shape how players interact with a game, and also come into play in how consumers engage with a company. [12]

In this context, the motivation for "Achievement" was interpreted as Mastering skills. This is related to flow theory, which approaches the idea that people become happier when they apply their skills and become absorbed in them.

(Source: Game player motivations from Jon Radoff [12])

Figure 2.3 Game player motivations

2.1.3 Societal Impact of Video Games

Over time, games have become popular worldwide and have had a major impact on people's lives. Many people who play games consider themselves as gamers. The development of hardware has also allowed multiplayer games to evolve. Online-games become more social, gamers find themselves in growing social networks. Playing video games can both be entertainment as well as competition, as the trend known as electronic sports has become more widely accepted.

However, there is a lack of full understanding of exactly how gaming affects people's daily lives. Shi et al. [13] aims to gain a more holistic understanding of the activities in the daily lives of problem gamers; particularly, what is important to them, what motivates gaming, and what supports/constraints engagement in other life activities. Video gaming offered both positive and negative experiences in gamers' lives. The negative experiences mainly resulted from using video games as a coping strategy for other life stressors. Second, individual, interpersonal, and environmental influences acted simultaneously to push and pull on the amount of gaming. The push and pull influences on the amount of gaming can occur in real-life or virtually. Assistance for problem gamers could include minimizing/removing the pull forces and obtaining adequate push forces to enable their desired participation in daily activities.

Some researchers are also concerned that gaming can have a negative impact on life. Barlett et al. [14] focused on the negative and positive consequences of exposure to violent and non-violent video games. The negative consequences included a desire for aggression, aggressive behaviour, while the positive effects included various types of learning. The study showed that the number of negative effects outweighed the positive outcomes.

Przybylski et al. [15] studied the reasons why players play games and proposed a model of motivation to play games. Also, they evaluated players' motivation and enjoyment of playing games. Johannes et al. [16] collaborated with two games companies, Electronic Arts and Nintendo of America, to obtain players' actual play behaviour. They investigated the happiness and well-being of the players in *Plants VS. Zombies: Battle for Neighborville* and *Animal Crossing: New Horizons* for their well-being. Contrary to the notion that many people think that playing games leads to negative effects such as addiction or mental illness, the study proved some positive correlations between gaming and well-being.

2.2. Engagement State in Game

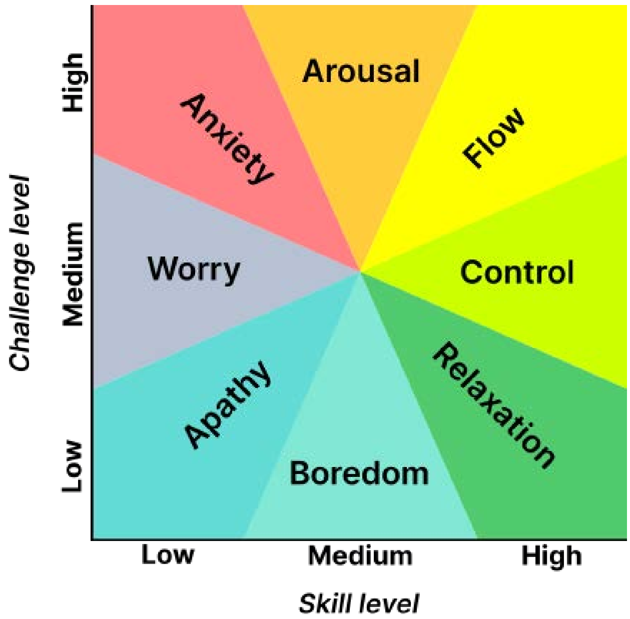
2.2.1 Flow Theory

Flow theory is widely used in game design. Studying video game experience often rely on the multi-dimensional construct from Flow. Flow is described by Csikszentmihalyi to be the state of optimal or "peak" experience.

In positive psychology, a flow state, also known colloquially as being in the zone, is the mental state in which a person performing some activity is fully immersed in a feeling of energized focus, full involvement, and enjoyment in the process of the activity. In essence, flow is characterized by the complete absorption in what one does, and a resulting transformation in one's sense of time. [17]

Jeanne Nakamura and Csíkszentmihályi [19] identify the following six factors as encompassing an experience of flow:

- Intense and focused concentration on the present moment
- Merging of action and awareness
- A loss of reflective self-consciousness



(Source: According to Csikszentmihalyi's flow model [18])

Figure 2.4 Mental state in terms of challenge level and skill level

- A sense of personal control or agency over the situation or activity
- A distortion of temporal experience, as one's subjective experience of time is altered
- Experience of the activity as intrinsically rewarding, also referred to as autotelic experience

2.2.2 Flow Theory in Game Design

The main movements of the game comes from the player's intrinsic motivation to perform tasks and get feedback through action, which is closely related to the theory of flow.

The video game *flOw* was designed as part of Jenova Chen's master's thesis for exploring the design decisions that allow players to achieve the flow state, by adjusting the difficulty dynamically during play.

Figure 2.5 flOw PS3/PS4 2007

Chen thinks a well-designed game transports its players to their personal Flow Zones, delivering genuine feelings of pleasure and happiness. [20] He believes that in order to provide an enjoyable interactive experience for the widest group of gamers, the design of a game should follow four steps:

- Mix and match the components of Flow
- Keep the user's experience within the user's Flow Zone

- Offer adaptive choices, allowing different users to enjoy the Flow in their own way
- Embed choices inside the core activities to ensure the Flow is never interrupted

The game is designed of flow theory for education field. Hamari et al. [21] investigate the impact of flow, engagement, and immersion on learning in game-based learning environments. The results show that engagement in the game has a clear positive effect on learning, however, we did not find a significant effect between immersion in the game and learning. Challenge of the game had a positive effect on learning both directly and via the increased engagement.

Generally, high-school students have been characterized as bored and disengaged from the learning process. However, certain educational designs promote excitement and engagement. In a study, the concept of flow is used as a framework to investigate student engagement in the process of gaming and to explain effects on game performance and student learning outcome. [22] Frequency 1550, a game about medieval Amsterdam merging digital and urban play spaces, has been examined as an exemplar of game-based learning. Generally, these students show flow with their game activities, although they were distracted by solving problems in technology and navigation. Flow was shown to have an effect on their game performance, but not on their learning outcome. Distracting activities and being occupied with competition between teams did show an effect on the learning outcome of students: the fewer students were distracted from the game and the more they were engaged in group competition, the more students learned about the medieval history of Amsterdam.

As Chen mentions [20], to get players into a state of flow or keep them interested in playing a game on an ongoing basis, this is usually done using dynamic difficulty adjustment system in the game mechanics.

2.2.3 Dynamic Difficulty Adjustment in Game

Conventional wisdom suggests that while players enjoy unpredictability or novelty during gameplay experiences, they will feel "cheated" if games are adjusted during or across play sessions. In order for adjustment to be effective, it must be performed without disrupting or degrading the core player experience. Robin Hunicke [23] examines basic design requirements for effective dynamic difficulty adjustment (DDA) given this constraint, presents an interactive DDA system (Hamlet), and offers preliminary evaluation results which challenge common assumptions about player enjoyment and adjustment dynamics.

As I mentioned in Chapter 1, a lot of companies have already designed the dynamic difficulty adjustment. Game companies are often limited to changing the difficulty by modifying the game values within the framework of the game mechanics. There are usually two ways of doing this: one is based on the player's performance in the game, such as how often they take damage, how many supplies they have, etc. The other is to let the player choose the difficulty of the game before the game starts, such as easy, medium, hard, etc.

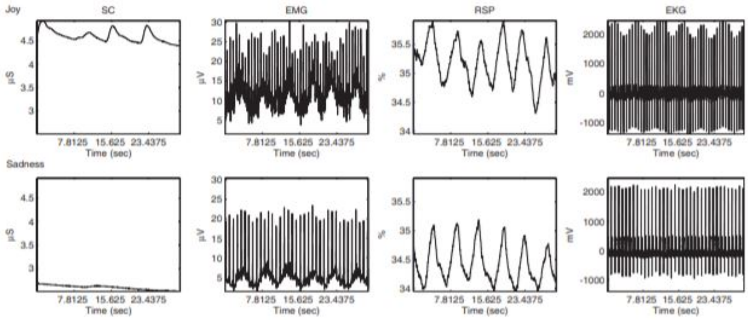
However, to give the player a more engaging experience through dynamic difficulty levels, it is necessary to measure the player's body data to reflect the player's mental state during the game.

2.3. Biofeedback

Biofeedback is to use devices that measure human physiological signal to understand more about how people's minds work and to improve them, such as electromyogram, skin conductance, and heartbeat.

Wagner et al. [24] discuss the most important stages of a fully implemented emotion recognition system including data analysis and classification. For collecting physiological signals in different affective states, we used a music induction method which elicits natural emotional reactions from the subject. Four-channel biosensors are used to obtain electromyogram (EMG), electrocardiogram, skin conductivity and respiration changes.

Biofeedback also used in research for determine the mental status when playing games. Chanel et al. [25] proposed to maintain player's engagement by adapting game difficulty according to player's emotions assessed from physiological signals. The validity of this approach was first tested by analyzing the questionnaire responses, electroencephalogram (EEG) signals, and peripheral signals of the players playing a *Tetris* game at three difficulty levels.



(Source: Wagner J.'s thesis)

Figure 2.6 An example of data collected from four sensors in two affective states: joy (top) and sadness (bottom).

2.4. Sense of Agency

2.4.1 Definition of Agency

Sense of agency refers to the subjective awareness that one is initiating, executing and controlling one's volitional actions in the world. [26] It is the pre-reflective awareness or implicit sense that it is "me" who is actually executing bodily movement or thoughts.

If someone else were to move your arm (while you remained passive) you would certainly have sensed that it were your arm that moved and thus a sense of ownership for that movement. However, you would not have felt that you were the author of the movement; you would not have a sense of agency. [27]

The concept of personal agency refers to the capacity to make decisions and have a role in the direction of one's life.

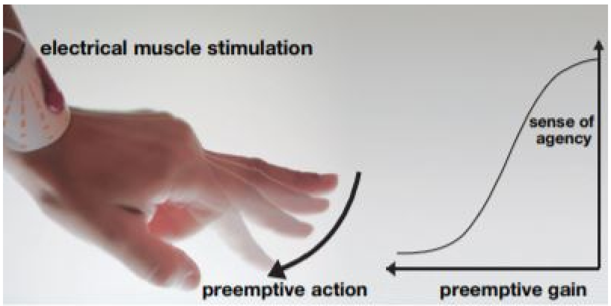
Significant research in a number of disciplines centers on the concept of the sense of agency. Because many of these studies cut across disciplinary lines there is good reason to seek a clear consensus on what 'sense of agency' means. Someone try to make a definition about sense of agency. Gallagher [28] indicate some complexities that this consensus might have to deal with. He also highlight an important phenomenological distinction that needs to be considered in any discussion of the sense of agency, regardless of how it gets defined.

2.4.2 Mechanics of Agency

Moore et al. [29] investigated the processes underlying the feeling of control over one's actions ("sense of agency"). Sense of agency may depend on internal motoric signals, and general inferences about external events. We used priming to modulate the sense of agency for voluntary and involuntary movements, by modifying the content of conscious thought prior to moving.

Some researchers believe that the lack of a sense of agency may be a key cause of some mental illnesses. In psychopathology, Moore et al. [30] indicated that sense of agency is a compelling but fragile experience that is augmented or attenuated by internal signals and by external cues. A disruption in sense of agency may characterise individual symptoms of mental illness such as delusions of control.

Studying the trigger conditions for the sense of agency also helps to facilitate human-computer interaction. Kasahara et al. [31] enabled preemptive force-feedback systems to speed up human reaction time without fully compromising the user's sense of agency. When the user and system move congruently, the user feels that they initiated the motion, yet their reaction time is faster than usual.



(Source: Kasahara's study)

Figure 2.7 Relationship between a user's agency and the preemptive gain

In gameplay, generally having the sense of agency with your avatar costs players a great deal of time. As the research Kasahara did, if it is possible to create the connection between players and avatar by some way to increase agency. It should be a new way for dynamic difficulty adjustment.

2.5. Summary

In all the current research, there is little to no research on how the sense of agency works in gameplay. However, the player's sense of agency while playing directly affects the game experience. The research about the immersive game experience has often been conducted on the premise that players are already familiar with the operation of the game and can give commands to the game characters proficiently, and has not focused on the issue of sense of agency.

I argue that players may not feel difficulty in action games simply because the difficulty value of the game is too high, but rather because the player is unable to manipulate the game character well. This study attempts to determine the player's emotions through the player's physiological data. If the player shows uneasiness and nervousness, it does not reduce the difficulty of the game from the numerical system but enhances the sense of agency through the haptic feedback of the controller, which is a way to improve the player's gaming experience.

Chapter 3
Concept Design

3.1. Phenomenon and Our Mission

In recent years, the image progressing technology of games has developed rapidly, which can help us experience the game like watching a movie. Many people would rather just watch the game content on YouTube than experience it by themselves. Ever since Twitch was acquired by Amazon, it has been a great place for gamers to watch games. In 2019, twitch attracted 17.5 million daily subscribers and over 600 billion minutes of game viewing on the platform.[1]

One study suggests that gamers choose to watch other people play games as a learning behaviour. [32] This study was analysed specifically for Twitch users, and according to user reports, players learn new ways of playing games by watching others play, and can also decide whether they want to buy a game based on its content. In addition, people who watch live streams form a online community, and the longer they watch a stream the more likely they are to interact in the online community.

There is a big difference in terms of experience between watching someone else play a game and playing it yourself. There is no way to experience the sense of achievement when completing a challenge just by watching someone else play. The goal of this study is to moderate the difficulty of the game through sense of agency to give players more confidence to complete the challenge and enhance their gaming experience.

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1 https://theconversation.com/crucible-the-science-behind-why-watching-others-playing-video-games-has-become-so-popular-139190

3.2. Pilot Survey

To find out what players really think, I created a questionnaire about action games.

The questionnaire was placed on the Internet in Japan and China and received a total of 149 responses. The response rate in Japan was 52%. Responses were mainly from students and young people in urban areas.

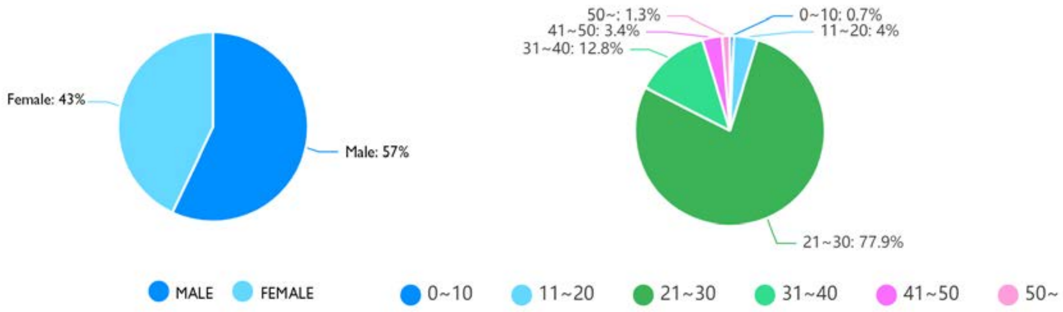


Figure 3.1 Participants Information

According to Bartle Taxonomy of Player Types [9], unlike my expectation that most game players are *Socializer*, 58.4% of the players consider to be *Achiever*.

3.2.1 Action Game Experience

Meanwhile, regarding action games, most of people think they enjoy playing action games, even if there are many who are not confident that they can play the game well. Also, close to 80% of players have experienced a great sense of achievement in an action game for completing some kind of challenge. For example, get a higher score or beat a monster.

3.2.2 Watching Game or Playing Game

The core questions in this questionnaire were the following two:

- Which do you prefer, watching others play or playing yourself?

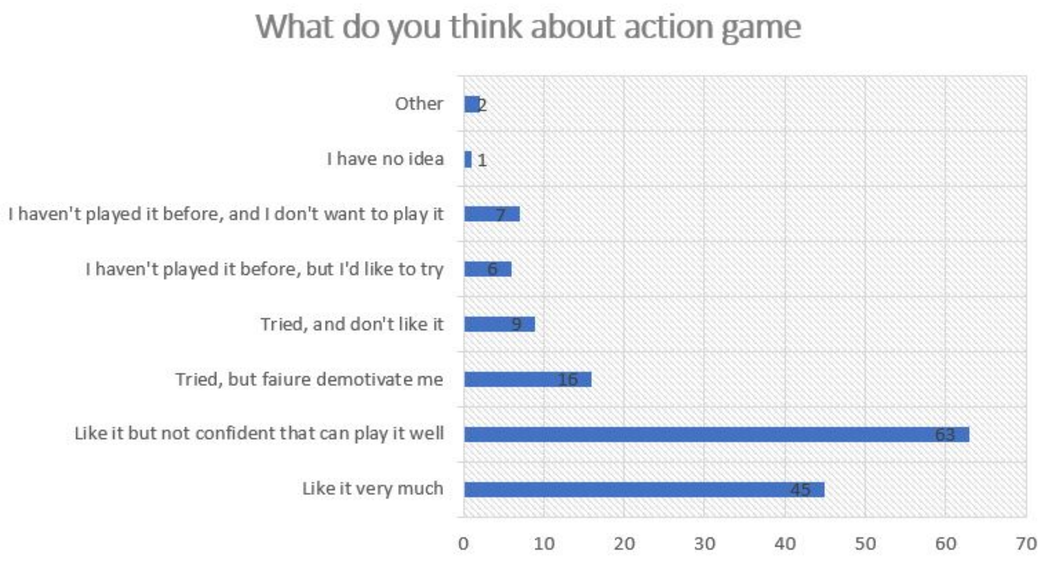


Figure 3.2 What do you think about Action Game?

- Do you think you can to get the same pleasure from watching and playing?

More than 75% of players believe that they get different enjoyment from watching others play the game than they do by themselves. And 65% of players think they prefer playing the game themselves to watching someone else play.

A number of players mentioned the sense of experience and accomplishment. "The difference between watching and playing by yourself is whether there is a sense of achievement"; "I don't really like playing games, I'm fine playing a bit by myself, watching others play feels boring and a waste of time"; "The pleasure of watching others play comes mainly from admiring them, while the pleasure of playing by myself comes mainly from the sense of achievement". "Playing on your own requires you to make it, and there is the great sense of achievement that comes from succeeding one attempt at a time."

There are also players who care about the process of the game and they enjoy overcoming the difficulties. "Watching other people play without thinking the details, or equipment and so on, just by looking at the screen; playing on my own allows me to understand the details of each part more completely, and I can dig out my own game style"; "Other people make choices or skills in the game that are different from mine, so it seems to be useless for me".

Figure 3.3 Two Core Questions

Many players have mentioned how much they enjoy the feeling of challenge and the exhilaration of overcoming difficulties in an action game, but many have also said that the game is too difficult and that they easily lose confidence. To reduce players' frustration, we hope to develop a more reasonable difficulty curve based on each player's own situation to help them complete the challenge.

3.3. Initial Prototype: relationship between EDA and game difficulty

3.3.1 Concept Design

The ultimate aim of this study is to be able to determine the psychological state of the player based on the physiological data to adjust the difficulty level in sense of agency. However, in the beginning, it was necessary to understand how physiological data and game difficulty relate to each other.

Detecting the player's physiological data in video games to adjust the difficulty of the game in real time. The prototype uses electrodermal activity (EDA) [33] to determine the player's emotions while playing a platform game and adjust the difficulty of the game as feedback.

Figure 3.4 Game Difficulty Adjustment System

The game adapts its difficulty to the player's emotion to keep the player in a constant state of excitement, where they can immerse themselves in the experience and even reach a state of flow.

3.3.2 Game Design

This game was developed on the Unity engine[2]. The game was created by using the material of 2D Game Kit[3].

The game character will appear in the middle of the screen. As the game start, the character automatically starts to move to the right. At the same time, platforms will be created for character to stand on.

Figure 3.5 Game and Level (Difficulty: Lv.2)

2 Unity https://unity.com/

3 2D Game Kit https://assetstore.unity.com/packages/templates/tutorials/2d-game-kit-107098?locale=ja-JP

The control of the character are similar to 2D Super Mario.[4] Player need to jump from platform to platform without falling off. As the character will be forced to move all the way to the right, only the player needs to do is press the jump button at the right time to make sure they don't lose.

The platforms are randomly generated, but the way they are generated is related to the difficulty level of the game. In the game system, there is a difficulty value which ranges from 0 to 30. When the difficulty is 0, the game will always generate flat land and the player will never die from falling. As the difficulty level gradually increases, the platforms will be separated, the width of the platforms will become narrower, the gap between platforms will become larger and the height difference between platforms will become larger.

As a result, when the game becomes more difficult, the player is faced with more complex levels of play. However, the minimum length of the platforms will not be less than 3 units each. And the maximum length of the gaps will not exceed 5 units, otherwise the player will not be able to jump through them successfully.

3.3.3 Difficulty and EDA Signal

The difficulty of the game is determined by the player's EDA level. *Grove - GSR Sensor*[5] is used to measure the player's EDA, which increases when the player's skin is dry and decreases when the player sweats more. The game's difficulty values are linearly mapped to the EDA values, which range from 0 to 700. So, the 700 value range is divided into 30 segments, with each segment increasing in difficulty by one level.

3.3.4 Experiment Procedure

The whole experiment is divided into 3 parts. First, the player needs to familiarise himself with the game, this is a practice section. In this section, the difficulty of the game is controlled at a constant level of 5. After this, Two sections is set for

4 `https://topics.nintendo.co.jp/article/5d6e9160-06ba-4341-b081-331de6756497`

5 `https://wiki.seeedstudio.com/Grove-GSR_Sensor/`

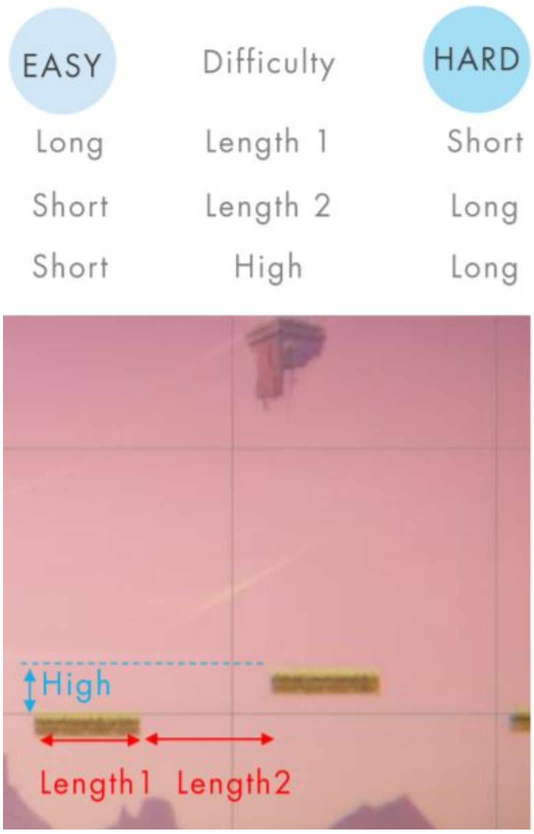


Figure 3.6 How Platforms Are Generated?

Figure 3.7 Game Level with difficulty lv.24

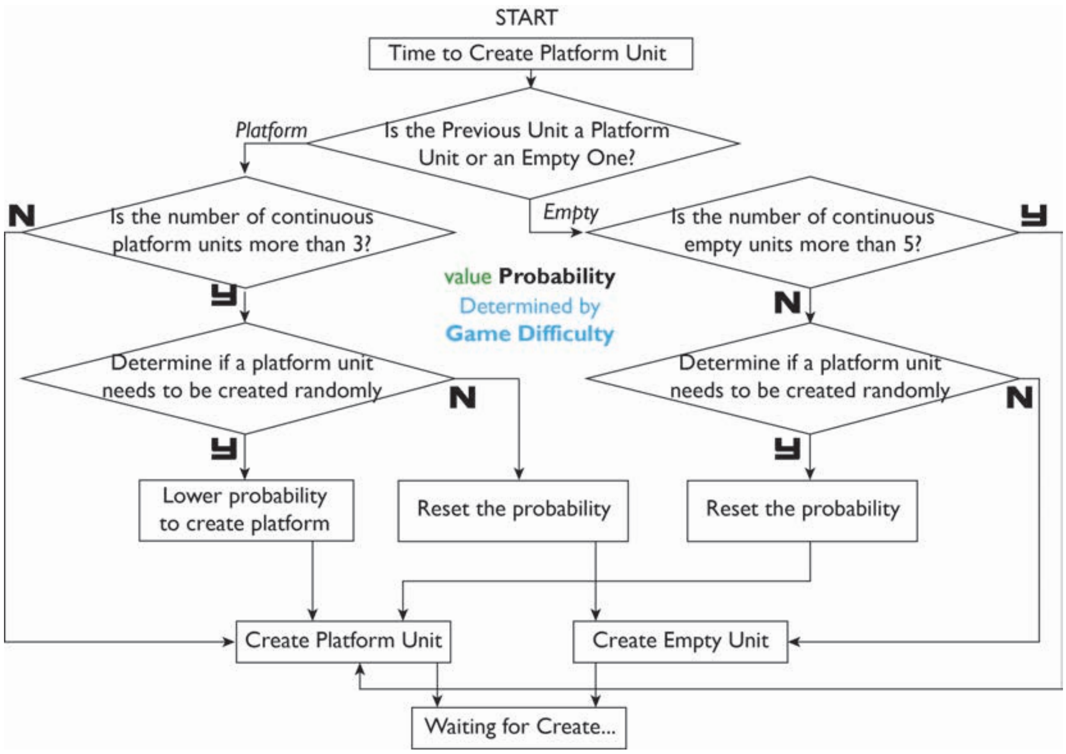


Figure 3.8 Platform Generation Logic

the main experiment. In one section, the game automatically adjusts its difficulty level according to the user's EDA value. In the other, the difficulty is kept at a constant difficulty level of 15. Each section is played three times, and the order of the second and third section is randomised. When the second or the third section have been completed, the player is required to take a questionnaire.

Arduino UNO[6] is used to receive the data from *Grove - GSR Sensor* and send it to the computer for changing difficulty.

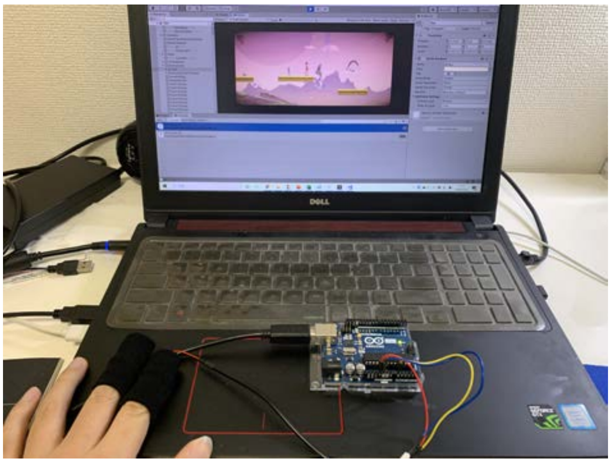


Figure 3.9 Playing with GSR Sensor

In the questionnaire, the participant is asked questions in two aspects. The first is about the difficulty of the game. The experimenter is asked to self-evaluate their own level of game-play and to rate the difficulty of this game. The second part is related to the player's emotional state. Players were asked to rate their feelings during the game on four dimensions: fatigue, concentration, effort and stress.

3.3.5 Result

There were five participants in this experiment. Table 3.1 recorded the playing time of the player's game. The value which is less than 60 seconds were those cases that player died in the middle of the game. Table 3.2 records the results of

6 Arduino UNO `https://store-usa.arduino.cc/products/arduino-uno-rev3/`

Info.				Game-play			
Participant	Sex	Age	Game Skill Level	Game with DDA	First	Second	Third
Participant 1	M	25	5	Yes	60	60	60
				No	60	37.22	60
Participant 2	F	23	1	Yes	51	60	60
				No	8.53	14.71	60
Participant 3	M	25	4	Yes	60	60	60
				No	54	60	57
Participant 4	F	23	2	Yes	60	55.39	11.49
				No	20.11	60	60
Participant 5	F	22	5	Yes	60	60	60
				No	4.01	60	60

Table 3.1 Result of Game-play

the player's questionnaire.

Comparing the data of the two sections, the dynamic difficulty level is much easier than the static difficulty model. Hence, it is difficult for the experimenter to notice the changing. Another point is the higher the difficulty of the game, the higher the concentration and effort level players have.

According to the EDA data, after playing the game for a long time, the value of EDA gradually decreased. The decrease in the player's EDA values was smaller in dynamic difficulty than in static difficulty, and it can be inferred that the change in the player's mindset may be smaller in dynamic difficulty situations than in static difficulty. However, it is hardly proves that players can have a better gaming experience on dynamic difficulty with these data.

Participant	Emotion Status When Playing				
Participant	Game with DDA	Fatigue	Concentration	Effort	Stress
Participant 1	Yes	1	3	2	2
	No	1	5	2	4
Participant 2	Yes	1	3	1	2
	No	1	4	4	1
Participant 3	Yes	3	6	5	3
	No	2	6	5	2
Participant 4	Yes	2	4	3	5
	No	2	4	5	5
Participant 5	Yes	1	2	2	1
	No	1	1	2	1

Table 3.2 Result of Questionnaire

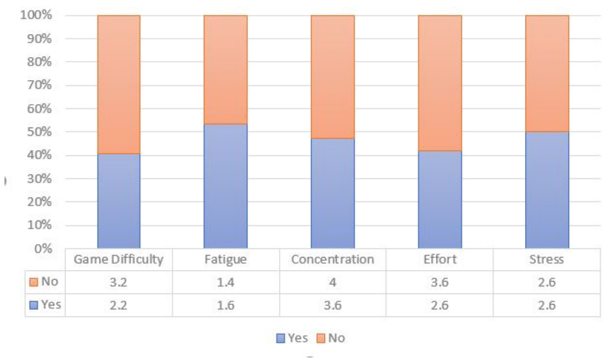


Figure 3.10 Comparison averages value of questionnaire between dynamic and static difficulty

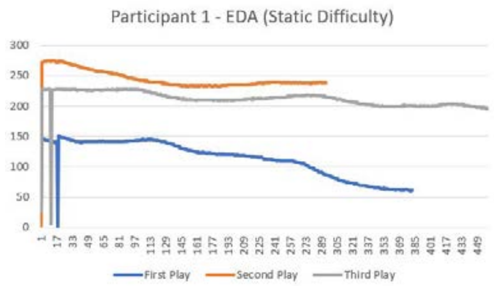


Figure 3.11 Static Difficulty

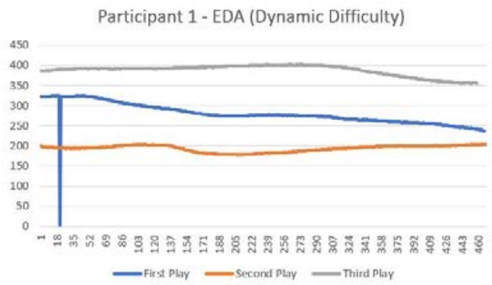


Figure 3.12 Dynamic Difficulty

3.4. Second Proposal: Platform Game with Self-Determination Theory

3.4.1 Concept Design

In the first prototype, only one device, the EDA, was used to measure physiological data, which did not provide a good grasp of the human psychological condition. The dynamic game difficulty system also lacked a theoretical basis. The relationship between the player's physiological data and difficulty needed to be further explored.

The second proposal, I have improved the game system by using self-determination theory [34] to allow players to choose whether the game can be made harder or easier. In the previous prototype, the device for measuring EDA needs to be worn on two fingers for detecting data, which is very inconvenient for playing games. To obtain better data and to allow players to use the controller playing without having to spend time wearing the device, I designed a controller that can measure physiological data.

The goal of second study is to understand the correlation between the player's physiological state and their intention towards changing the game's difficulty level.

3.4.2 Game with Self-Determination difficulty System

As well as the previous one, the core mechanic of the game is still jumping. The game will keep track of the player's position in real-time, generating platforms on the far right of the screen at each time when the player moves one unit to the

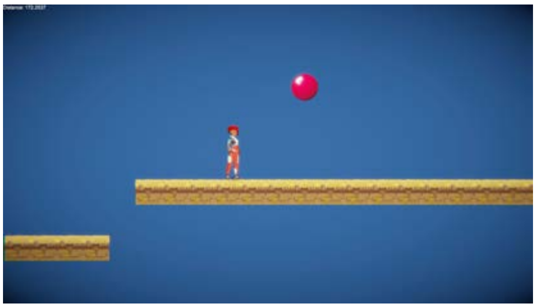


Figure 3.13 Red Ball

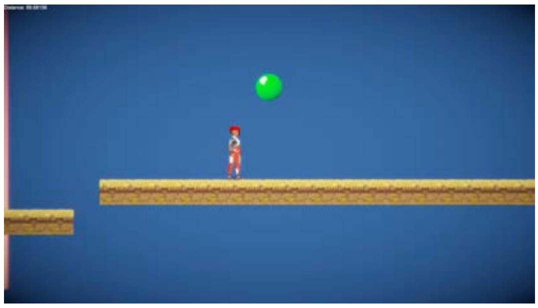


Figure 3.14 Green Ball

right. In this game, the character will no longer be forced to move to the right forever. Instead, the player will have full control of the character's movement.

In the first prototype, the game difficulty changes depending on the data of EDA value. In this prototype, the game's difficulty system will leave it up to the player to decide how difficult the game is.

At each fixed distance in the game, a difficulty ball is generated, which appears on a longer platform for the player to safely touch it. The difficulty ball is slightly taller than the character's height, so the player can choose whether or not they need to jump to touch the difficulty ball. Once the ball is activated, it disappears and the difficulty of the game changes.

There are two types of difficulty balls: red and green. Touching the red ball will make the game more difficult, touching the green ball will make it less difficult. The difficulty range is still from 0 to 30. When a red ball is touched, the relationship between the original difficulty (D_p) and the current difficulty (D_u) is as follows.

$$D_u = D_p + (30 - D_p)/6.$$

When the green ball is activated, the current difficulty(D_d) is calculated as follows.

$$D_d = D_p - D_p/6.$$

Division operations are rounded-up to the closest integer, so each time the difficulty ball is touched, the difficulty changes by at least 1.

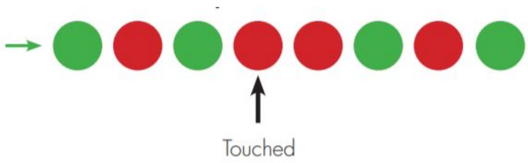


Figure 3.15 When a difficulty ball is touched

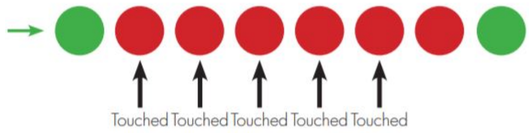


Figure 3.16 Easy for reaching appropriate level

The initial difficulty of the game is set to 5. Every time the player moves 70 units to the right, the system offers a difficulty ball. The first ball that appears must be green. After this, the red and green balls will alternate. Once the player has activated a ball, the next ball that appears will be the same colour as the one was touched. This is designed to make it easier for players to quickly increase or decrease the difficulty to a level appropriate to them.

3.4.3 Controller with Physiological Sensor

I have designed a controller prototype. The internal circuit board of the controller uses an existing product. But the original case do not have enough space for putting sensor inside.

I designed an embedded controller to record the player's physiological data. Three sensors are placed in the controller. The heartbeat sensor is placed on the left handle of the controller so that when it is held, the ring finger just touches the sensor. The EDA sensor is placed on the right side of the handle, with two metal tabs protruding from the handle to measure changes of skin resistance in real-time. The pressure sensor is placed on the R1 button which is used for jumping. This measures the amount of pressure applied to the button by the player during each jump operation.

The data from sensors is passed through the Arduino, into the computer and in Unity, the system saves the physiological signal as a CSV file. The data being saved is as follows.

- Heartbeat Raw Data
- EDA Raw Data
- Pressure Data from Button R1

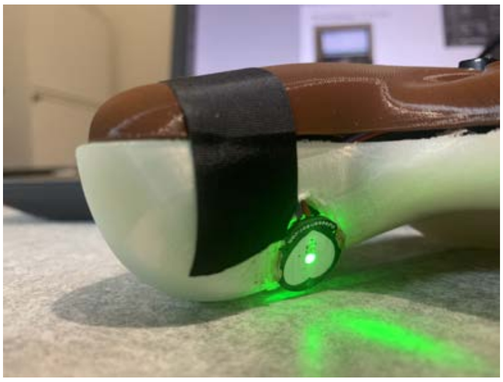


Figure 3.17 Heartbeat Sensor

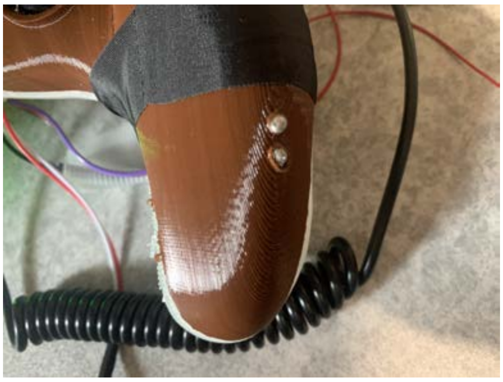


Figure 3.18 EDA Sensor

- The time Red Ball is activated
- The time Green Ball is activated

3.4.4 Experiment on Exhibition Area

The games and grips were exhibited at an exhibition area. During the two-day exhibition, many user data and feedback were collected.

The system will record the distance the player has moved as a score. If the player falls from the platform, the game is over. The participants can try the game for several times.

We asked different players to self-evaluate their level of game-play and let them play the game. Based on the results of the questionnaire and their performance, there was a significant difference between the players' understanding of the game. For professional players, they can figure out how to play the game in a short time. However, by observing the performance of novices, they tend to make mistakes over and over again for the same reasons, for example, in this experiment, mistakes often stemmed from not being able to find the right time to jump. Novice player cannot easily feel controllable to the avatar.

There exists a gap between professional players and novice players in terms of the overall game mastery. Professional players can grasp a game-play mechanic much faster, whereas a novice player tends to make repeated mistakes initially.

Figure 3.19 The Exhibition

3.4.5 Result

The experimental was conducted over two days at a semi-public exhibition space. All visitors were able to take part in this test. The same spectator could also try it several times. A total of 224 data were received, of which 48 were valid.

From the figure 3.20(b), the cyan curve at the top represents the player's EDA level. The blue curve at the bottom is the player's heartbeat data, and the yellow line shows the timing and pressure of each press of the player's jump button. The value of pressure will get lower if the JUMP button is pressed harder. There are also red and green vertical lines in the graph, which indicate the moments in the game when the red and green difficulty balls are activated respectively.

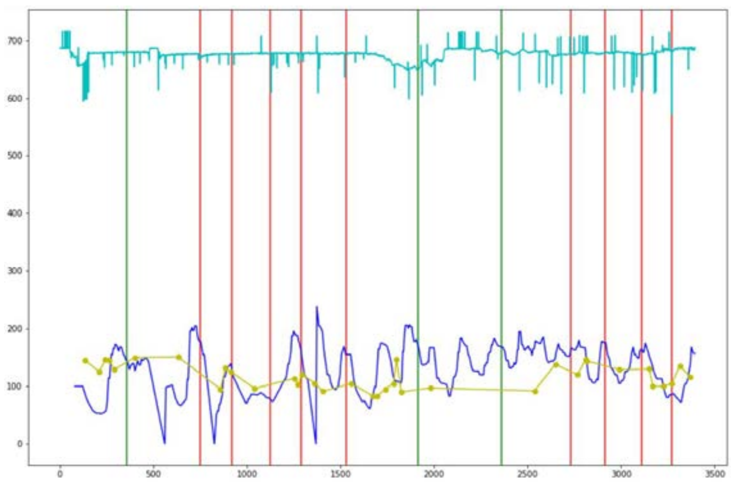
The value of EDA gradually decreases over a period of time. When the player makes the game harder, the EDA signal has no significant change. When the player makes the game easier, the EDA signal tends to fluctuate and sometimes a little lower than usual. The BPM is often in a high level. The value of pressure seems to be not related to the difficulty changing.

3.4.6 Limitation

There were also some issues that arise from the study.

44	GSR	653
45	GSR	652
46	GSR	652
47	GSR	653
48	GSR	667
49	GSR	677
50	GSR	679
51	Pressed	145
52	GSR	662
53	GSR	646
54	BPM	111
55	GSR	638
56	GSR	634
57	GSR	641
58	GSR	648
59	GSR	651
60	GSR	652
61	Pressed	118
62	GSR	653
63	GSR	652
64	GSR	652

(a) Raw Data



(b) Line Chart

Figure 3.20 Result of Data

Some players didn't finish the game. Sometimes, the BPM data was noisy because the participant could not keep their finger on the heartbeat sensor all the time. Some players also played the game without reading the direction sheet. They continuously touch the green ball just because it appeared.

So, it is necessary to improve the controller by moving the heartbeat sensor to the bottom and detecting the signal from the middle finger which used to support the controller to get more consistent data.

3.5. Third Proposal: Final Game and Controller Design

3.5.1 Concept Design

By knowing the correlation between difficulty and physiological data, The final study is try to find a way to improve player's sense of agency. Controller can work as a media to give a hint when it is the right time to jump, which can help players, especially novices, to manipulate avatars better.

3.5.2 Final Game Design

According to previous feedback from players, the game is not difficult enough and some participants who play games regularly were able to stabilise the highest difficulty of the game after several practice sessions. On the other hand, the game does not give specific goals, such as how far to jump forward. A scoring system could also be used to evaluate the player's performance, which would help increase the motivation to continue playing.

The design of the game this time around is still based on the previous level design, but with many new elements added.

Character Movement

The character movement system goes back to the original mechanics. Each time the game starts, the character is set in the centre of a long platform and automatically moves to the right. The player cannot control the horizontal movement of the character. However, it is still possible to control the vertical movement of the character by jumping. The jump button can be pressed for a long time and the duration of the button determines the height of the character's jump, the longer the button is pressed the higher the jump. A double jump system has been added to the air, allowing the character to jump twice, two times for jump will be reset when he hits the ground. A melee attack has been added to the character, with the range of the attack being approximately two body lengths in front of the character.

Health Point and Death

Players start the game with five health points and if they reach zero or fall off the platform, they die and the game is over.

Enemy

Two new types of monsters have been added to the game. The first type of enemy is flying in the sky, it will intermittently be set on the far right and then fly head-on towards the player. When the monster collides with the player, it will cost the player one health point. The flying enemy will appear higher than the height

(a) Monster with spit something (b) Standing Monster (c) Flying Monster

Figure 3.21 Enemies

of the platform currently being generated, in a range between 0 and 6 unit. The second type of enemy is a green monster on a platform. They do not move but will send long-range attacks with the slow bullet velocity at the player. You will lose one health point if you touch the monster or the liquid it spits out.

Difficulty System

As before, the game difficulty ranges from 0 to 30.

The way platforms are generated is still controlled by the difficulty level. In the previous design, the maximum height change of platforms was kept to 4 units or the player would fail due to difficulty in jumping to the specified height. However, because of the addition of the two-jump setting, the maximum height change range from platform to platform have been increased to 6 units. In terms of generation logic, the higher the difficulty of the game, the shorter the length of the platforms, the greater the platform-to-platform spacing, and the greater the height variation of the platforms will be.

As the difficulty increases, the probability of enemies refreshing becomes higher, with the possibility of three enemies appearing on the same screen. The horizontal movement speed of the character is also related to the difficulty, the higher the difficulty the faster the character movement to the right.

Score System

The game has a score system to evaluate the player's performance in the game, mainly in terms of the horizontal distance the character moves(S), the number of kills(N_k), and the difficulty factor. If the game starts from difficulty D_1 and stop in difficulty D_2, the specific formula is as follows.

$$Score = \sum_{n=D_1}^{D_2} (S(1 + n/10) + N_k n).$$

Input System

The game's inputs are simple, with the R1 button on the controller when jumping and the attack being the bottom of the four buttons on the right (corresponding to the X button in DUALSHOCK 4). The reason for this design is that the player would normally press R1 with their index finger and X with their thumb. For this experiment, it is important to provide the player with haptic feedback on the attack button. If the jump button is set next to the attack button (as is the case with the O button in DUALSHOCK4), the player is likely to use only his thumb to enter game commands. It is more likely that the finger will always be on the jump button, which is used more frequently than the attack button. This can result in the player not feeling haptic feedback.

3.5.3 Controller with Actuated Button and Sensors

Overview

The design of the controller presented at the exhibition has been significantly reworked. The first version of the controller was designed using a cheaper controller as a template, but the buttons had a poor feel, so this time a new prototype was designed using the electric circuit board from the official PlayStation 4 controller, DUALSHOCK4.[7] A total of nine prints were made using a 3D printer during the styling design phase. Of these, seven were successful and two were unsuccessful. Two DUALSHOCK4 circuit boards were consumed and the controller case was printed in ABS material[8] during the production phase, with the final product

7 DUALSHOCK4`https://pur.store.sony.jp/ps4/lineup/ps4_controller/`

8 Acrylonitrile butadiene styrene is a common thermoplastic polymer. Its glass transition temperature is approximately 220 °F (104 °C). ABS is amorphous and therefore has no true melting point. `https://en.wikipedia.org/wiki/Acrylonitrile_butadiene_`

Figure 3.22 Controller Product Design

printed on a Formlabs Form 3.[9]

Actuated Button

To provide good haptic feedback for prompting the player, it was necessary to control the buttons to move down automatically like being pressed. After several attempts, the more feasible solution was to use a solenoid to pull the buttons. The structure is shown in figure 3.23, with one end of the electromagnet connected to a fishing line. The fishing line goes through a circuit board and connect the other end to the bottom of the button. If the electromagnet is switched on, the magnetic force will tug on the fishing line and cause the button to move.

The space inside the controller is very small, so to make it feel as comfortable as possible, I removed the vibration motor from the right side of the handle and installed the solenoid there. The downward movement of the button requires a vertical pull, but the placement of the solenoid only provides a horizontal pull.

styrene

9 https://www.form2.shop/product-page/form3-printer

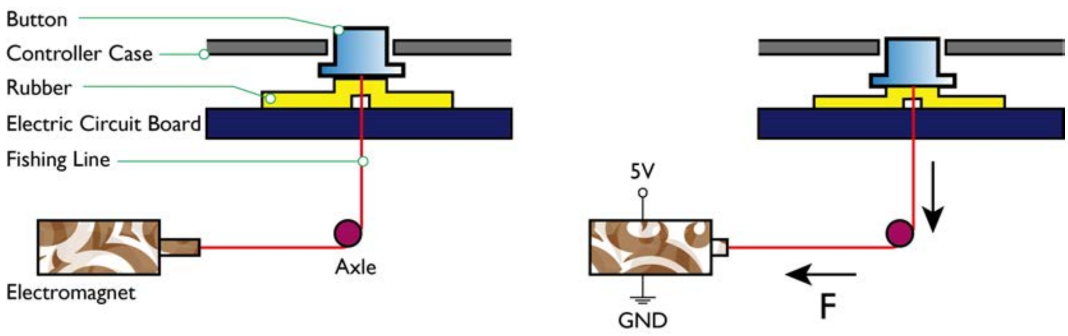


Figure 3.23 Actuated Button Moving by Electromagnet

Therefore, a fixed axle is placed directly below the button to change the direction of the rope pull.

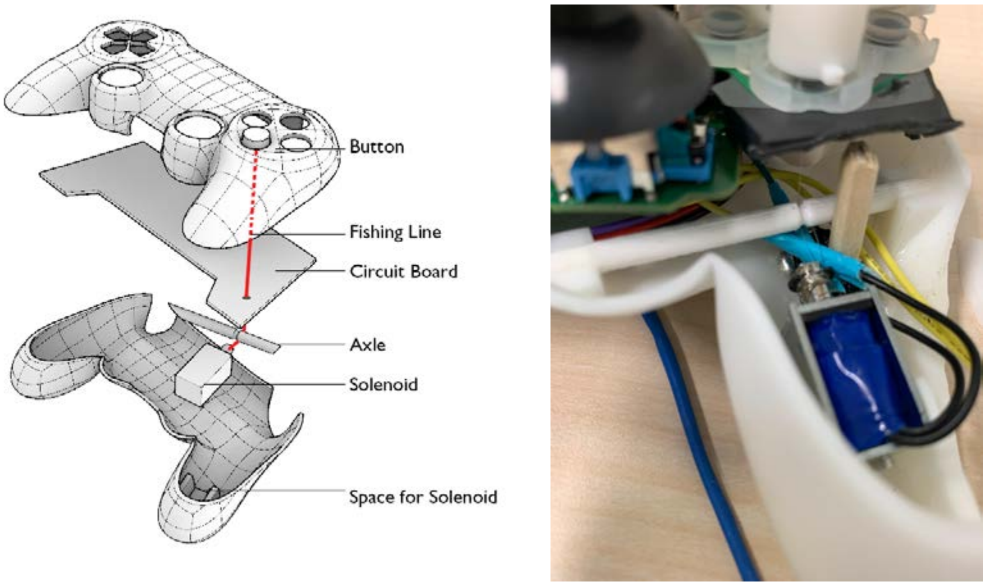
To ensure that the button can be pressed vertically downwards without horizontal movement and rotation, a movement track needs to be designed for the keys. Figure 3.25 shows the specific design.

When designing the buttons, special icons were designed for each button (Figure 3.25(d)), but due to the lack of material in the printer, they did not print successfully and the final result is shown in Figure 3.25(c).

Physiological Sensor

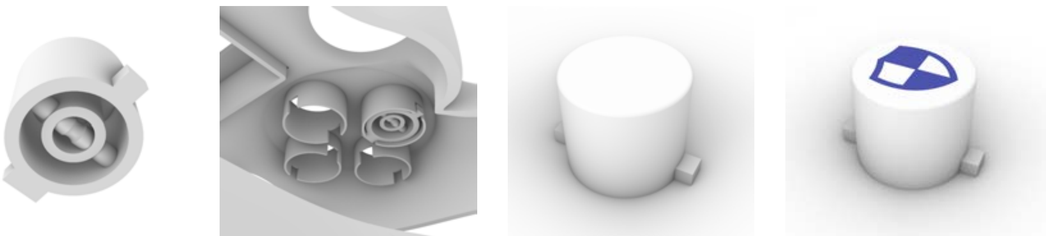
The sensors used in this product are the heartbeat and EDA. In previous prototypes, the heartbeat sensor was placed in a specific position on the left-hand handle of the controller, which often failed to detect the heartbeat due to the varying shapes and sizes of players' hands. Forcing the player to place their fingers on the sensor would have affected the player's grip on the controller.

The best way to measure the heartbeat is to wrap and secure the sensor around the belly of the finger and minimise the movement of the finger. However, I believe that this is too cumbersome to wear. Ideally, the way the controller measures physiological data would be more convenient, simply by holding it normally in the hand, data can be measured. So, after trying different places, I placed the heartbeat sensor at the bottom of the controller in the position shown in Figure



(a) Device Placement (b) Photo of Solenoid

Figure 3.24 Structure of Actuated Button



(a) Button Design (b) Track (c) Button without Icon (d) Button with Icon

Figure 3.25 Button Design

(a) Pulse Sensor (b) EDA sensor

Figure 3.26 Physiological Sensor

3.26(a). Here the data from the second knuckle of the finger can be detected. Although the signal is weaker compared to the belly of the finger, it can be a place for most players to have their middle or ring finger resting on the sensor when holding the controller.

The position of the EDA sensor is the same as the previous one, only changing a little given the internal construction of the controller.

Display on Controller

To observe the data, I added a small screen to the controller. I used the M5StickC[10], which has ESP32[11] inside that can be used for both receiving and sending data as well as for easy human-computer interaction in the form of a display. The display starts initialising with a prompt for Wifi connection information until the controller is connected to the set Wifi. After a successful connection, two curves appear on the screen in blue and green. The blue curve indicates the player's EDA value and the green indicates the player's current heartbeat signal. The M5StickC has a built-in IMU[12] chip, which uses a combination of accelerometers, gyroscopes,

10 M5StickC https://docs.m5stack.com/#/en/quick_start/m5stickc/m5stickc_quick_start

11 ESP32 https://ja.wikipedia.org/wiki/ESP32

12 IMU https://en.wikipedia.org/wiki/Inertial_measurement_unit

(a) Connecting (b) Pulse and EDA (c) IMU

Figure 3.27 Display

and magnetometers. Some players may tilt their bodies in the direction of their character while playing the game due to nervousness. Sometimes, they may move their controller too quickly by pressing the keys too hard. These movements will also be recorded. When the button on the right side of the screen is pressed, the heartbeat and EDA information will be replaced with IMU information. Pressing it again will switch it back.

3.5.4 System Structure

Communication

The data communication between the controller and the game is carried out both wirelessly via WiFi and wired. For data collection, the M5StickC in the controller transmits the heartbeat, EDA and IMU information collected via WiFi to Unity, which writes the data received to a CSV file and saves it. During gameplay, Unity determines in real-time whether the player needs to press the attack button to kill the monster. At the right time, unity sends a message to the controller via WiFi and when M5StickC receives the message, it controls the electromagnet to energise for 100ms, thus activating the haptic feedback. Input to the game is done via wired USB communication.

Power

The M5StickC comes with a 95mAh lithium battery, but its usefulness is very limited. Due to the high current required to operate the solenoid, when using the

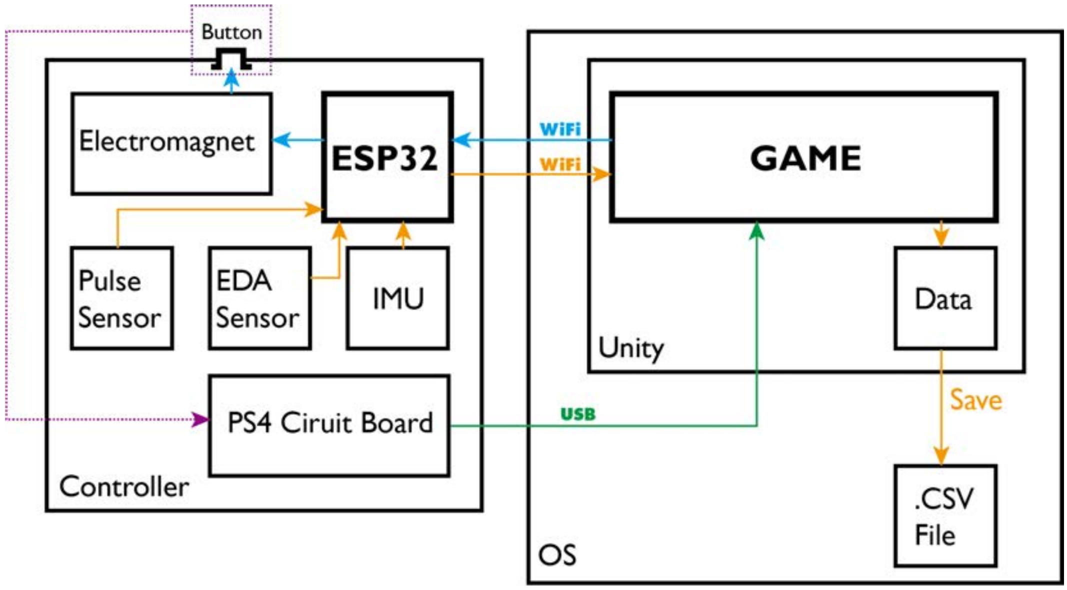


Figure 3.28 Communication System

M5StickC's battery power or USB power supply, it is not enough to provide stable power and the physiological data will be disturbed. Therefore, I chose a 5V max current 6A power supply for the power supply to obtain stable data. The power supply for the input section of the handle is left on independently and is powered directly from the USB.

3.6. Summary

The build of the experiment is almost complete through the design of the software and hardware. The game has a more systematic difficulty adjustment algorithm and a reasonable input system. The communication between the controller and the game is smooth and data can be received and sent freely. The feel of the controller has been debugged over time and is far better than the previous buttons. When the right thumb is placed on the attack button, the haptic feedback provided by the button can be felt. In the next chapter, experiments will be conducted to verify the effect of the sense of agency on the difficulty of the game.

Chapter 4
Proof of Concept

4.1. Pilot Study

4.1.1 Overview

In pilot study, I need to collect feedback from the players on the buttons, as well as their feedback on the content and difficult design of the game. At the same time, I will record their data for preliminary analysis.

4.1.2 Experience on Exhibition Area

I spent a lot of time adjusting the feel of the actuated button, but it remains to be seen how well they work. To get feedback from players, I presented my research for the audience to play at a exhibition area on 26 November, 2021. In total, nine people (male = 6, female = 3) experienced the game in two hours.

The game experience is set in a crowded exhibition area. Players can try the game any times they want.

When the game starts, the difficulty level starts at 1 and automatically increases by one difficulty level every 20 seconds. The total distance travelled and the current difficulty level is displayed on the game screen. The player has 5 health points. It is considered dead if health point reach zero or fall off the platform. The final score is displayed on the screen when player dead.

Haptic feedback from the button will always be present in the game. Whenever the horizontal distance between the player and the monster reaches the player's attack range, the attack button will move to give a hint to player.

Figure 4.1 Playing Experience on Exhibition

4.1.3 Result

This experiment collected the player's heartbeat, skin resistance and 9-axis acceleration data. Also, the game recorded the player's final score.

Heartbeat Data

The design of the heartbeat sensor took a lot of time, but it never worked very well. Because the sensor is set on the controller, and even subtle hand movements can interfere with the signal. I tried putting it in different positions but either the signal was too weak or the interference was huge. In this experiment, it appears that about half of the heartbeat data was available from the recorded data.

EDA Data

The EDA data is more stable and changes in SCR and SCL can be observed after doing basic cleaning of the raw data. In the SCR, GSR Peaks due to the sympathetic nervous system can be clearly seen.

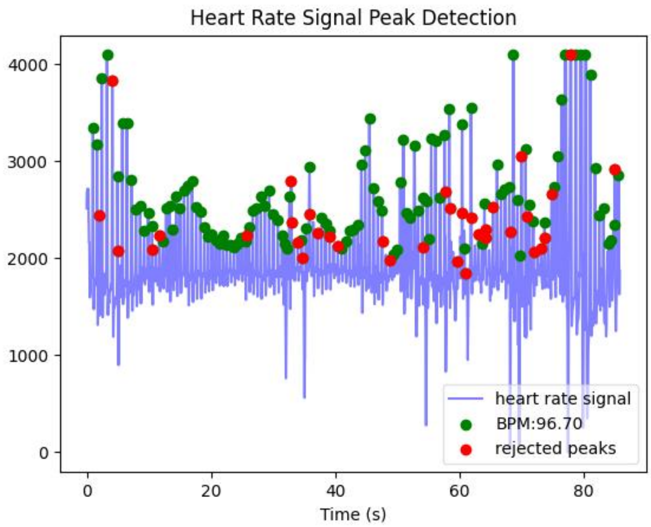


Figure 4.2 Raw Heartbeat Data and Peak Detection

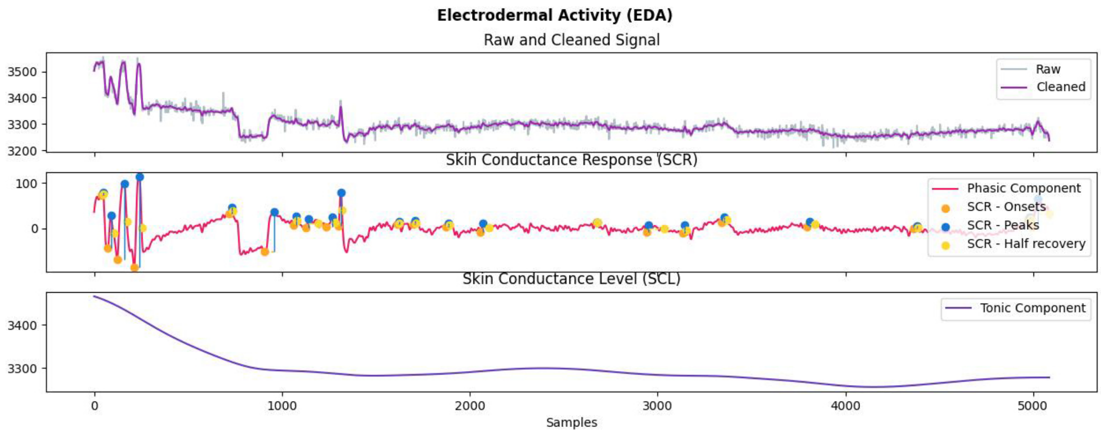


Figure 4.3 EDA Data and Analysis

Actuated Button Feedback from Interview

All participants reported a good gaming experience. One of the experimenters did not perceive haptic feedback from the buttons. Two players reported that the feedback from the actuated button helped them to better understand the operation of the game and that they understood the gameplay more quickly through the feedback. Two players also reported that the timing of the haptic feedback affected his judgement of the game.

"There were times when the controller had given me feedback expecting me to press the attack button just as I was about to go for it. In that split second, it interrupted my original thought process and made me a little confused whether I was thinking about it the wrong way. Just that little time thinking caused me to miss pressing the attack and then die." So said, one participant. One player also said, "Once I realised that the button would hint me when I attacked, I wanted to take advantage of the game mechanic. I could completely ignore the monsters flying towards me and just focus on jumping, leaving the judgement of attacking monsters entirely to the computer."

One participant gives me the advice for even design a experiment. "I was thinking, maybe the actuated button may not be so helpful for players who don't know how to play. But maybe it could be helpful for players who know how to play already, and who want to optimize their play style. Perhaps it would be interesting to have two groups of players, each practicing for 1 hour. One group with the actuated button and one without. I could imagine that on average, the group with the actuated button will have higher scores after the practice session."

4.1.4 Improvement

Record of Players' Performance

In this trial, no player scores were recorded, nor any data that could be used to measure player performance. Therefore, I have improved the code that records the data. The game will record the player's distance travelled, score and number of kills at the end of the game.

Screen Size

There are many parameters to adjust in the game. For example, when the same player plays multiple times, the difficulty level rises from 1 each time, which slows down the pace of the game. To get skilled players to higher difficulties faster, the game difficulty values need to be changed manually. For this reason, the game was tested in Unity software without generating an isolate executable file. So, participants played it in a small screen.

Others

Even after many careful measurements, the final version still had some areas that were not the right size. When the internal structure of the controller was fully designed and assembled, I found that the cover of controller did not fit together very well. This resulted in a certain amount of looseness between the internal circuit board and the external controller case, which directly affected the feel of the buttons. Some participants report the problems they encountered. When they press the R1 button for jumping, sometimes the circuit board is pushed and moving inside a little bit, which affects players' behaviour. They may think the controller is going to be broken. To make the controller stable, I used a shackle as shown(Figure 4.4) to hold the controller together perfectly.

Figure 4.4 Holding Element

4.1.5 Summary

From this test, it can be ascertained that all data is well recorded and that the communication system and haptic feedback are working well. Users mostly had positive feedback on the actuated button. The difficulty of the game can be distinguished and players will mostly start to feel the pressure and start to make mistakes at difficulty 7.

Based on this test and improvements, the next study will specifically analyse the characteristics of physiological data in different difficulty. Also, based on the player's performance of the game, it is possible to test whether the sense of agency can be enhanced by actuated button.

4.2. Study of Agency in Game-play

4.2.1 Overview

In this experiment, the participants will play in a semi-isolated environment. In terms of gameplay, the player's game performance, and self-evaluation will be recorded. In terms of data collection, information on the player's heartbeat, EDA and acceleration of the controller will be recorded. The difficulty of the game is used to analyse the physiological data characteristics of the player at different levels of difficulty. Also, two sets of data with and without actuated button are compared to analyse the effect of the sense of agency on the behavioural performance of the game.

Twelve participants took part in this experiment (3 males, 9 females). The experiment was carried out in semi-isolated environment. Due to the quiet environment of the experiment, the sounds of the electromagnet moving could easily be heard. In order to prevent the sound from interfering with the experiment, the players were asked to wear noise-cancelling headphones.

Figure 4.5 Experiment Environment

4.2.2 Experiment Design

Baseline Recording

The participant will be asked to hold the controller but not do anything. All the data is recorded in one minute. The data is regarded as a baseline for the player.

Practice in the Game

During this part, players are free to play the game for an unlimited amount of time. The game's difficulty level will start at 1 and increase every 15 seconds. As you can restart the game even if you die, this stage encourages you to try out the game and familiarise yourself with the basics of the game, the way platforms are generated, how to deal with enemies and how to get used to the operation of game.

Once the players themselves have indicated that they are familiar with the game, the experiment moves on to the next step.

Difficulty Determination

During this section, different players will be matched with different difficulty levels through their game performance. Players need to concentrate and play the game

	WITH actuated button	WITHOUT actuated button
EASY(BDL - 2)	a	d
NORMAL(BDL)	b	e
HARD(BDL + 2)	c	f

Table 4.1 6 Sections of Experiments

to the full. The game still starts at a difficulty level of 1 and goes up every 15 seconds. When a player dies (falls off a platform or drops to zero health point), the current difficulty level of the game at the time of death will be recorded. This difficulty is used as the player's base game difficulty.

The player can ask anytime to end the test during the game and the current game difficulty will be used as the baseline game difficulty for that participant. Conversely, the player can disagree with this result and start the test again, even if he die. The player can test up to three times and the highest of the three difficulty levels is used as the baseline difficulty for the player.

Testing

Based on the baseline difficulty level(BDL) of the players obtained in the previous step, three game difficulties will be developed for different players: EASY, NORMAL and HARD.(Table 4.1) Each participant will be required to perform 6 sets of experiments depending on whether the actuated button is triggered or not.

To avoid interference of the experimental order with the results, a latin square order is used for each participant.

Participants were required to play the game a total of six times, each time for one minute, and if they died within one minute, the experiment was terminated and goes on next one.

Evaluation

NASA-TLX [35] is used to evaluate the performance in the game. After each of experiments, players were asked to fill out a questionnaire. In this experiment,

(a) Holding Elements (b) Final Design

Figure 4.6 New way for Holding Controller

the Official NASA TLX for Apple iOS App[1] is used for collecting data.

4.2.3 Pre-test and Improvement

Before the formal experiment, I invited an participant to do a pre-test to confirm the process of the experiment and to see if there were any unreasonable points that needed to be fixed.

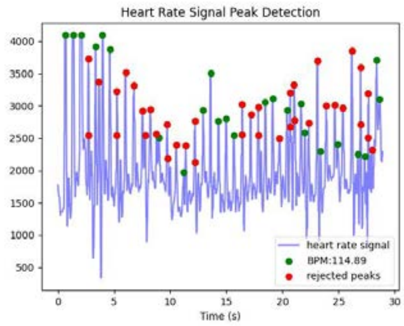
The experiment was carried out in the order a-b-c-d-e-f. After the test, the following problems were identified.

The difficulty of the game and the distance are displayed on the screen and can be seen by the participant. This results in the players themselves understanding about what level of the game is. To exclude psychological aspects, the game screen will not display any data during the formal experiment.

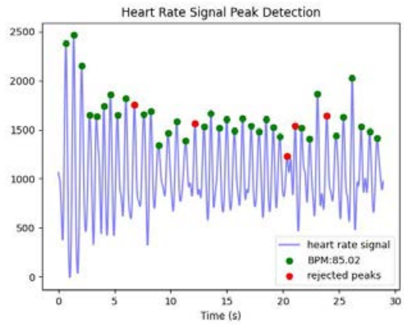
During the experiment, I did not inform the player about actuated button. After discussion, I have decided that in the formal experiment, the player should be given a general explanation of the buttons, but only be told that ”the attack button will give the player haptic feedback at certain times”, without specifying the trigger conditions and the principle.

In addition, the stuff that holds the handle is too heavy and may interfere with the player’s control. Hence, I used a laser cutter to reprint elements(Figure 4.6) used to hold the controller.

1 https://apps.apple.com/us/app/nasa-tlx/id1168110608



(a) Original Heartbeat Data



(b) Data with Bandpass Filter

Figure 4.7 Data and Filter

4.2.4 Result from Physiological Data

Based on the experiments, a total of 84 data reports were collected, corresponding to A-F section for each participant, plus one section of baseline data. The data was inevitably problematic due to the different habits of the players and their familiarity with the controller. For heartbeat data, eight of the data collected were invalid due to excessive noise, and some of the remaining data may have been recorded for too short a time, resulting in less accurate data results.

Heartbeat Data

The heartbeat data was processed using Python 3.7[2] and the HeartPy Package[3]. The raw data was processed using bandpass filtering to avoid noise interference with the signal.

Figure 4.8 and Figure 4.9 show the whole heartbeat data of one participant.

As Group a and d are the easy modes of the game, there tended to be longer periods of data sampling. As the difficulty rises, the sampling time for heartbeats becomes progressively shorter because player loses the game faster. We try to analyse these data for HRV information. In general, analyses of HRV tend to be

2 Python `https://www.python.org/`

3 `https://python-heart-rate-analysis-toolkit.readthedocs.io/en/latest/`

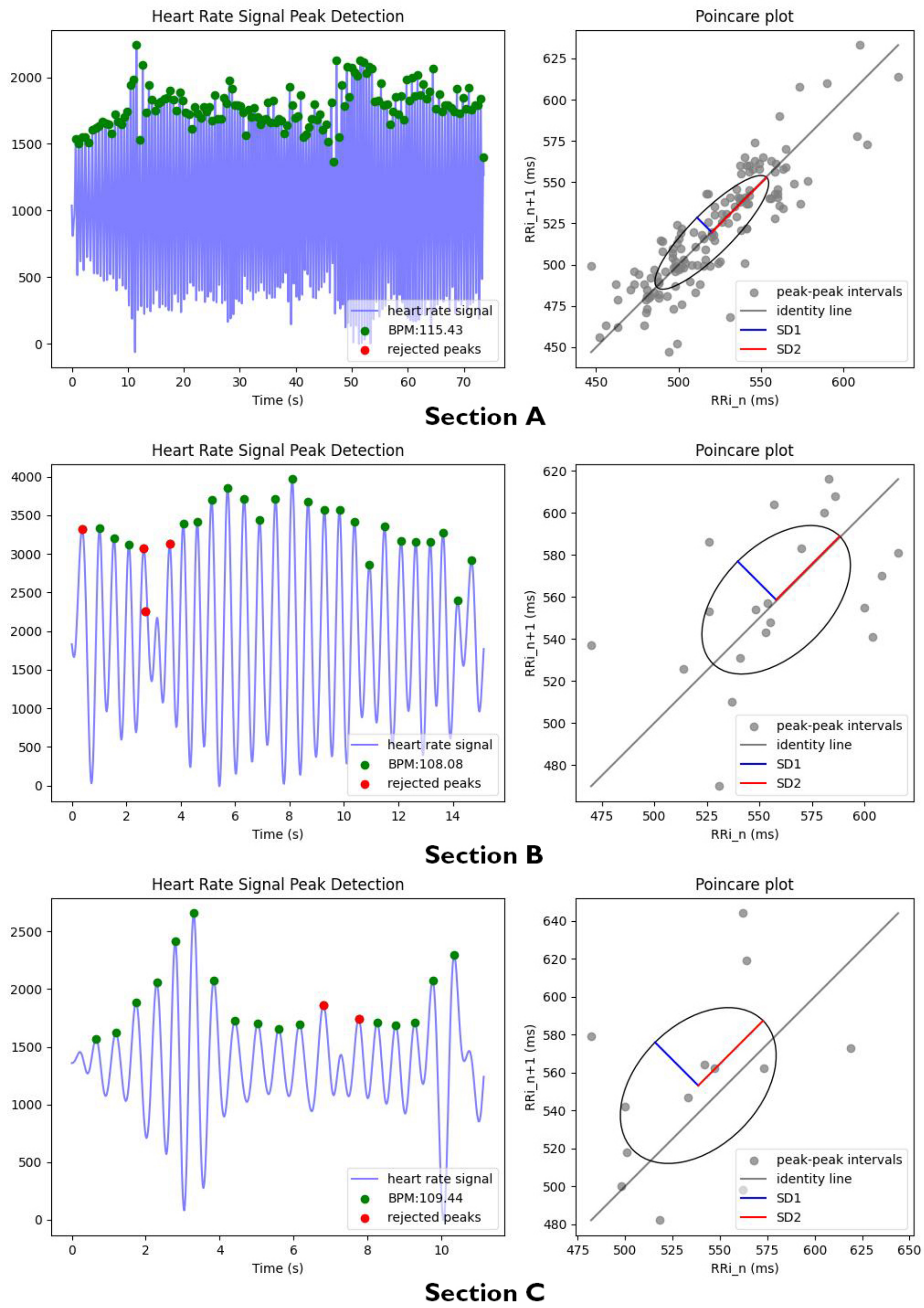


Figure 4.8 Heartbeat Data in Section a-b-c

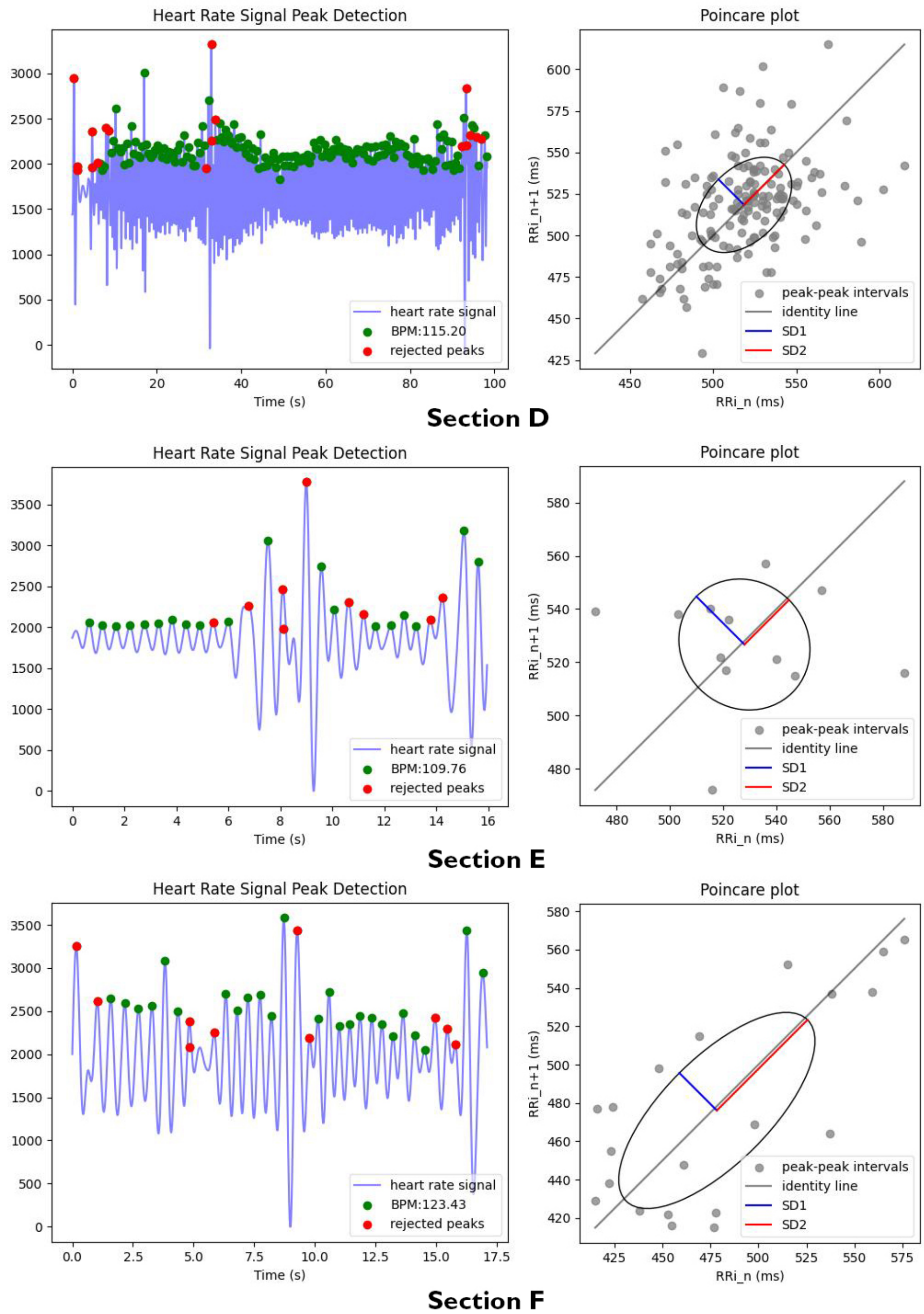


Figure 4.9 Heartbeat Data in Section d-e-f

based on data of 5 minutes or more, but some researchers have indicated that some features, such as the RMSSD[4], can be measured in ultra-short-term periods of 10 seconds. [36]

The figure on the right side is Poincaré plot. A Poincaré plot is graphed by plotting every R–R interval against the prior interval, creating a scatter plot. Poincaré plot analysis allows researchers to visually search for patterns buried within a time series (a sequence of values from successive measurements). Unlike frequency-domain measurements, Poincaré plot analysis is insensitive to changes in trends in the R–R intervals. [37]

After analysing the heartbeat data of the 12 participants, it was found that in the overall trend, the values of RMSSD and pNN50[5] were gradually increasing with increasing difficulty. There was also a gradual trend towards higher BPM. To compare the BPM in different section and the baseline BPM, The vertical axis of the chart shows the difference between the current Section's BPM data and the Baseline's BPM data. Figure 4.10 shows the heartbeat per minute of each participant.

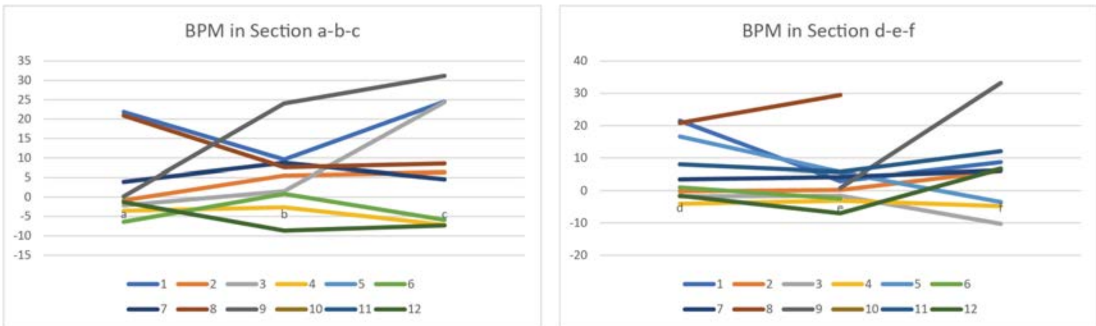


Figure 4.10 BPM Changing in different Sections

4 The root mean square of successive differences between normal heartbeats (RMSSD) is obtained by first calculating each successive time difference between heartbeats in ms. Then, each of the values is squared and the result is averaged before the square root of the total is obtained.

5 The percentage of adjacent NN intervals that differ from each other by more than 50 ms.

	Number of Peaks	Duration(second)	Peak per Minute
Baseline	10	63.02	9.52
A	2	57.48	2.08
B	6	29.84	12.06
C	13	24.34	32.05
D	19	74.58	15.28
E	4	20.54	11.68
F	4	16.2	14.81

Table 4.2 Peak per Minute in Different Section

EDA Data

The EDA data can provide a measurement of how strongly an emotion was experienced, although not the direction of the emotion. Increases in EDA activity have been directly related to a variety of emotional states, showing the importance of this physiological response in the experience of emotions. [38]

In EDA analysis, there are two components, tonic skin conductance level(SCL) and phasic skin conductance response(SCR).

The SCR is proportionally related to the number of sweat glands that are activated, meaning in essence that the more emotionally aroused an individual is, the more the SCR amount is increased. It can also be inferred that the SCR amplitude is a suitable proxy of sympathetic nervous system activity. [39] The other component is the tonic, continuous, slowly-changing Skin Conductance Level (SCL).

This EDA analysis used neurokit2[6] to help calculating the SCL and SCR features.

The two parameters can be understood as SCR a transient change in skin resistance for analysis, characterised by rapidly changing peaks. While SCL describes a flat and slowly changing amount of skin resistance change.

The EDA data from one participant is shown.(Table 4.2)

Based on the experimental results, as the difficulty of the game increases, the

6 `https://neurokit2.readthedocs.io/en/latest/`

peak in SCR increases accordingly. In general, the SCR activity level at game time was higher than in the baseline. anomalous data from section D showed that the player had been active at the beginning of the game, probably because the excitement in the previous high difficulty section had affected the experimental data.

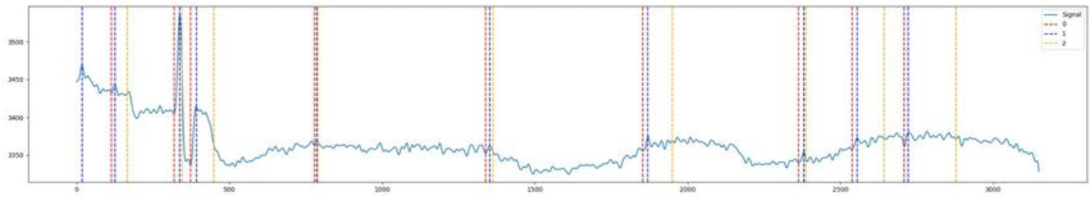


Figure 4.11 Baseline EDA Data

IMU

The acceleration sensor is primarily used to observe the player's physical behaviour during play through the movement of the controller. Some players will press the keys harder when they are nervous and the pressure exerted by their fingers on the controller will be reflected in the acceleration data. The excitement of some players can lead to rapid movement of the controller for short period. We also observed that some players' bodies followed the game's character while operating. For example, when a participant operate to jump to the right, body also lean to the right without having to do so voluntarily.

In the data shown (Figure 4.14 and Figure 4.15), accX, accY and accZ represent the change in acceleration of the controller in the x, y and z axes respectively. "acc" is the change in the overall value of acceleration.

The acceleration data for the baseline is generally stable, and simply holding the controller does not cause large fluctuations in acceleration. As the difficulty of the game increases, the movement of the controller becomes more violent, especially on hard difficulty, where the controller is unstable for most of the time. The acceleration fluctuations at each stage can be observed in the figures. Also, at the end of the data, there is a large change in acceleration regardless of the difficulty

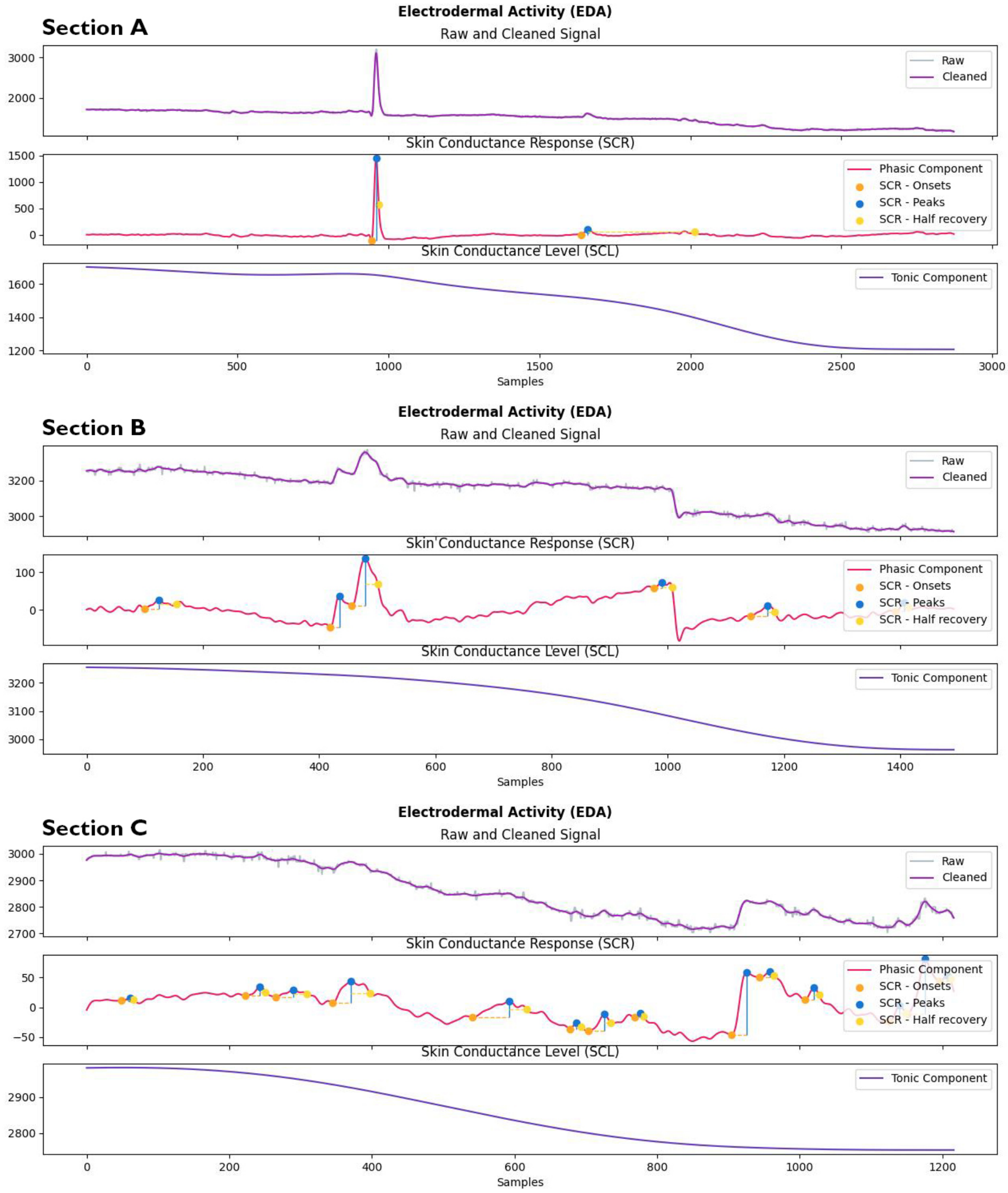


Figure 4.12 EDA Data in Section a-b-c

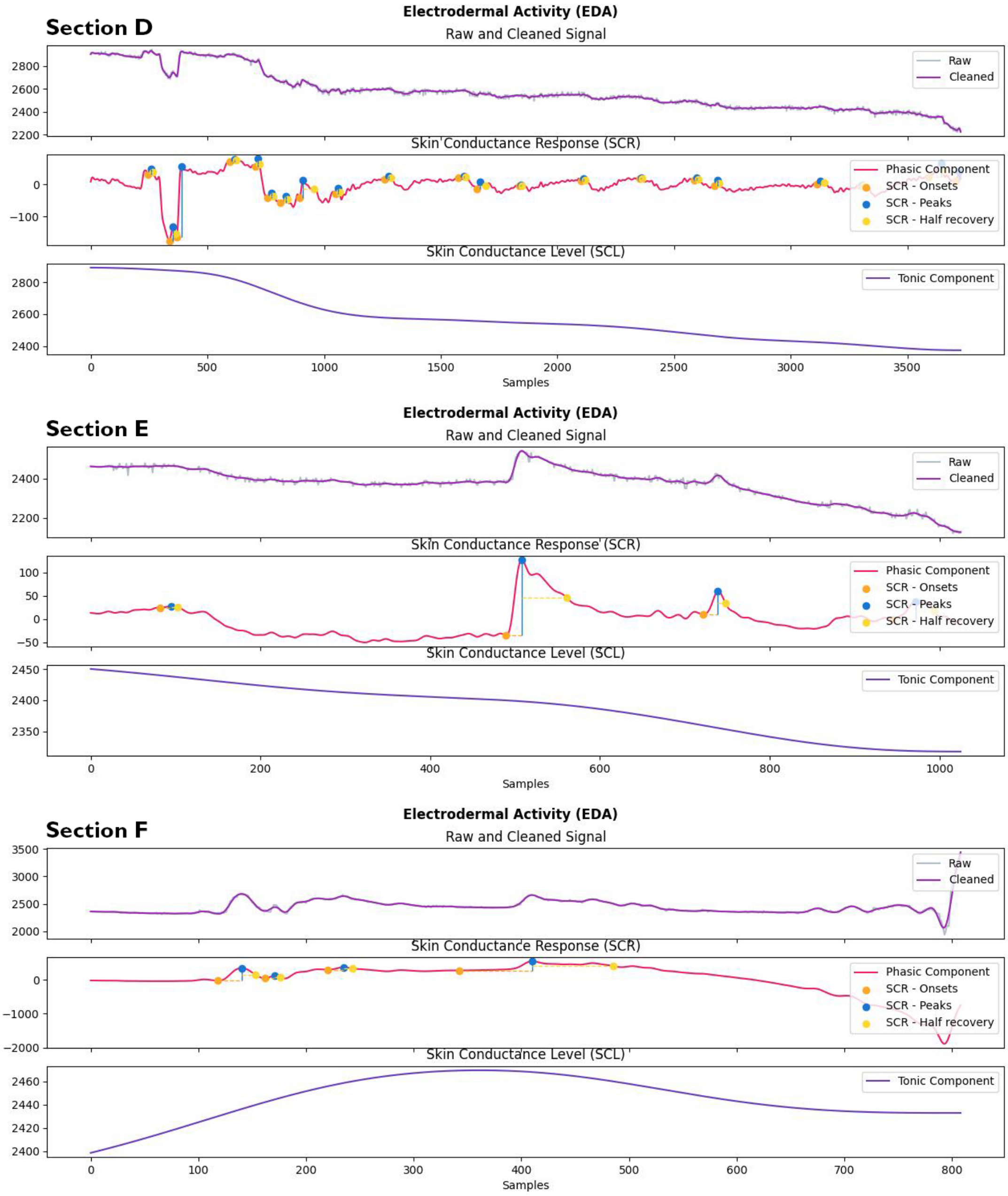
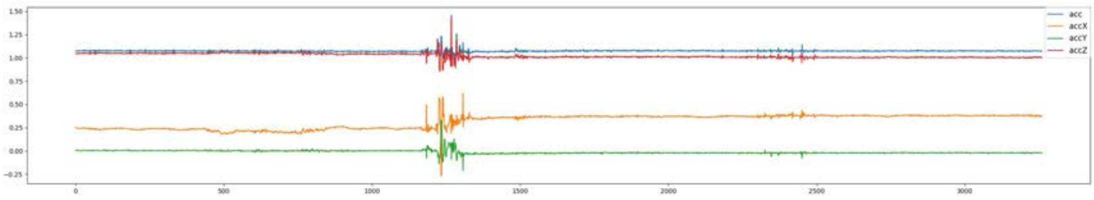
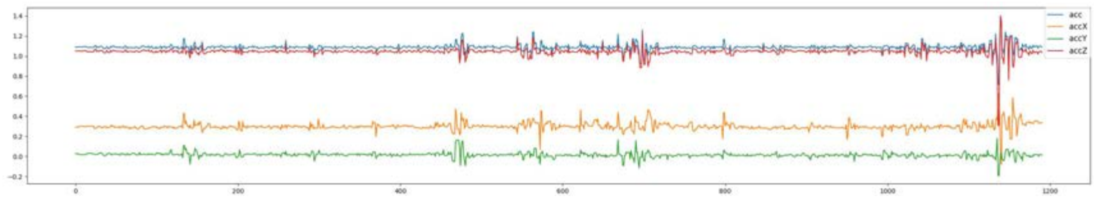


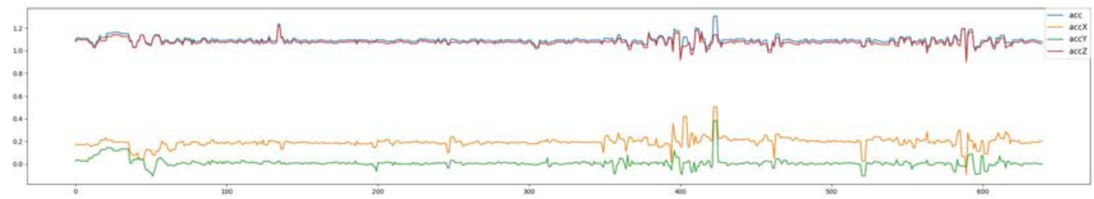
Figure 4.13 EDA Data in Section d-e-f



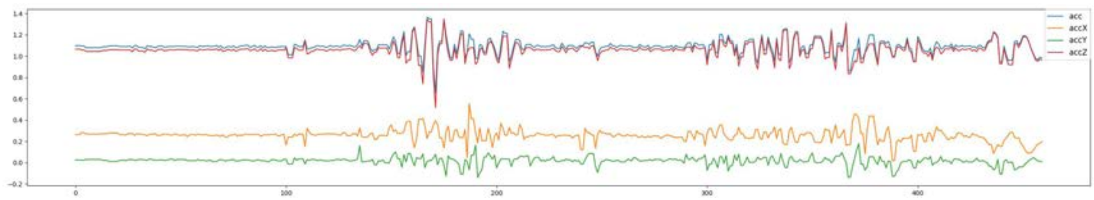
(a) Accelerate Data - Baseline



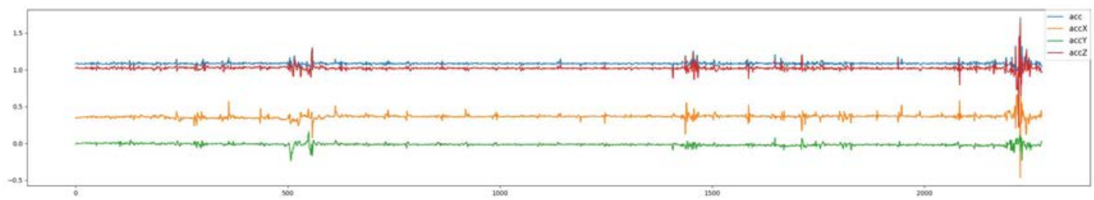
(b) Accelerate Data - a



(c) Accelerate Data - b

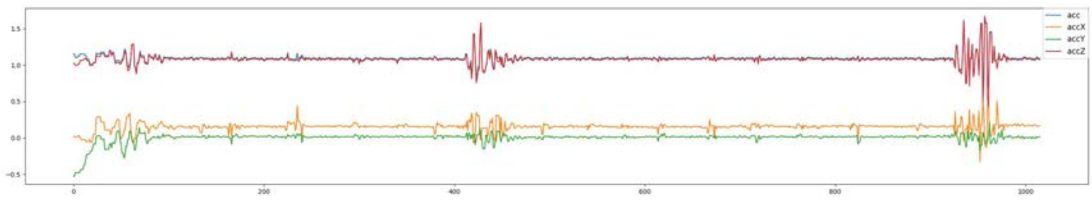


(d) Accelerate Data - c

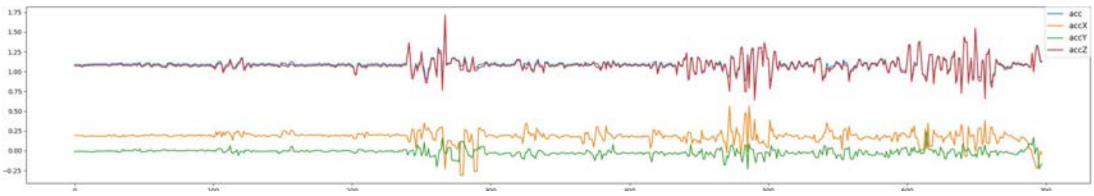


(e) Accelerate Data - d

Figure 4.14 Accelerate Data Part 1



(a) Accelerate Data - e



(b) Accelerate Data - f

Figure 4.15 Accelerate Data Part 2

level, presumably due to a death caused by a miss in the game. The intense tension from impending death affects the movement of the controller.

4.2.5 Result of Questionnaire and Score in Game

NASA-TLX Questionnaire

After each game, the player is asked to fill out a NASA-TLX questionnaire. In the questionnaire, the player is asked to make a self-evaluation of the game he or she has just played. The evaluation criteria will be measured in 6 dimensions.

- Mental Demand
- Physical Demand
- Temporal Demand
- Overall Performance
- Effort
- Frustration Level

The second part of TLX intends to create an individual weighting of these subscales by letting the participant compare them pairwise based on their perceived importance. This requires the user to choose which measurement is more relevant to workload. The number of times each is chosen is the weighted score. [40] However, some researchers have used the questionnaire without this section, and the results obtained without weighting are referred to as ”Raw TLX”. [35]

In this experiment, Raw TLX was used as the evaluation. When using the ”raw TLX”, individual subscales may be dropped if less relevant to the task. [41] the *Temporal Demand* in the questionnaire was not very meaningful because the player controlled a character that would be forced to move to the right. Therefore, the results of *Temporal Demand* were excluded from the calculation of the work.

Figure 4.16 Overview of Workload in Differernt Section

Overall, players perceived the game to be more task-loaded when haptic feedback was present. This feature was found at all difficulties, but none of the features was very pronounced. The difference is only slightly greater on difficult difficulties.

	With Actuated Button	Without Actuated Button
Score	15312	15044
Distance	8846.5	8951.2
Kill	109	105

Table 4.3 Score and Performance in Game-play

In terms of *Mental Demand* and *Physical Demand*, triggering the buttons is very good at reducing the player's *Mental Demand* in the easy mode, but can be counterproductive when faced with more complex situations in hard mode. This feature is particularly evident in the case of *Mental Demand*. On normal difficulty, players perceive that they need to work harder to complete the game with actuated button, while the data also indicates that actuated button triggered on high difficulty cause more stress.

Score

Contrary to the results of the player's self-evaluation, the in-game scores show that the player has better performance in the game when actuated button is available.

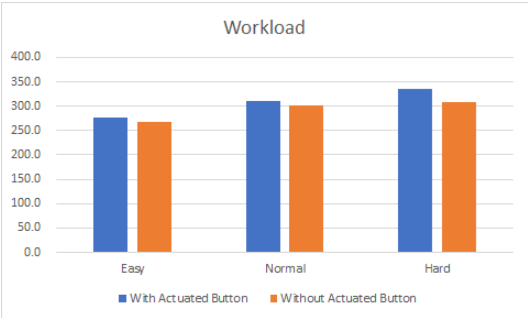
The score value is used as an overall assessment of the player's performance in the game and is determined in conjunction with the total distance the player has moved and the number of kills the player has made. As the program fixes the player's horizontal speed, it can also be broadly seen that the longer the player plays, the higher the score will be. Killing enemies will give the player bonus points. As the Figure /refkl shown, the actuated button performs well on normal difficulty and it greatly improves playing in the game.

The total distance player moved and number of kills is recorded.

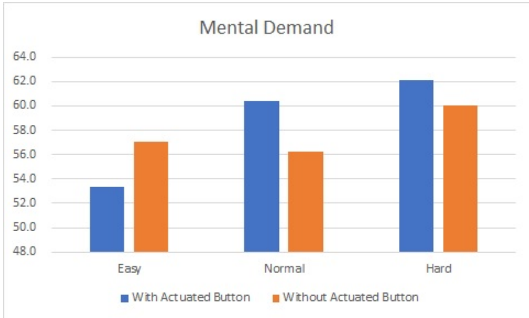
The player's total distance travelled in the game(Dis) and the number of kills(Kil) is also recorded separately. To evaluate the influence of actuated button on the player's play behaviour, a numerical value KpD is used.

$$KpD = 100(Kil/Dis).$$

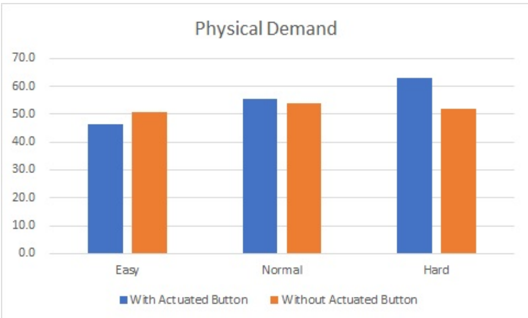
In the game, when the player encounters an enemy, the player can choose to either kill the enemy or skip it. kpD can be used to assess the player's game



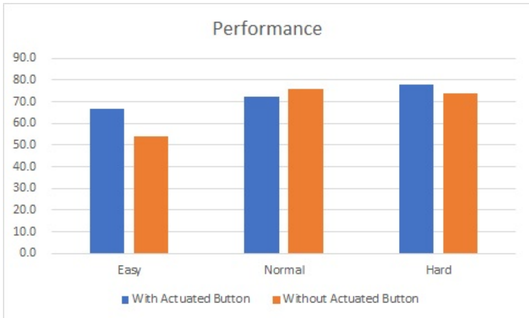
(a) Workload



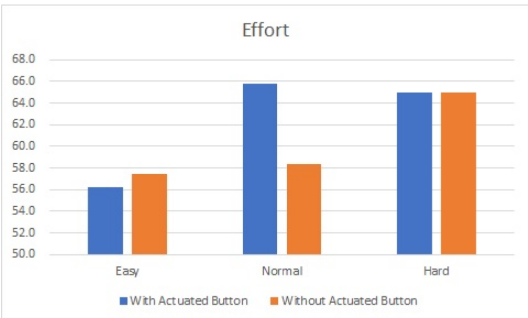
(b) Mental Demand



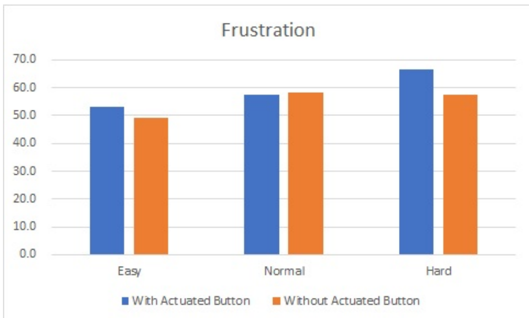
(c) Physical Demand



(d) Overall Performance



(e) Effort



(f) Frustration

Figure 4.17 Result of Workload in 5 Dimensions

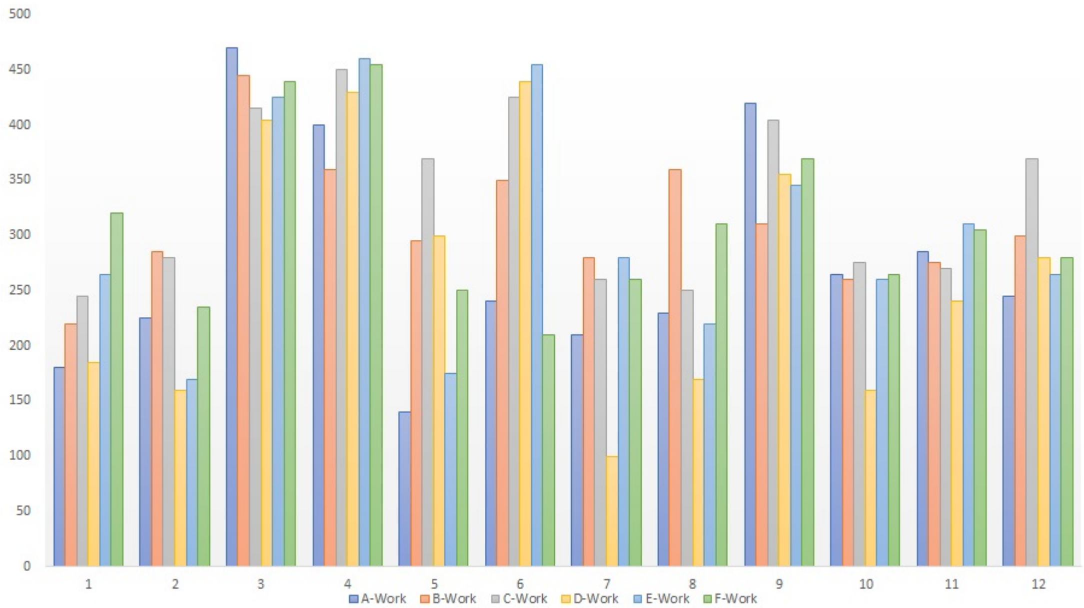


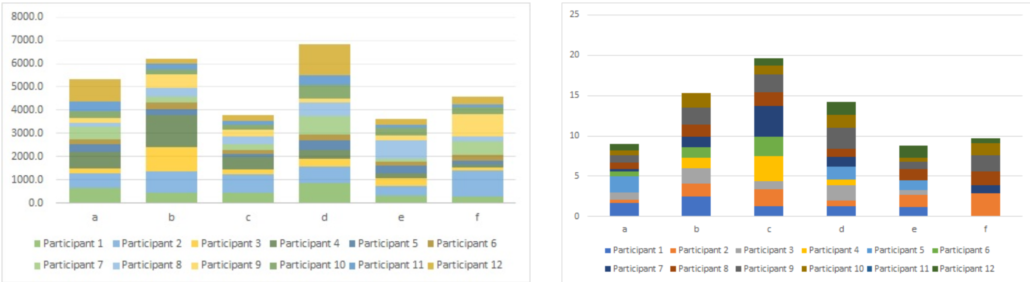
Figure 4.18 12 Participants' Workload Result in Different Section

play behaviour, if the KpD is higher, it proves that the player is more inclined to choose to kill the enemy.

From the KpD data in Figure 4.19(b), it is clearly evident that with the actuated button, the player prefers the option of killing the enemy. Especially on both normal and hard difficulties. This is the same conclusion that I reached in my experimental observations. During the experiment, three of the participant's were always focused on avoiding enemies during the trial game and during the phase of determining the difficulty. Two experimenters started to change their behaviour and tried to attack the enemy after sensing the move button.

4.3. Summary

From the analysis of the results of this experiment, the players' physiological data show certain characteristics at different game difficulties. BPM in HRV tends to rise when the game difficulty increases. pNN50 and RMSSD values also tend to rise slowly, but the correlation has yet to be certified due to the short duration of



(a) Score (b) Kill per Distance

Figure 4.19 Analysis of Score Data

data and the more serious noise interference. The change in difficulty also brought about a change in the peak of SCR. In general, increasing difficulty resulted in easier activation of the SCR peaks. It can also be speculated from the accelerator data in the controller that an increase in game difficulty is more likely to cause the controller to be in a non-stationary state, and this non-stationary state is likely to be associated with an intense state in game-play.

According to the player's self-feedback in NASA-TLX questionnaire, the task is less loaded when there is no haptic feedback. However, in terms of game score comparisons, players performed better when haptic feedback was present. Actuated button had an impact on player behaviour and game experience, and it affect players not in the same level at different levels of difficulty.

Although some conclusions were drawn from the experiment, the study still has some limitations. Firstly, the physiological data, especially the HRV, requires a higher level of data duration and data accuracy. The fact that the experiment was recorded for only 1 minute in each section and the sensor was set in controller, the device prone to noise interference, undoubtedly had a greater impact on the analysis of the experimental data. In the future, it will be necessary to design a better way to measure heart rate. There are also some issues with the game and controller design. It was observed during the experiment that many players did not keep their hands above the attack button when they did not need to press it while playing, which would result in the player not feeling it immediately even if the button was triggered. One participant was not even aware of moving the button until the end of the 6 sets of experiments.

Chapter 5
Conclusion

Dynamic game difficulty adjustment is a system that has been around for many years in the gaming industry. There have also been many studies on dynamic difficulty. However, this study attempts to look at game difficulty systems from the perspective of sense of agency. The traditional dynamic difficulty adjustment system is based on the player's behaviour to adjust the values in the game, and the player can only passively accept the result of such difficulty adjustment. In particular, in action games, which require a high degree of manipulation, reducing the difficulty of the game is not likely to please the player who wants a challenge. This study aims to enhance the sense of agency between the player and the game character through the haptic stimulation from an actuated button on controller, allowing the player to become familiar with the game's actions and understand the game's systems more quickly. The development of sense of agency will not only make the game less difficult but will also change the player's gaming experience. However, giving players tactile cues can undermine the sense of challenge. This study analyses the emotion state of the player through the recording of physiological signals. The data of physiological signal is used as a basis to determine whether haptic feedback is activating to enhance sense of agency.

Two preliminary conclusions can be drawn from the experimental analysis. The first is that players' heart rate and skin resistance show different characteristics depending on the difficulty of the game, confirming the correlation between physiological signals and the difficulty of the game. The second is that haptic feedback from controller can, to a certain extent, change players' gaming behaviour and gaming experience. But whether it can enhance the sense of agency needs further proof.

The conclusions drawn from this study are limited due to the limited amount of data. Different player types lead to inconsistent criteria for evaluating the experience of the game, individual differences in players' physiological data, and how to verify whether the sense of agency is enhanced. Many questions need further research. On the other hand, controller is not suitable for measuring physiological data. The frequent movement of the hand greatly increases the interference of noise with the data. However, for the controller prototype, the goal is to design a device that eliminates the need for cumbersome wearing steps and instead simply holds the device in the hand and records the data. The development of controller still requires a great deal of experimentation.

In the future potential use, if data collection on the controller becomes stable, mass-produced controller will facilitate researchers with access to huge amounts of data. In turn, the characteristics from psychological data obtained from players can be used as a new form of input to create more interaction with the game content. For example, influencing the story direction of the game and influencing the attitude of the NPC in the game towards the player.

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Appendices

A. Code for M5StickC in Arduino IDE

```
#include <M5StickC.h>
#include <WiFi.h>
#include<WiFiUdp.h>
#include <Ticker.h>
#include <AsyncUDP.h>
#include <OSCMessage.h>
#define PulseSensorPurplePin 36
#define EDASensor 33
#define Sore 26
#define X0 5
#define sendNum 2
int EDA;
int pEDA = 0;
int Heart;
int pHeart = 0;
int change = 0;
int pressed = 1000;
bool pressA = false;
int pressAA = 0;
float accX = 0.0F;
float accY = 0.0F;
float accZ = 0.0F;
float gyroX = 0.0F;
float gyroY = 0.0F;
float gyroZ = 0.0F;
float pitch = 0.0F;
float roll  = 0.0F;
float yaw   = 0.0F;
Ticker Draw;
Ticker accelerate;
```

```
Ticker Press;
typedef union {
  int32_t ival;
  float fval;
  byte binary[4];
} uf;
uf sendData[sendNum];
IPAddress broadcastIP;
WiFiUDP udp;
AsyncUDP udpServer;
void setup() {
  M5.begin();
  M5.IMU.Init();
  Serial.begin(115200);
  String ssid = "Bucunzaide";
  String pwd = "Cunzaide";
  WiFi.mode(WIFI_STA);
  WiFi.disconnect(true);
  delay(250);
  WiFi.onEvent(WiFiEvent);
  WiFi.begin(ssid.c_str(), pwd.c_str());
  M5.Lcd.print("Cnnecting" + ssid);
  while (WiFi.status() != WL_CONNECTED){
    delay(250);
    M5.Lcd.print(".");
  }
  M5.Lcd.println("");
  M5.Lcd.print("Success!");
  udp.begin(9003);
  broadcastIP = WiFi.localIP();
  broadcastIP[3] = 255;
  delay(3000);
  Draw.attach_ms(20, graph);
  //accelerate.attach_ms(10, acc);
  Press.attach_ms(1, pre);
  pinMode(PulseSensorPurplePin, INPUT);
  pinMode(Sore, OUTPUT);
  M5.Lcd.setRotation(1);
}
void WiFiEvent(WiFiEvent_t event){
```

```
    switch(event) {
      case SYSTEM_EVENT_STA_DISCONNECTED:
          Serial.println("WiFi lost connection");
          break;
      case SYSTEM_EVENT_STA_GOT_IP:
          Serial.print("WiFi connected! IP address: ");
          Serial.println(WiFi.localIP());
          broadcastIP = WiFi.localIP();
          broadcastIP[3] = 255;
          if (udpServer.listen(9003)){
            Serial.print("UDP Listening: ");
            Serial.println(WiFi.localIP());
            udpServer.onPacket([](AsyncUDPPacket packet){
              uint8_t * data = packet.data();
              if (data[0] == 'h'){
                pressed = 0;
              }
            });
          }
      default: break;
    }
}
void loop() {
  M5.update();
  if (M5.BtnA.wasPressed()) pressA = !pressA;
//  int PacketSize = udp.parsePacket();
//  if (PacketSize) {
//    pressed = 0;
//    char xx = udp.read();
//    Serial.println(xx);
//  }
}
void graph(){
  EDA = analogRead(EDASensor);
  Heart = analogRead(PulseSensorPurplePin);
  M5.update();
  M5.IMU.getGyroData(&gyroX, &gyroY, &gyroZ);
  M5.IMU.getAccelData(&accX, &accY, &accZ);
  M5.IMU.getAhrsData(&pitch, &roll, &yaw);
  sendData[0].ival = EDA;
```

```
  sendData[1].ival = Heart;
  OSCMessage edaSend("/test");
  edaSend.add(EDA);
  //edaSend.add(',');
  edaSend.add(Heart);
  edaSend.add(accX);
  edaSend.add(accY);
  edaSend.add(accZ);
  edaSend.add(gyroX);
  edaSend.add(gyroY);
  edaSend.add(gyroZ);
  edaSend.add(pitch);
  edaSend.add(roll);
  edaSend.add(yaw);
  //Serial.println(edaSend);
  udp.beginPacket(broadcastIP, 22225);
  edaSend.send(udp);
//   for (int a = 0; a < sendNum; a++) {
//     udp.write(sendData[a].binary, sizeof(uf));
//   }
  udp.endPacket();
  edaSend.empty();
  //Serial.println("sent something");
//   udp.flush();
   if (pressA){
     change = 200;
     if (pressAA < 1){
       M5.Lcd.fillScreen(BLACK);
       M5.Lcd.setCursor(40, 0);
       M5.Lcd.println("IMU TEST");
       M5.Lcd.setCursor(0, 10);
       M5.Lcd.println("   X       Y       Z");
       M5.Lcd.setCursor(0, 50);
       M5.Lcd.println("  Pitch   Roll    Yaw");
     }
     pressAA++;
     float temp = 0;
    M5.IMU.getTempData(&temp);
    M5.Lcd.setCursor(0, 20);
    M5.Lcd.printf("%6.2f  %6.2f  %6.2f o/s\n", gyroX, gyroY, gyroZ);
```

```
      M5.Lcd.printf(" %5.2f   %5.2f   %5.2f G\n\n\n\n", accX, accY, accZ);
      M5.Lcd.printf(" %5.2f   %5.2f   %5.2f\n", pitch, roll, yaw);
      M5.Lcd.printf("Temperature : %.2f C", temp);
    }
    else {
      pressAA = 0;
      if (change > 150){
      M5.Lcd.fillScreen(BLACK);
      change = 0;
      }
      change++;
      int preHeart = map(pHeart, 1000, 4095, M5.Lcd.height(), 0);
      int NewHeart = map(Heart, 1000, 4095, M5.Lcd.height(), 0);
      int preEDA = map(pEDA, 1000, 4095, M5.Lcd.height(), 0);
      int NewEDA = map(EDA, 1000, 4095, M5.Lcd.height(), 0);
      M5.Lcd.drawLine(change - 1 + X0, preHeart, change + X0, NewHeart, GREEN);
      M5.Lcd.drawLine(change - 1 + X0, preEDA, change + X0, NewEDA, BLUE);
      pEDA = EDA;
      pHeart = Heart;
    }
}
void acc(){
  M5.update();
  M5.IMU.getGyroData(&gyroX, &gyroY, &gyroZ);
  M5.IMU.getAccelData(&accX, &accY, &accZ);
  M5.IMU.getAhrsData(&pitch, &roll, &yaw);
  //Serial.printf("%6.2f,%6.2f,%6.2f,%5.2f,%5.2f,%5.2f,%5.2f,%5.2f,%5.2f\n", gyroX, gyroY, gyroZ, accX, accY, accZ, pitch, roll, yaw);
  udp.beginPacket(broadcastIP, 22222);
  udp.printf("%6.2f,%6.2f,%6.2f,%5.2f,%5.2f,%5.2f,%5.2f,%5.2f,%5.2f\n", gyroX, gyroY, gyroZ, accX, accY, accZ, pitch, roll, yaw);
  udp.endPacket();
}
void pre(){
  pressed++;
  if (pressed < 100){
```

```
    digitalWrite(Sore, HIGH);
    Serial.println("lai le");
  } else {
    digitalWrite(Sore, LOW);
  }
}
```

B. Game Level Design Code by C#

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using System;
using Random = UnityEngine.Random;
using UnityEngine.SceneManagement;

using System.Threading;

[Serializable]
public class RandomTry : MonoBehaviour
{
    public GameObject unit;
    //public GameObject DifUp;
    //public GameObject DifDown;
    public GameObject El;
    public GameObject bullet;
    public GameObject Monster;
    public GameObject background;
    public GameObject lihaide_Monster;

    [SerializeField]
    public bool baseLine;

    private float timer;

    [SerializeField, Range(0, 100)]
    private float difficultyUp = 15;
    [SerializeField]
    public bool difficultyChange;
```

```
    //private float timer2;
    //private float waitTime = 0.14f;
    //private float changeDifTime = 10f;

    int howManyMonster = 12;

    private Transform boardHolder;
    private List<Vector3> gridPosition = new List<Vector3>();
    private float startPositionX = 16.0f;

    public static int difficulty = 8;
    public static int KillNum = 0;

    //public float GSR = 600;
    private static int platformWidth = 4;
    private float platformHigh = -0.8f;
    private int holeLength = 0;
    private bool Whichone = true;
    private bool platformWhite = false;
    public static float x1 = 0.0f;
    private float x11 = 0.0f;
    private int killPre = 0;
    private float y = 0.0f;

    private float monsterAppearHigh;

    private int MaxCreateNum = 100 + difficulty * platformWidth;

    private float x2 = 0f;
    private int x4 = 0;
    private int x5 = 100;

    private bool lihaideMonsterOK = false;
    private bool canCreateFirst = false;
    private int platformCount = 0;

    bool calNewDif = false;
    public static int ScoreInTotal = 0;

    void SetDifficulty()
```

```
    {
        difficulty++;
        print(difficulty);
        //float floatDif = GSR;
        //difficulty = (int)(Remap(floatDif, 700, 50, 25, 1));
    }


    public float Remap(float X, float a1, float a2, float b1, float
        b2)
    {
        return b1 + (X - a1) * (b2 - b1) / (a2 - a1);
    }

    void Create()
    {
        gridPosition.Clear();
        boardHolder = new GameObject("Board").transform;
    }

    bool randomCreatePlatform()
    {
        MaxCreateNum = MaxCreateNum - difficulty;
        int Num = Random.Range(0, 100);
        if (Num < MaxCreateNum)
        {
            return true;
        }
        else
        {
            return false;
        }
    }

    private bool holeControl(int length)
    {
        if (length > 5)
        {
            return true;
        }
```

```
        float dif = Remap((float)(difficulty), 0f, 30f, 0f, 4f);
        float holeCount = length - dif;

        float y = -holeCount * holeCount * 5 + holeCount * 25;
        float Num = Random.Range(0f, 35f);

        if (Num < y)
        {
            return true;
        }
        else
        {
            return false;
        }
    }

    private void scoreCalculate()
    {
        ScoreInTotal += (int)((1 + difficulty * 0.1) * (x1 - x11));
        ScoreInTotal += (int)(difficulty * (KillNum - killPre));
        x11 = x1;
        killPre = KillNum;
        calNewDif = false;

    }

    private void monsterAppear(float x)
    {
        int xx = Random.Range(1, 50);
        int yy = Random.Range(1, 30);
        if (difficulty > xx)
        {
            GameObject monster = Instantiate(Monster, new Vector3(x,
                monsterAppearHigh, 0f), Quaternion.Euler(0, 180, 0))
                as GameObject;
            //GameObject monster = Instantiate(Monster, new Vector3(x
                , monsterAppearHigh, 0f), Quaternion.identity) as
                GameObject;

        }
```

```
        if (difficulty > yy)
        {
            lihaideMonsterOK = true;
        }
    }



    private void initial(float x)
    {

        if (Whichone)
        {
            platformWhite = randomCreatePlatform();
        }

        if (platformWhite) {
            GameObject baseCube = Instantiate(unit, new Vector3(x, platformHigh, 0f), Quaternion.identity) as GameObject;
            platformCount++;
            if (lihaideMonsterOK & canCreateFirst)
            {
                GameObject qiang = Instantiate(lihaide_Monster, new Vector3(x, platformHigh + 1, 0f), Quaternion.identity) as GameObject;
                lihaideMonsterOK = false;
            }
            if (platformCount >= 2)
            {
                canCreateFirst = true;
            }


        }
        else
        {
            Whichone = false;
            holeLength = holeLength + 1;
            if (holeControl(holeLength))
```

```
            {
                platformWhite = true;
                Whichone = true;
                holeLength = 0;
                //float deltaDif = Remap(GSR, 700f, 50f, 1.5f, 0f);

                float deltaDif = difficulty * 0.2f;
                if (deltaDif > 4f) deltaDif = 4f;
                platformHigh = Random.Range(-deltaDif, deltaDif);

                monsterAppearHigh = Random.Range(platformHigh + 1f,
                    platformHigh + 5f);

                MaxCreateNum = 100 + difficulty * platformWidth;
                canCreateFirst = false;
                platformCount = 0;

            }
        }
        //print(difficulty);

    }

    public void platformCreate()
    {
        timer = timer + Time.deltaTime;
        //timer2 = timer2 + Time.deltaTime;
        x1 = El.transform.position.x;
        float x3 = x1 - x2;
        if (timer > difficultyUp)
        {
            if (difficultyChange) SetDifficulty();
            scoreCalculate();
            //print(ScoreInTotal);
            timer = 0;
        }
        if (x3 > 1f)
        {

            initial(startPositionX);
```

```
                x4++;
                x5++;
                if (x4 > howManyMonster)
                {
                    monsterAppear(startPositionX);

                    x4 = 0;
                }
                if (x5 > 110)
                {
                    GameObject back = Instantiate(background, new Vector3
                        (x1 + 100, -5, 0f), Quaternion.identity) as
                        GameObject;
                    x5 = 0;
                }
                startPositionX = startPositionX + 1.0f;
                x2++;
            }

            y = El.transform.position.y;
            if (y < -40 & !baseLine)
            {
                scoreCalculate();
                print(ScoreInTotal);
                GameOver();
            }
            //Display.txt.text = "Distance: " + (int)(x1);
            //Display2.txt2.text = "Difficulty: " + difficulty;

        }
        public void GameOver()
        {
            //SceneManager.LoadScene(0);
            print(difficulty);
            UnityEditor.EditorApplication.isPlaying = false;


        }
}
```

C. Data Analysis by Python

C.1 HRV Analysis Code

```
import os
import heartpy as hp
import matplotlib.pyplot as plt

Location = 'Section2/addHeader/'
Name = 'TA_F'
FileName = Location + Name + '.csv'
saveLocation = 'Section2/output/' + Name + '/'
try:
    os.mkdir(saveLocation)
except:
    print('Create failed, but it is OK. Mei Shi de')

sampleRate = 50

heartData_With3 = hp.get_data(FileName, column_name = 'Heart')

heartData = heartData_With3[:-3]

filteredData = hp.filter_signal(heartData, cutoff = [0.8, 2.5], filtertype = 'bandpass', sample_rate = sampleRate, order = 3, return_top = False)

working_data, measures = hp.process(filteredData, sampleRate, high_precision = True, clean_rr = True)
working_data_2, measures_2 = hp.process(heartData, sampleRate, high_precision = True, clean_rr = True)

plt.figure(figsize = (15, 6))
#plt.plot(heartData[0:(1 * 60) * sampleRate])
#plt.show()
#plt.xlim(0, 2 * 60 * sampleRate)

plot_object = hp.plotter(working_data, measures, show = False)
plot_object_Ori = hp.plotter(working_data_2, measures_2, show = False)
```

```
plot_poincare = hp.plot_poincare(working_data, measures, show = False
    )
for key in measures.keys():
    with open(saveLocation + 'HRV_' + Name + '.txt', 'a') as f:
        f.write('%s: %f' % (key, measures[key]))
        f.write('\n')

plot_object.savefig(saveLocation + 'Heart_' + Name + '.jpg')
plot_poincare.savefig(saveLocation + 'Heart_' + Name + '_poincare.jpg
    ')
plot_object_Ori.savefig(saveLocation + 'Heart_' + Name + '_Original.
    jpg')
```

C.2 EDA Data Analysis Code

```
import neurokit2 as nk
import matplotlib.pyplot as plt
import pandas as pd
import os

sampleRate = 50
Location = 'Section2/addHeader/'
Name = 'Cady_A'
FileName = Location + Name + '.csv'
saveLocation = 'Section2/output/' + Name + '/'
try:
    os.mkdir(saveLocation)
except:
    print('Create failed, but it is OK. Mei Shi de')


plt.rcParams['figure.figsize'] = [30, 5]
data = pd.read_csv(FileName)
EDAdata = data['EDA'].tolist()

for x in range (0, 3):
    EDAdata.pop()


signals, info = nk.eda_process(EDAdata, sampling_rate=sampleRate)

```

```
cleaned = signals["EDA_Clean"]
features = [info["SCR_Onsets"], info["SCR_Peaks"], info["SCR_Recovery"]]

plot = nk.events_plot(features, cleaned, color=['red', 'blue', 'orange'])
plot2 = nk.eda_plot(signals)
plot.savefig(saveLocation + 'EDA_' + Name + '.jpg')
plot2.savefig(saveLocation + 'EDA_' + Name + '_SCR_SCL.jpg')
decomposedData = nk.eda_phasic(nk.standardize(EDAdata), sampling_rate=sampleRate)
decomposedData["EDA_Raw"] = EDAdata
```

C.3 Acceleration Data Analysis Code

```
import matplotlib.pyplot as plt
import pandas as pd
import os
import math

sampleRate = 50
Location = 'Section2/addHeader/'
Name = 'Karen_Baseline'
FileName = Location + Name + '.csv'
saveLocation = 'Section2/output/' + Name + '/'
try:
    os.mkdir(saveLocation)
except:
    print('Create failed, but it is OK. Mei Shi de')


plt.rcParams['figure.figsize'] = [30, 5]
data = pd.read_csv(FileName)
accX = data['accX'].tolist()
accY = data['accY'].tolist()
accZ = data['accZ'].tolist()
acc = []

for x in range (0, 3):
    accX.pop()
    accY.pop()
```

```
    accZ.pop()

for i in range(0, len(accX)):
    result = math.sqrt(accX[i] ** 2 + accY[i] ** 2 + accZ[i] ** 2)
    acc.append(result)

plt.plot(acc, label="acc")
plt.plot(accX, label="accX")
plt.plot(accY, label="accY")
plt.plot(accZ, label="accZ")
plt.legend(bbox_to_anchor=(1, 1), loc='upper right', borderaxespad=0,
    fontsize=12)
plt.savefig(saveLocation + 'ACC_' + Name + '.jpg')
```

D. Action Game Questionnaire

E. Self-Evaluation Questionnaire

Action Game Questionnaire

*必須

1. Sex / 性別 *

- ◯ Male / 男
- ◯ Female / 女

2. Age / 年齢 *

- ◯ ~10
- ◯ 11~20
- ◯ 21~30
- ◯ 31~40
- ◯ 40~50
- ◯ 50~

3. Do you play games regularly? / 普段からゲームをすることがありますか。 *

- ◯ Yes / はい
- ◯ No / いいえ

4. What kind of player you are? / 自分はどんなタイププのプレイヤーだと思いますか。 *

- ☐ Achiever: looking for a sense of achievement (Level up, Equipment) / 達成感を求める人
- ☐ Explorer: want to see new things and discover new secrets. / 探検家：探索することが好き
- ☐ Socializer: experiencing fun in their games through their interaction with other players. / 社交的な人
- ☐ Killer: are highly competitive, and winning is what motivates them. / キラー：他人と競争するを好む
- ☐ I have no idea. / 分からない
- 其他: ☐ ____________

Figure D.1 Action Game Questionnaire Page 1

5。 What do you think about action game (emphasizes physical challenges, including hand–eye coordination and reaction-time)? / アクションゲーム（キャラクターの行動をボタンなどにより直接操作し、すばやくゲーム内の事象を制御する能力を競うというゲームジャンル）についてどう思いますか。 *

- ◯ Like it very much / 大好き
- ◯ Like it but not confident that can play it well / 好きだけど、うまくできる自信がない
- ◯ Tried, but faiure demotivate me / 試してみたが、失敗してやる気をなくしてしまった
- ◯ Tried, and don't like it / 試してみたが、気に入らなかった
- ◯ I haven't played it before, but I'd like to try / プレイしたことはないが、やってみたいと思っている
- ◯ I haven't played it before, and I don't want to play it / したことがないし、プレイしたいとも思わない
- ◯ I have no idea / 分からない
- ◯ 其他: ____________________

6。 Have you experienced joyful from action game by complete a goal, for example, get a higher score or beat a monster. / アクションゲームで、高得点やモンスターを倒すなど、目標を達成したときの喜びを味わったことがありますか？ *

- ◯ Yes. / はい
- ◯ No. / いいえ

7。 Do you often watch someone play action game on Twitch (livestreaming service) or Youtube (Video)? / TwitchやYoutubeなどのプラットフォームで、誰かがアクションゲームをプレイしているのをよく見ますか？ *

- ◯ Yes. / はい
- ◯ No. / いいえ

8。 If yes, why do you watch? / 「はい」と答えた方は、なぜ見るのですか？

- ☐ Want to know about the story / 物語を知りたい
- ☐ Watch them as Game walkthroughs or strategy guide/ ゲーム攻略として観る
- ☐ Beautiful picture quality / ゲーム画質が美しい
- ☐ Just want to know more about the game / あるゲームのことをもっと知りたい
- ☐ kill time / 暇を潰す

其他: ☐ ____________________

Figure D.2 Action Game Questionnaire Page 2

9。 Which do you prefer, watching others play or playing yourself? / 人がプレイするのを見るのと、自分がプレイするのとでは、どちらが好きですか？ *

- Watching / 見ること
- Playing / プレイすること
- I don' know / わからない

10。 Do you think you can to get the same pleasure from watching and playing? / 人がゲームをするのを見るのと、自分がゲームをするのとでは、楽しみ方が違うと思いますか？ *

- Yes. / いいえ
- No. / はい
- I don' know / わからない

11。 (Optional) If no, what is the different bewteen them? / 「はい」と答えた方は、宜しければ、違うところを具体的に教えてください。

Figure D.3 Action Game Questionnaire Page 3

NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand — How mentally demanding was the task?

Very Low — Very High

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?

Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?

Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High

Figure E.1 NASA-TLX