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Doctoral Dissertation

A Study on Entertainment Mechanism with Focus on Play and Ride Comfort

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Abstract

Game refinement (GR) theory, taking the game process as the elimination of game outcome uncertainty, proposes a logistical model of game information progress to quantify and evaluate the sophistication of different kinds of games [1]. It firstly and profoundly raises the idea that if we consider the information process in the human brain, which can be measured as in physics, taking Newton's second law into comparison, we could get the game acceleration in mind, which we denote as GR value. From the evaluation by GR, we could better design and optimize a game [2]. Similarly, the changes in speed acceleration in driving have been taken as a key and universal factor in assessing riding comfort-ability in practice.

We analyzed Action Games from several perspectives to deeply analyze game refinement theory. Technology advancements allowed the development of action games that packed multifaceted play in a single match while requiring fast-paced movements. Since modern action game is composed of boss battles, evaluating them was scarcely investigated. In this study, the analysis of the boss battle was conducted based on the God of War (GoW) series, where the underlying entertainment aspects of the game were identified. The information progress of the boss battle of each of the considered GoW series was modeled using the game refinement (GR) theory and its extension, called motion in mind. The evolution of challenge, anticipation, and unpredictability between different GoW series was identified while the entertainment aspects of the game were investigated. The evolutionary trend of the sophistication and unpredictability of the GoW series games provided insights into the intended narrative design, harmonic balance between skill and chance, and provided learning comfort for player mastery of the game-playing.

As for ride comfort from the passenger's perspective, we knew that the passenger's experience could be reflected through velocity and acceleration in the vehicles. Velocity and acceleration are fluent except for sudden breaks or sudden starts, and that may not offer the game player stimulation. In taking the roller coasters, the attendant body can be affected by gravity, roughly showing the riders' different experiences in its moving motions (Eager 2016). Roller Coaster, as an overlapping transmission of combining game and driving, is both for entertainment and for a driving experience in physics. So this study chooses a roller coaster as an important medium for the research object.

The extension of game refinement theory, the Motion in mind model will efficiently indicate how velocity, acceleration, jerk, momentum, and potential energy changes affect the comfort concerned, this gives the convenience to study the correlation between the players and the riding comfort.

Further in-depth research into the use of the motion-in-mind theory to study comfort in games is needed. Previous studies have established a model based on data from the world's most popular roller coaster. However, in order to gain a more realistic understanding of user motion and build a roller coaster model that is more suitable for players, it is important to consider their preferences. To this end, this study used focus group interviews and questionnaire surveys to gather specific data on roller coaster preferences. By using this first hand information, it is possible to simulate a roller coaster model that is more suitable for contemporary players, and the motion in mind theory can be used to analyze the player's psychological movement and improve the comfort level of both reality and play in the future.
Keyword: *Play comfort*; *Ride comfort*; *Game refinement theory*; *Motion in mind*; *Entertainment mechanism*; *Action game*

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Chapter 1

Introduction

Game refinement (GR) theory is a well-known theory that leverages the game progress model of game outcome uncertainty [1]. Its GR value is a standard for measuring the entertainment value of games in which sophisticated games were located in a reasonable zone of $GR \in [0.07, 0.08]$. In addition, it was previously applied to measure the design sophistication in domains of business [4], and education [5], and act as a tool for exploring the evolution of popular board games [1] and [6].

With the expansion and extension of the game's refinement theory in recent years, the theory was expanded, considering the physics of motions as an analogy to the motions in mind. As such, this study explored the link between physical motions and psychological emotions of in-game information. This situation leads to the exploration of balancing the various range of motions in mind, where it could be a reasonable and comfortable zone. The comfort in mind when players play the game is essential because a comfortable experience can make us enter a region similar to "flow" and can attract us to continue to enjoy playing games, and constantly start the next round.

1.1 Problem Statement and Research Questions

Recently, topics such as autonomous driving and gamification have become more and more popular. Vehicular automation involves the use of mechatronics, artificial intelligence, and multi-agent systems to assist the operator of a vehicle (car, aircraft, watercraft, or otherwise). These features and the vehicles employing them may be labeled as an intelligent or smart vehicle or transportation. A vehicle using automation for difficult tasks, especially navigation, to ease but not entirely replace human input, may be referred to as semi-autonomous [7], whereas a vehicle relying solely on automation is called robotic or autonomous [8].

Gamification is the strategic attempt to enhance systems, services, organizations, and activities by creating similar experiences to those experienced when playing games in order to motivate and engage users. This is generally accomplished through the application of game-design elements and game principles (dynamics and mechanics) in non-game contexts [9]. However, vehicular automation had rarely been associated with gamification, which raises concerns over how vehicular automation can help put operators and passengers alike on the feeling of "comfort" in such a mode of transportation.

As such, the research questions of this thesis explored upon can be summarized as follows:

- How to combine or bridge the experience of driving and the experience of playing games?
- How to build the associated "motion" between the physical experience of driving and the mental emotions of game playing?
- Finally, how to determine the most comfortable situation that links between play comfort and ride comfort?

1.2 Research Objectives

We also analyzed the GoW series via the GR theory and its extension, called motion in mind, based on the actions of the boss battles available in each of the series of the GoW considered finding the relations between dynamic m (risk rate) in the game domain and dynamical v (physical speed) roller-coaster-like gameplay experience. From the analysis, the evolutionary trend of the GoW series was identified not only in the challenge increases, insights into the narrative design, levels of predictability, and balances the experience of play for beginner and advanced players. Additional features identified include the learning comfort imposed by the developers, where the player is expected to learn and master the battle when reaching the final boss for each GoW series. In addition, when players start to enter the next round or next boss, they do not know if the m is decreasing or increasing, it is all unknown to players, the m dynamics of the game imply a roller-coaster-like gameplay experience, where the uncertainty makes it enjoyable to the player.

This paper explores the comfort in the player's mind when playing games and the comfort in the player's mind when the player's driving, Here, we will use a roller coaster to create the model to analyze the link between real physical motions and psychological emotions, and we will collect the tendency of motions changed such as the tendency of velocity, to link how the emotions changed, finally to deeply analyze the link between play comfort and ride comfort, compare real speed, acceleration, and jerk during the roller coaster and connect with the speed, acceleration, and jerk of the information process in the mind, to find out the relationship between the real ride comfort and play comfort, and how to use our research in the future to apply it in scenarios with real physical quantity changes, such as automatic driving and other related fields.

1.3 Thesis Structure

This thesis comprises six main chapters, given as follows,

- **Chapter1: Introduction**

  This chapter's objective is to introduce the big picture of the research, such as its definitions, how each of the keywords relates to each other in the research, as well as a brief historical overview of the domain considered. It serves to explain the main problem that the research aims to solve. The Introduction chapter also includes the statement of the research questions, as well as the goal and significance of the research. At the end of this chapter, the structure of the dissertation will be stated.

- **Chapter2: Literature Review**

  The chapter serves as a review of the theoretical background related to this research well as presenting state-of-the-art research in the field. The first section of this chapter is a short introduction to the subsequent literature review.

  The second section is a review of roller coasters, the origin, and development of roller coasters, principles of physics and design of roller coasters, the reason people enjoy roller coasters, safety mechanisms, and technology, the evolution of comfort using the bridge between games and rides revealing a glimpse of what the relations between ride comfort and play comfort.

  The third section covers the review of the overview of Action Games, and the Literature Review covers the research related to the action games using the god of war series.

The fourth section includes the Uncertainty in Entertainment with Game Refinement Theory and Motion in Mind model.

The fifth section shows the method of data collection in this paper.

The last section shows the conclusion in this chapter.

- **Chapter3: Bridging Ride and Play Comfort**

A new trend emerged with the development of autonomous driving, where the comfort and convenience of transportation were redefined to include the risk and comfort of riding. From the rider's perspective, the notion of risk causes a thrill due to uncertainty during the ride's progress. Meanwhile, the notion of ride comfort had been related to physic motion and its biomechanical effects on the rider itself. In this section, the way such risk and comfort affect the ride experience is investigated, and the connection between play comfort and ride comfort is explored. A roller coaster ride simulation was adopted as the target environment for this research, which combines thrill feeling and comfort simultaneously. At the same time, this section also expands research on roller coaster rides while bridging the ride and game via the analogy of physics law, a concept currently known as the motion in mind. This study's contribution involves the roller coaster ride model that provides an extended understanding between physical performance and the mental experience relative to the concept of motion in mind while establishing critical criteria for a comfortable experience in both rides and play.

- **Chapter4: Action Games Evolution Analysis:A Case Study Using the God of War Series**

For action games, the difficulty of each boss and each round is different. As the player continues to focus on the game, the difficulty of the subsequent game rounds does not increase linearly, nor does it decrease linearly, but it is very dynamic. So when the player starts the next round, they will feel more relaxed if the difficulty decreases but if the difficulty increases, they will feel less relaxed, which is very uncertain, the mentality when players play action games is like a roller coaster.

Technology advancements allowed the development of action games that packed multifaceted play in a single game while requiring fast-paced movements. Since modern action game is composed of boss battles, evaluating them was scarcely investigated. In this study, the analysis of the boss battle was conducted based on the God of War (GoW) series, where the underlying entertainment aspects of the game were identified. The information progress of the boss battle of each of the considered GoW series was modeled using the game refinement (GR) theory and its extension, called motion in mind. The evolution of challenge, anticipation, and unpredictability between different GoW series was identified while the entertainment aspects of the game were investigated. The evolutionary trend of the sophistication and unpredictability of the GoW series games provided insights into the intended narrative design, harmonic balance between skill and chance, and provided learning comfort for player mastery of the game-playing.

- **Chapter5: Psychological changes When People Ride Roller Coasters**

Using motion in mind theory to study comfort in games deserves more in-depth research. In previous studies, a model was established based on the data from the most popular roller coaster in the world. In order to understand a more realistic user motion in mind and build a roller coaster model that is more suitable for players, it is particularly important to adjust the user's roller coaster preferences. Through focus group interviews and questionnaire surveys, this study collected specific data on roller coaster preferences, which means that a roller coaster model that is more suitable for contemporary players can be simulated through this first-hand information, and the motion in mind theory can be used for analysis in the future. The player's psychological movement and how to better improve the comfort level of reality and play.

- **Chapter6: Conclusion**

The last chapter is the conclusion of the dissertation. It concludes the whole dissertation relative to the main aim and objectives of the dissertation. Some potential future works are also outlined.

Chapter 2

Literature Review

2.1 Chapter Introduction

This chapter reviews the theoretical background related to this research and introduces the latest research results in this field, which include the influence of passenger comfort, roller coaster, action games, game refinement theory, motion in mind, the methods of data collection we used, and so on.

2.2 Overview of roller coaster

Comfort is a subjective concept that is difficult to define and measure. For example, Branton (1972) suggests that, like health, the only appropriate definition of comfort is in terms of its absence, thus arguing that it is possible only to measure varying degrees of discomfort. Nevertheless, some investigators have tried to measure degrees of positive comfort.

In transport, it is axiomatic that passenger comfort is extremely important. We need to consider the concept of comfort and its relationship to the passenger's other travel experiences. These factors include temperature, ventilation, illumination, photic stimulation, pressure changes on the ear, journey length, and task impairment.

Passenger ride comfort has become a focus of attention in rail transportation equipment design, manufacture, and later operation to meet people's demand for travel quality. However, comfort is a very subjective concept, which is difficult to quantify and evaluate directly, and can be affected by various factors, leading to the corresponding technologies for ride comfort improvement becoming diverse. The main types of ride comfort are summarized first according to the sources of discomfort, including static comfort, vibration comfort, noise comfort, aural pressure comfort, thermal comfort, and visual comfort. Starting from the current assessment methods of ride comfort, we currently analyze the existing ride comfort from two aspects: Environmental parameters and human parameters.

2.2.1 Origin and Development of Roller Coaster

Roller coasters have a long, fascinating history. Roller coasters are the direct ancestors of monumental ice slides — long, steep wooden slides covered in ice, some as high as 70 feet (21 meters) — that were popular in Russia in the 16th and 17th centuries. Riders shot down the slope on sleds made of wood or blocks of ice, crash-landing in a sand pile. Coaster historians diverge on the exact evolution of these ice slides into actual rolling carts. The most widespread account is that a few Frenchmen imported the ice slide idea to France. The warmer climate of France tended to melt the ice, so the French started building waxed slides instead, eventually adding wheels to the sleds. Roller coasters are driven almost entirely by basic inertial, gravitational, and centripetal forces, all manipulated in the service of a great ride. Amusement parks keep upping the ante, building faster and more complex roller coasters, but the fundamental principles at work remain basically the same. Through this part of this study, we can know why people enjoy roller coasters, and it can also infer the development of the roller coaster.

The oldest roller coasters are believed to have originated from the so-called "Russian Mountains", specially constructed hills of ice located in the area that is now Saint Petersburg, Russia. Roller coaster amusement rides have origins back to ice slides constructed in 18th-century Russia. Early technology featured sleds or wheeled carts that were sent down hills of snow, reinforced by wooden supports.

Roller coaster amusement rides have origins back to ice slides constructed in 18th-century Russia. Early technology featured sleds or wheeled carts that were sent down hills of snow, reinforced by wooden supports. The technology evolved in the 19th century to feature railroad tracks using wheeled cars that were securely locked to the track. Newer innovations emerged in the early 20th century with side friction and under-friction technologies to allow for greater speeds and sharper turns. By the mid-to-late 20th century, these elements intensified with the introduction of steel roller coaster designs and the ability to invert riders.

A roller coaster is a type of amusement ride that employs a form of elevated railroad track designed with tight turns, steep slopes, and sometimes inversions. Passengers ride along the track in open cars, and the rides are often found in amuse-

Figure 2.1: Roller coasters, as one of the most popular attractions in amusement parks, offer an exhilarating experience that is loved by players all over the world. (Image credit: Pexels, licensed under Creative Commons Zero)

Figure 2.2: Roller Coasters, with its numerous loops and towering heights, bring joy and excitement to players. (Image credit: Unsplash, licensed under Creative Commons Zero)

ment parks and theme parks around the world [10]. LaMarcus Adna Thompson obtained one of the first known patents for a roller coaster design in 1885, related to the Switchback Railway that opened a year earlier at Coney Island [11]. The track in a coaster design does not necessarily have to be a complete circuit, as shuttle roller coasters demonstrate. Most roller coasters have multiple cars in which passengers sit and are restrained [12]. Two or more cars hooked together are called a train. Some roller coasters, notably Wild Mouse roller coasters, run with single cars.

2.2.2 Principles of Physics and Design of Roller Coaster

A roller coaster is a machine that uses gravity and inertia to send a train of cars along a winding track. The combination of gravity and inertia, along with g-forces and centripetal acceleration, give the body certain sensations as the coaster moves up, down, and around the track. The forces experienced by the rider are constantly changing, leading to feelings of joy in some riders and nausea in others. The basic principles of roller coaster mechanics have been known since 1865, and since then roller coasters have become a popular diversion [13].

Initially, the car is pulled to the top of the first hill and released, at which point it rolls freely along the track without any external mechanical assistance for the remainder of the ride. The purpose of the ascent of the first hill is to build up potential energy that will then be converted to kinetic energy as the ride progresses. The initial hill, or the lift hill, is the highest in the entire ride. As the train is pulled to the top, it gains potential energy, as explained by the equation for potential energy below:

$$U_g = mgh \tag{2.1}$$

Where U_g is potential energy, m is mass, g is the acceleration due to gravity and h is the height above the ground. Two trains of identical mass at different heights will therefore have different potential energies: the train at a greater height will have more potential energy than a train at a lower height. This means that the potential energy for the roller coaster system is greatest at the highest point on the track, or at the top of the lift hill. As the roller coaster train begins its descent from the lift hill, the stored potential energy converts to kinetic energy, or energy of motion. The faster the train moves, the more kinetic energy the train gains, as shown by the equation for kinetic energy:

$$K = \frac{1}{2}mv^2 \tag{2.2}$$

Where K is kinetic energy, m is mass, and v is velocity. Because the mass of a roller coaster car remains constant, if the speed is increased, the kinetic energy must also increase. This means that the kinetic energy for the roller coaster system is greatest at the bottom of the largest downhill slope on the track, typically at the bottom of the lift hill. When the train begins to climb the next hill on the track, the train's kinetic energy is converted back into potential energy, decreasing the train's velocity. This process of converting kinetic energy to potential energy and back to kinetic energy continues with each hill. The energy is never destroyed but is lost to friction between the car and the track. Brakes bring the ride to a complete stop.

The design of a roller coaster ride is the first and most important part of the manufacturing process. Because each roller coaster is unique, every detail must be designed literally from the ground up.

To begin, roller coaster designers must consider what kind of riders will use the coaster. If the coaster is designed for small children, the hills and curves will be gentle, and the car's speed will be relatively slow. Families usually want a somewhat faster ride with plenty of turns and moderate forces. Ultimate thrill seekers want extreme heights and speeds.

Designers must then consider the space available for the coaster. Roller coasters not only take up a lot of ground space but also a lot of airspace. Designers look at the general terrain, other surrounding rides, power lines, access roads, lakes, trees, and other obstacles. Some amusement parks have added so many rides that a new roller coaster has to be designed to thread its way through existing rides and walkways.

The next objective for the designers is to achieve a unique "feel" for the coaster. Designers can draw on a number of techniques to provide a memorable ride. The initial incline can be made steeper or the speed of the lift chain can be made slower to heighten the apprehension of the passengers. Once up the incline, the first drop is usually designed to be the steepest, and therefore the fastest and scariest. Other drops can be designed with a brief flattened section in the middle, and are called double dips. Drops with very abrupt transitions to a flat or upturned section are called slammers because they slam the passengers down into their seats. Letting the cars run close to the ground, in what is called a gully coaster, gives the illusion of increased speed.

The advent of steel construction for coasters has allowed a number of variations on the basic roller coaster ride. In some modern coasters, the passengers sit suspended below the tracks rather than riding on top of them. In others, the passengers ride standing up rather than sitting down. Some coasters, known as bobsleds, have no track at all, and the cars roll free in a trough, like a bobsled run.

Most of the actual design and layout of a roller coaster is done on a computer. The height of the first incline must be calculated to give the cars enough energy to propel them all the way through the ride and back to the station. The horizontal and vertical forces that the loaded cars exert on the track must be calculated at every point to ensure that the support structure is adequate. Likewise, the forces exerted on the passengers must be calculated at every point. These forces are usually expressed as “g’s,” which are multiples of the force that gravity exerts on our bodies. For example, if a person weighs 100 lb (45.5 kg), then a 2 g force would exert 200 lb (91 kg) of force on that person. Coasters in the United States generally exert no more than about 3.5 g’s, which is the limit that most people find tolerable. Three coasters outside the United States exert more than 6.5 g’s and are considered ultra-extreme. Jet fighter pilots black out at about 10 g’s.

Because each coaster usually incorporates one or more new and untried features, a working prototype of the new features may be built for testing and evaluation. The prototype is erected at the manufacturer’s facility, and weighted test cars outfitted with instrumentation are propelled through the test section at the desired speed. Based on these tests, the designers may alter their original designs before building the final product.

When the calculations, design, and testing are complete, a computer-aided drafting (CAD) program is used to prepare detailed drawings for each of the thousands of parts that will be used to build the new coaster [14].

2.2.3 Why do people enjoy Roller Coasters?

When going around a roller coaster’s vertical loop, the inertia that produces a thrilling acceleration force also keeps passengers in their seats. As the car approaches a loop, the direction of a passenger’s inertial velocity points straight ahead at the same angle as the track leading up to the loop. As the car enters the loop, the track guides the car up, moving the passenger up as well. This change in direction creates a feeling of extra gravity as the passenger is pushed down into the seat.

At the top of the loop, the force of the car’s acceleration pushes the passenger off the seat toward the center of the loop, while inertia pushes the passenger back into the seat. Gravity and acceleration forces push the passenger in opposite directions with nearly equal force, creating a sensation of weightlessness.

At the bottom of the loop, gravity and the change in direction of the passenger's inertia from a downward vertical direction to one that is horizontal push the passenger into the seat, causing the passenger to once again feel very heavy. Most roller coasters utilize restraint systems, but the forces exerted by most inverting coasters would keep passengers from falling out.

G-forces (gravitational forces) create the so-called "butterfly" sensation felt as a car goes down a gradient. An acceleration of 1 standard gravity (9.8 m/s^2) is the usual force of Earth's gravitational pull exerted on a person while standing still. The measurement of a person's normal weight incorporates this gravitational acceleration. When a person feels weightless at the top of a loop or while going down a hill, they are in free fall. However, if the top of a hill is curved more narrowly than a parabola, riders will experience negative Gs and be lifted out of their seats, experiencing the so-called "butterfly" sensation.

Though hard to pin down, people enjoy roller coasters thanks to a combination of speed, conquering fear, and the positive effects associated with a massive rise in physiological arousal. A roller coaster ride is a legal, generally safe, and relatively cheap means of experiencing a natural high.

Some people, especially thrill-seeking extroverts, seem to enjoy rollercoasters because they get to experience the physical sensations of fear while knowing on some level that they are in fact safe (putting aside rare accidents). Psychologists refer to this enjoyment of sensations that are usually considered negative as 'benign masochism' and it seems to be a uniquely human phenomenon. In the case of rollercoasters, these sensations are fear-related, but other examples of benign masochism include the enjoyment of sad and scary films, disgusting jokes, and painfully spicy chilies. The enjoyment of rollercoasters may be distinct from the pleasure some people get from extreme sports, where the fear and risk of danger are entirely real.

2.2.4 Safety Mechanisms and Technology

As we all know, the premise of comfort is to ensure absolute safety and stability. No matter in the process of a roller coaster, driving, or game, personal safety is always the most important thing.

A variety of safety mechanisms protect riders on roller coasters. One of these is the block system. Most large roller coasters have the ability to run two or more trains at once, and the block system prevents these trains from colliding. In this system, the track is divided into two or more sections known as blocks. Only one train is permitted in each block at any given time. There is a section of track at the end of each block where a train can be stopped if necessary, such as preventing dispatch from the station, stopping a lift, or simply applying brakes. Sensors detect when a train passes so that the system's computer is aware of which blocks are occupied. If a train attempts to enter an occupied block, the stopping mechanisms in all blocks are engaged.

Restraints are another critical aspect of roller coaster safety. Generally speaking, roller coasters usually have two different types: Over-the-shoulder-restraints and lap bar restraints. Both, hydraulic and mechanical safety mechanisms are used within the restraints [15]. Mechanical restraints use a system known as a ratchet and pawl. When riding a roller coaster with a ratchet and pawl system, the sound of clicks can be heard when pulling down the restraint [16]. Hydraulic restraints use a piston and cylinder. Unlike mechanical restraints, there is no feeling of physical or sound of clicks from the restraint being locked in place. Most modern-day roller coasters have sensors that are used to make sure each restraint is locked. If all the restraints are locked, it will send a signal to the ride computer letting it know that it is clear for dispatch. If all restraints are not locked, the train will not be able to move out of the station until each restraint is locked.

Braking systems such as pivoting paws are used on the bottom of the train and on the inclined lift hill. While the cart goes up the lift hill, it is usually pulled by a chain. The pawl moves over bumps that are separated closely apart. In the event that the train ever becomes disconnected from the chain, the anti-roll-back system will engage, and it will fall back into the nearest downhill stop, preventing the train from falling down the lift hill.

Another key to safety is the programmable logic controller (PLC) [16], an essential component of a roller coaster's computer system. Multiple PLCs work together to detect faults associated with the operation and automate decisions to engage various elements (e.g. lift, brakes, etc.). Periodic maintenance and visual inspection by ride engineers are also important to verify that structures and materials are within expected wear tolerances and functioning correctly. Effective operating procedures further enhance safety as well [17].

Roller coasters may seem like a very modern type of entertainment—constantly getting bigger, faster, and scarier thanks to advances in technology. But they actually date back to the mid-1800s. Gravity-propelled railways built to transport coal from up in the mountains down to the town in Pennsylvania, US, were hired out at weekends by fare-paying passengers riding purely for the fun of it.

Today, theme parks are big businesses. But with queues occasionally as long as eight hours for an average ride of under two minutes—not to mention reports of riders suffering strokes, brain deformation, and serious injury due to crashes—we analyzed how come we put ourselves through it. What is it about roller coasters that some love so much?

Enjoying roller coasters is linked to sensation seeking—the tendency to enjoy varied, novel, and intense physical experiences such as rock climbing and parachute jumping. But what sensation do roller coasters provide that is so alluring? At first glance, it may seem to be down to the experience of speed. But the evidence for linking sensation seeking to speed is not compelling. For example, when it comes to driving at speeds above the legal limit, many people do it, not just sensation seekers.

Perhaps the draw of roller coasters is the enjoyment of the visceral sensation of fear itself, much like watching a horror movie. Physical signs of fear such as a pounding heart, faster breathing, and an energy boost caused by the release of glucose are known collectively as the "fight or flight response".

2.3 Overview of Action Games

2.3.1 History of Action Games

Shooter games have been around since the beginning of the video game industry. Notable examples of shooting arcade video games during the early-to-mid-1970s include Syzygy Engineering's Computer Space (1971), Galaxy Game (1971), Tank (1974) by Kee Games, Gun Fight (1975) by Taito and Midway Manufacturing, and Midway's Sea Wolf (1976). In turn, early arcade shooter video games were inspired by early mainframe games such as Spacewar (1962) as well as arcade electromechanical games such as Periscope (1965) and gun games.

During the arcade golden age, from the late 1970s to the early 1980s, a wide variety of new subgenres were created. The success of Space Invaders led to space shooters becoming the dominant genre in arcades for a few years, before a new genre of character-driven action games emerged in the early 1980s.

The term "action game" began being used in the early 1980s, in reference to a new genre of character action games that emerged from Japanese arcade developers, drawing inspiration from manga and anime culture. According to Eugene Jarvis, these new character-driven Japanese action games emphasized "character development, hand-drawn animation and backgrounds, and a more deterministic, scripted, pattern-type" of play. Terms such as "action games" or "character games" began being used to distinguish these new character-driven action games from the space shooters that had previously dominated the video game industry. The emphasis on character-driven gameplay in turn enabled a wider variety of subgenres.

Alongside side-scrollers, rail shooters and light gun shooters also became popular during the mid-to-late 1980s. Popular examples include first-person light gun shooting gallery games such as Nintendo's Duck Hunt (1984), pseudo-3D third-person rail shooters such as Sega's Space Harrier (1985) and After Burner (1987), and Taito's Operation Wolf (1987) which popularized military-themed first-person light gun rail shooters.

In the 1990s, there was a "3D Revolution" where action games made the transition from 2D and pseudo-3D graphics to real-time 3D polygon graphics. 3D arcade system boards that were originally designed for 3D racing games during the late 1980s to early 1990s, such as the Namco System 21, Sega Model 1, and Sega Model 2, were used to produce 3D arcade action games in the early 1990s, including 3D rail shooters such as Namco's Galaxian 3 (1990) and Solvalou (1991), 3D fighting games such as Sega AM2's Virtua Fighter (1993) and Namco's Tekken (1994), and 3D light gun shooters such as Sega AM2's Virtua Cop (1994) and Namco's Time Crisis (1995). On personal computers, the first-person shooter (FPS) genre was popularized by Doom; it is also considered, despite not using 3D polygons, a major leap forward for three-dimensional environments in action games.3D polygon texture mapping appeared in action games around the mid-1990s, introduced to fighting games by Sega AM2's Virtua Fighter 2 (1994), to light gun shooters by Sega AM2's Virtua Cop in 1994, and to FPS games by Parallax Software's Descent (1995).

Whether you're a fan of pizza-gobbling mutant turtles or the pistol-wielding witch on the Switch, 2022 was a breakout year for action games. TMNT: Shredder's Revenge and Bayonetta 3 showed these much-loved icons are still at the top of their game, while Sifu's brutal learning curve made it all the more satisfying when everything clicked. Cult of the Lamb is as adorable as it is unsettling and don't be fooled by Vampire Survivor's simplistic looks, because underneath the pixel art is a roguelike that'll keep you hooked [18].

Action games have developed drastically with advancements in graphic technology over the last decade. Unlike the single character-based Super Mario series, modern action games involve simultaneous fast-paced elements such as shooting and fighting. Further, they have exciting visuals, complex narratives, and boss battles. In action games, the players always have to overcome "enemy boss" characters to reach the next level.

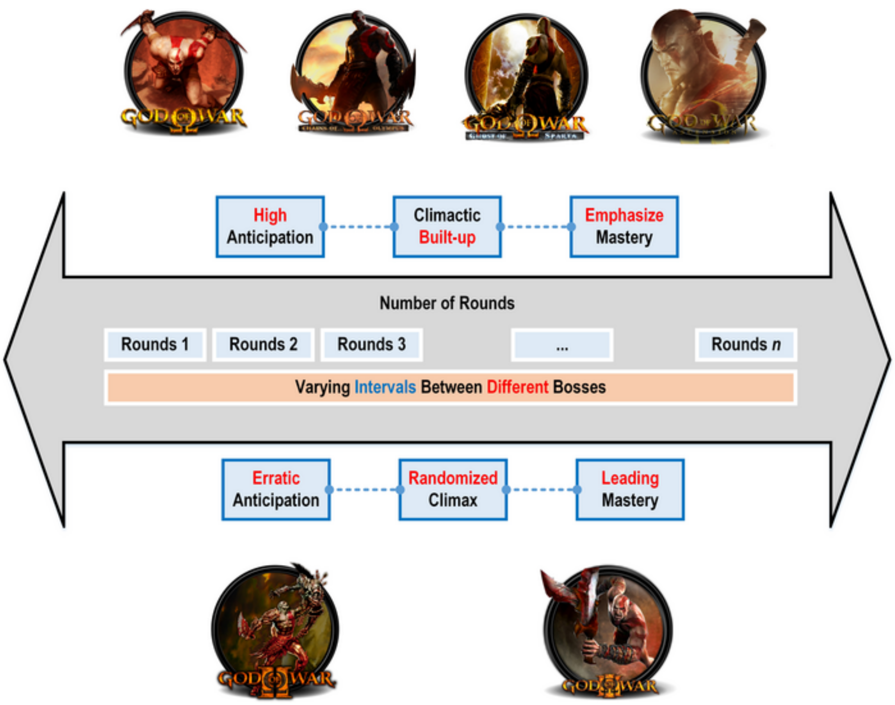

Figure 2.3: The boss battles in the God of War series were analyzed via the game-refinement theory and motion-in-mind, where their entertainment aspects were determined. These aspects provide an exciting game experience for players and insightful design principles for developers.

2.3.2 Action Games Developments

As one of the fastest-growing entertainment industries, the video game industry [19] has various platforms, genres, and cutting-edge technologies. In addition, video games have evolved with specific game mechanics making genres not definitive, while the genre itself is reshaped as the technology develops [20]. As video games become an immersive cultural medium with global implications, game metrics were essential to facilitate the development [21] and [20], which balance narrative (immersive stories), graphics (attractiveness), and game experience (delivering user experiences) towards a game that engaging, educational, and entertaining.

A narrative analysis of the GoW series was conducted by [22] to identify the impression of the game's fundamentals. The study found a significant discord between the advancements in the play mechanics, narrations, and puzzle-solving components of the game, implying that complex interactive elements existed that require a generalized measure or metrics [21], argued that game metrics and analytical techniques would provide the foundation for evaluating and understanding game development via a data-driven framework, allowing for quantifiable and verifiable measures. As such, a generalized game metric could provide the operational measure of development growth and quality of the game itself before its launch or release.

The previous research [23] explored action game design to promote empathy between young adults and the elderly using two play interfaces: finger and foot. The study found that shared action during intergenerational play between individuals and pairing the young and the elderly affected the difficulty and training due to different learning and evaluation metrics paradigms between the generations. Meanwhile, [24] reviewed the possibility and impacts of action video games as a tool to drive attentional control and characterize play style or preferences. However, not all games have the same features to determine player characteristics, implying the need for a paradigm shift from rigid genre categorization but instead relies on a methodology that emphasizes play experience (or data-driven).

Also, previous findings [25] developed an ontology of boss battles in a two-dimensional run-and-gun action game (Cuphead, studio MDHR). The boss attack was clustered using a Gaussian mixture model and multinomial regression to predict the player experience. It was found that fine-grained details of the attack information, instead of an aggregated one, are crucial for better attack clustering and leading to stronger correlation. Finally, Previous research [26] investigated the methods to improve agility in young boxers through action games. Attention should be paid to applying a more sophisticated variant of action games in the training of young boxers to improve the quality of the process to develop agility and unique agility qualities.

Action games also provided a monumental and highly effective training environment that could lead to improvement in vision [27], attention [27] and [24], cognition [27], and agility [27]and [26]. These situations showed that action games outside their original intentions were beneficial and would be invaluable in providing insights towards a better understanding of the player's cognition and coordination. However, an action game's "boss battle" is typically understudied, albeit being the critical component in making or breaking an action game.

Bosses have been part of the video game formula, especially generating and understanding one. Among the previous works on video games, a programming model for describing bosses in 2D action games was developed by [28]. Such a programming model formed the foundational work proposed by [29] which generated the bosses via a program synthesis. Another study by [30] explored the history of bosses to determine enjoyable features of boss battles. In contrast, the previous paper [31] finds metrics to predict qualitative human ratings on game levels in the domain of Super Mario Bros. Nevertheless, these studies do not strive to uncover the underlying entertainment aspect of the game, especially the one carried over from one series to another of the same game title, based on the boss battle.

2.4 Game Refinement Theory and Motion in Mind Concept

The game progress model of game uncertainty is based on early work by [1]. It has been previously applied to measure the design sophistication in domains of business [4], and education [5], and act as a tool for exploring the evolution of popular board games [1] and [6]. The GR values for most popular games are located in a reasonable zone of $GR \in [0.07, 0.08]$. From the player's viewpoint, the information on the game result is an increasing function of time (the number of moves in board games) t. Here, the information on the game result is defined as the amount of solved uncertainty (or information obtained) $x(t)$, as given by (2.3). The parameter n (where $1 \leq n \in N$) is the number of possible options and $x(0) = 0$ and $x(T) = 1$.

$$x'(t) = \frac{n}{t}\, x(t) \tag{2.3}$$

$x(T)$ stands for the normalized amount of solved uncertainty. Note that $0 \leq t \leq T$, $0 \leq x(t) \leq 1$. Equation (2.3) implies that the rate of increase in the solved information $x'(t)$ is proportional to $x(t)$ and inversely proportional to t. Solving (2.3), (2.4) is obtained.

$$x(t) = \left(\frac{t}{T}\right)^n \tag{2.4}$$

It is assumed that the solved information $x(t)$ is twice derivable at $t \in [0, T]$. The second derivative of (2.4) indicates the accelerated velocity of the solved uncertainty along the game progress, which is given by (2.5).

$$x''(t) = \frac{n\ (n-1)}{T^n}\, t^{n-2}\ |_{t=T} \ = \frac{n\ (n-1)}{T^2} \tag{2.5}$$

Accelerated velocity implies the difference in the rate of acquired information during the game's progress. Then, the acceleration motion or free-fall motion in mind, a, is given by (2.6). In the domain of board games, a is approximated as

(2.7), where B and D stand for the average number of possible moves and game length, respectively.

$$x(t) = \frac{1}{2}at^2 \tag{2.6}$$

$$a = \frac{n\ (n-1)}{T^2} \approx \frac{B}{D^2} \tag{2.7}$$

Figure 2.4 illustrates a model of move candidate selection based on skill and chance. This illustration shows that skillful players would consider a set of fewer plausible candidates (say b) among all possible moves (say B) to find a move to play and that there is a core part of its original game with branching factor B. The core part is a stochastic game with a smaller branching factor b since it is assumed that each among b candidates may be equally selected.

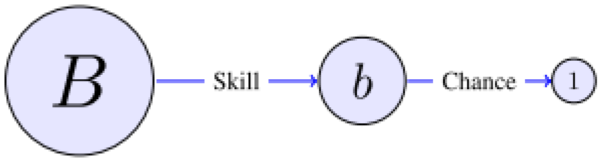

Figure 2.4: An illustration of move selection model based on skill and chance

2.4.1 Motion in mind model

In operant conditioning, a variable-ratio schedule is a schedule of reinforcement where a response is reinforced after an unpredictable number of responses [32] and [33]. This type of schedule creates a steady, high rate of reaction. Stochastic games such as gambling and lottery games are typical examples of a reward based on a variable-ratio schedule. Mind sports [34] games such as chess and Go were also essentially stochastic games while applying the move selection model [3]. This situation implies that a reward of variable-ratio reinforcement schedule characterizes a game [35].

Therefore, the reward function of a game can be characterized by defining the reinforcement schedule's variable rate (denoted as $VR(N)$). Then, velocity v (win rate) and mass m (win hardness) of the motion in mind model are given by (2.8), where $0 \leq v \leq 1$ and $0 \leq m \leq 1$. As such, N was used to measure the frequency of getting rewards, where the player can get a reward in a total average of N steps [36]. Let v_0 be the reward function over various masses for the perfect player as given by (2.9), which corresponds to the objectivity of play. Note that there is a distinctive computation of the v for the board and scoring games [3]. The success rate is defined as $v = \frac{G}{T}$ for scoring games (such as basketball, soccer, etc.), where G and T are the average successful score and the total scores. Meanwhile, the success rate is defined as $v = \frac{B}{2D}$ in a board game (i.e., Chess, Shogi, etc.), where B is the average branching factor, and D is the average game length.

$$v = \frac{1}{N} \quad \text{and} \quad m = 1 - v, \quad \text{where} \quad 1 \leq N \in \mathbb{R} \tag{2.8}$$

$$m + v_0 = 1, \quad \text{where} \quad 0 \leq m \leq 1 \quad \text{and} \quad 0 \leq v_0 \leq 1 \tag{2.9}$$

The notion of energy conservation had been proposed by [37] as a potential measure of engagement, where the formulation of momentum in the game ($\vec{p_1}$) and potential energy in the mind (E_p) are given by (2.10) and (2.11), respectively. Then, the momentum in mind ($\vec{p_2}$) can be derived based on the conservation of energy in mind, given by (2.12), which is associated with the measure of player's engagement, given by (2.13).

$$\vec{p_1} = mv \tag{2.10}$$

$$E_p = 2mv^2 \tag{2.11}$$

$$E_p = \vec{p_1} + \vec{p_2} \tag{2.12}$$

$$\vec{p_2} = E_p - \vec{p_1} = 2m^3 - 3m^2 + m \tag{2.13}$$

Applying (2.13) while assuming $\vec{p_2} = mv_2$, the subjective velocity v_2 is given by (2.14). Let $v_k(m)$ be a reward function over various m for a player with ability parameter k. Then, the relation is generalized as v_k using a parameter (say k where $0 \leq k \in \mathbb{R}$) that is the nature of the game under consideration, as shown in (2.15). The ability parameter k stands for players' strength in the competitive game context or error tolerance in the social or non-competitive context. For example, there is no error tolerance for the perfect player v_0. Note that objectivity and subjectivity perspective enables us to deepen the understanding of engagement and addictive mechanisms in games [37]. Thus, the objective velocity (v_0) and subjective velocity (v_k) were determined.

$$v_2 = 2m^2 - 3m + 1 = (1 - 2m)(1 - m) \tag{2.14}$$

$$v_k = (1 - km)\ v_0, \quad \text{where} \ \ 0 \le k \in \mathbf{R} \tag{2.15}$$

The notion of potential energy in mind was originally discussed by [3] and its formula is given by (2.11). The notion of velocity is derived from the reinforcement schedule $VR(N)$ with frequency N, so we call objective reinforcement (E_0) for the potential energy in mind of the perfect player (v_0). Otherwise, we call subjective reinforcement (E_k) for the potential energy in the mind of other players (v_k). A game would produce its potential energy in the field of play (hence we call it potential energy of play) by which people would feel engagement or reinforcement.

In behavioral psychology, the term "reinforcement" refers to an enhancement of behavior. This term was used as a positive interpretation, i.e., greater reinforcement gives people a more substantial interest to stay in the event under consideration. In the game context, reinforcement depends on the player's ability. The potential energy of play (E_k) is given by $E_k = 2mv_k^2$ which is denoted as *s*ubjective reinforcement. For the perfect player or game theoretical reward ($k = 0$), denoted as *o*bjective reinforcement E_0.

Figure 2.5 illustrated the objective and subjective reinforcement when $k = 3$. The reward function (v_k) represents a player's model or his/her sense of value. When assuming $k > 3$, $v_k < 0$ holds at $m = \frac{1}{3}$ where the objective reinforcement is maximized. This situation implies the learning context's most comfortable (peak of E_0). Therefore, it is highly expected to have $k \le 3$. Furthermore, a board game like Go ($m = 0.42$) is still not yet solved; thus, $2.38 < k$ is expected to hold.

2.4.2 Jerk and comfort in mind

Two processes with the same GR-value at the end of the game information progress may have different instantaneous GR-value tendencies. For example, two basketball teams have the same successful shootings and total shot attempts. So their GR values are the same when the game is finished. However, each team felt different tendencies to get scores. The team with a stable scoring process is predictable, and vice versa. As such, each team's force was not only felt but also the change of the force. In physics, acceleration can be felt in motion and the feeling of jerk [38].

The third derivative of (2.4) indicates the change of accelerated velocity (or jerk [38]) of the solved uncertainty along the game progress [39], which is given by (2.16). Hence, the motion with constant jerk j is given by (2.17), where it is approximate in the domain of board games as (3.4).

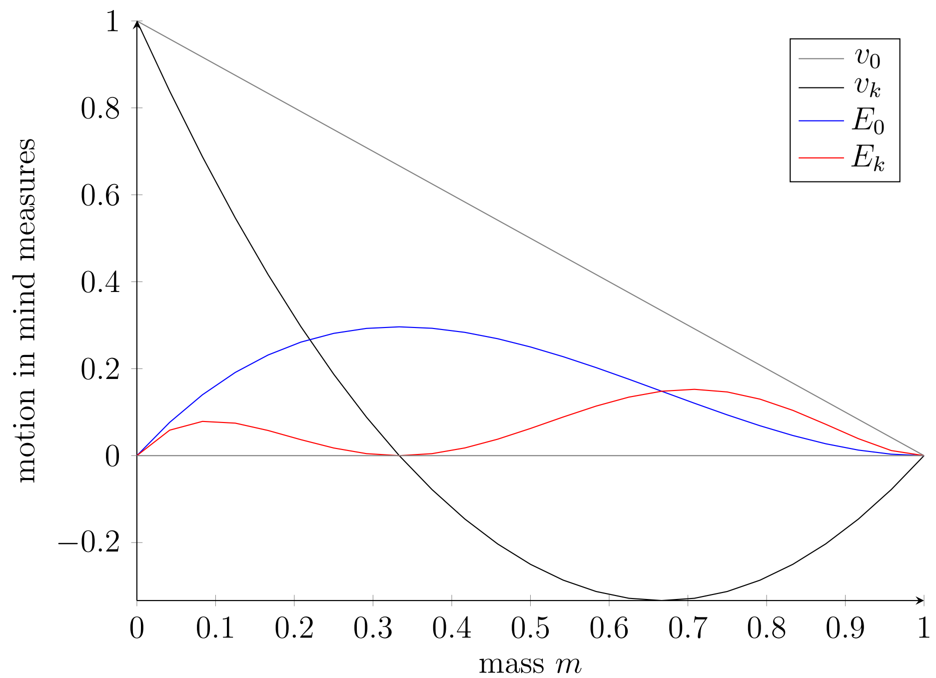

Figure 2.5: Objective and subjective reinforcement when $k = 3$

$$x'''(t) = \frac{n(n-1)(n-2)}{T^n} t^{n-3} \mid_{t=T} = \frac{n(n-1)(n-2)}{T^3} \tag{2.16}$$

$$x(t) = \frac{1}{6} j t^3 \tag{2.17}$$

$$j = \frac{n(n-1)(n-2)}{T^3} \approx 3\frac{B}{D^3} \tag{2.18}$$

Table 2.1 shows the measures of game refinement for board games. For sophisticated board games such as Chess, Shogi, and Go, it is assumed that there exists a reasonable zone for the acceleration (a) and jerk (j), which is between $0.07 - 0.08$, and $0.045 - 0.06$, respectively.

Table 2.1: Measures of game refinement for board games

	B	D	$\sqrt{a}$	$\sqrt[3]{j}$
Chess	35	80	0.074	0.059
Shogi	80	115	0.078	0.054
Go	250	208	0.076	0.044

The cross-point (Figure 2.6) between acceleration and jerk is the point where the maximum amount of achievement is greater than the discomfort (t_1), after t_1, the discomfort will be larger than achievement. The cross-point between velocity and jerk is the point where effort is greater than the discomfort (t_2), and the cross-point between velocity and acceleration is the point where effort is more excellent than achievement(t_3). The cross-point interval ensures a reasonable zone for game length [40].

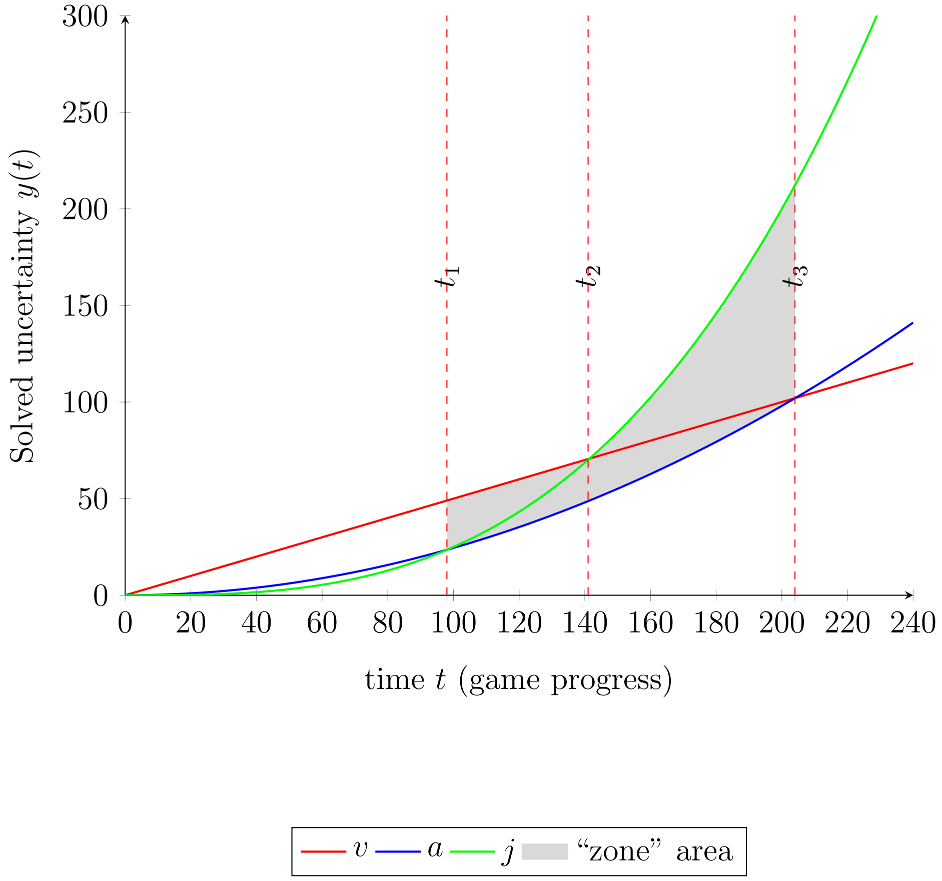

Figure 2.6: The cross point between the line with velocity v, curve with acceleration a and curve with jerk j. t_1; t_2 and t_3 represents the bound for effort, achievement, and discomfort, respectively.

2.5 Methods of data collection

In chapter 3, We collate and collect data from previous papers on roller coasters and the official website of roller coasters, and then analyze them using game refinement theory, to find how dynamic game progress affects players.

In chapter 4, We collate and collect data from action games from real cases and verified the collected data with the video data of skilled players, guaranteeing the accuracy of the data. Through the collected data, we not only analyzed it after combining it with game refinement theory but also fully analyzed the dynamics of the game progress, which is very similar to the design of the roller coaster, The difficulty of the next round is always unknown, unpredictable, non-linear, and dynamic. providing strong support for the subsequent analysis of the roller coaster.

In chapter 5, In order to explore the relationship between the player's psychological emotional state and the physical quantity while playing the roller coaster, we used a questionnaire to collect data.

A questionnaire is a research instrument that consists of a set of questions (or other types of prompts) for the purpose of gathering information from respondents through a survey or statistical study. A research questionnaire is typically a mix of close-ended questions and open-ended questions. Open-ended, long-term questions allow the respondent to elaborate on their thoughts. The Statistical Society of London [41] developed the Research questionnaire in 1838 [42].

2.6 Chapter Summary

In this chapter, related works to this thesis were illustrated. Works related to the important keywords, namely roller coasters, action games, and game refinement theory and motion in mind are reviewed.

Related work on the principle of roller coasters, as well as the analysis of action games, game refinement theory, and motion in mind, also the method of data collection are introduced.

Moreover, in the field of entertainment analysis, game refinement theory which relies on the uncertainty in the process of a game is introduced. Meanwhile, the measurement method of analyzing the change of motions in game-playing from the objective and subjective points of view of the player is expounded, which serves as the base for the linking between ride comfort and play comfort.

These studies are significant as it serves as the base for the research carried out in this thesis regarding the impact of the link between ride comfort and play comfort.

Chapter 3

Bridging Ride and Play Comfort

This chapter is based on the integration, update, and abridgment of the following publication:

- Zhang, Z., Xiaohan, K., Khalid, M. N. A., Iida, H., Bridging Ride and Play Comfort. Information, 12(3), 119, 2021.

3.1 Chapter Introduction

A roller coaster is a type of amusement ride that employs elevated tracks designed with steep slopes, tight turns, and sometimes inversions. The first known roller coaster was designed in 1884. As a popular form of entertainment, roller coasters are deeply loved and enjoyed by many people. Being a combination of games and rides, roller coasters provide a sense of entertainment (mentally) and a riding experience (physically).

In a game-playing context, people feel and ascertain something based on the brain's signals [43, 44]. Therefore, emphasis is placed on the correlation between the physical laws of nature and cerebral sensation and performance. Through the association of play experience with natural physics, a working model can be simulated where data can be collected to determine a mental model's relationship with real-world experiences. This research explores such a relationship by comparing the comfort experienced in play and the ride.

General information on and regulations of roller coasters was utilized to model and emulate the actual behaviors of the roller coaster ride. Tracing the relevant changes of such a roller coaster model was analyzed in the context of both natural physics and game refinement (GR) theory [45]. GR theory regards perfecting the game-playing experience [46, 47] and finding ideal game settings [48, 49], serving as the foundation that bridges natural physics and physics in mind (called motion in mind [3]). As such, a better understanding of the underlying mechanisms and regulations of human life can be established; moreover, new applications of GR theory present themselves.

This study's primary goal is to expand the horizon of riding comfort by bridging play comfort to physical performance and mental experience via roller coasters. The motivation to consider a roller coaster as the target for this research is that it provides the necessary facility to achieve such a purpose, adopting the motion-in-mind concept proposed by Professor Iida and Khalid [3]. The contribution of this study is twofold. First, the roller coaster ride model provides an extended understanding of mental comforts via the concept of motion in mind from a game-playing perspective. This situation involves measuring the rate of information change throughout a simulated roller coaster ride. Secondly, the concept of motion in mind also provides preliminary insights into the physical performance associated with ride comfort. This condition is achieved by bridging motion in mind to motion in physics.

3.2 Literature Review of Roller Coaster

3.2.1 Ride Comfort

Roller coasters have been a terrifying and exhilarating ride for thrill-seekers for centuries. A roller coaster is a large motorized recreational facility sought after by people in amusement parks and theme parks [50]. The earliest incarnation was an ice slide in St. Petersburg, Russia, in 1750 [51]. A Frenchman introduced the idea to Paris fifty years later by building a more permanent structure out of rails and wheels. Most roller coaster rides begin with a lift hill, where a chain connects with the train and carries the riders to the first and tallest incline. As the train reaches the crest of the hill, the chain pushes the train over the hill. Then, gravity takes over and pulls the train down the hill into a controlled free fall.

The maximum speed of the existing roller coaster can reach 206 km/h [52]. The key to the roller coaster's design and manufacture is to ensure the highest safety under high speed and high stimulation. This condition requires that the roller coaster's speed and acceleration must be within the range that the riders can withstand, and the static and dynamic loads on each component must be within its strength range. Research showed that the average person could bear the acceleration of up to 6G in a short time [38,52]. If the acceleration exceeds 8G, the physiological function or internal organ will likely be damaged. The riding experience can be improved through reasonable control of speed and other physical quantities while minimizing its riders' biomechanical effects.

3.2.2 Motions in Mind

Analogical links between motions in physics and motions in mind had been previously established based on the notions of winning rate (or velocity) v and winning hardness m [3]. The correspondence between the physics model and the game progress models is established as in Table 3.1. Such correspondence enables physics in mind in various games, specifically on three quantities: potential energy, momentum, and force.

Table 3.1: Analogical link between game and physics [3]

Notation	**Game Context**	**Notation**	**Physics Context**
y	solved uncertainty	x	displacement
t	progress or length	t	time
v	win rate	v	velocity
m	win hardness	M	mass
a	acceleration	g	gravitational acceleration
E_p	potential energy	U	potential energy

The momentum ($\vec{p}$) in the game refers to the competitive balance of a game, which involves the degree of challenge needed (m) and effort given (v) to drive the game progression [3], given by (3.1). Meanwhile, the potential energy (E_p) in the game is defined as the game playing potential or the expected game information required to finish a game [3]. It was derived from the analogy of gravitational potential energy given by (3.3), where the analogical link was adopted by linking the kinematics formula of displacement $h = y = \frac{1}{2}at^2$ and $g = a$, resulting into (3.3). The third derivative of the game progress model described by Iida and Khalid [3] indicates the change of accelerated velocity (or jerk [38]) of the solved uncertainty [46], where the motion with a constant jerk (j) is approximate in the domain of board games as (3.4).

$$\vec{p} = mv \tag{3.1}$$

$$U = mgh \tag{3.2}$$

$$E_p = ma(\frac{1}{2}at^2) = \frac{1}{2}ma^2t^2 = 2mv^2 \tag{3.3}$$

$$j = \frac{n(n-1)(n-2)}{T^3} \approx 3\frac{B}{D^3}. \tag{3.4}$$

3.2.3 Thrill Feeling

Under the premise of ensuring safety, improving rider engagement is an estimable topic in recent years. Riders were unable to sense or feel the speed of the ride intuitively. For example, when riding a train or bus, the general perception is the process of uniform decelerating (slowing down) at a certain speed when arriving. Such an experience is bland and, most likely, not fun at all. However, the experience of acceleration and its changes (say jerk) can be felt. In the physical world, passengers feel acceleration via force, while the jerk is felt through both positive and negative forces (inertia). When the subway starts and stops, it is often accompanied by much jerkiness [53]. If a passenger accidentally falls on a train ride, the acceleration after starting is much larger than when it is just started, but it is more “soft” and less likely to cause injury. Therefore, when designing the elevator’s power system, the elevator should be slowly accelerated, and when the train track turns, the straight rail cannot be directly connected to the large angle curved rail.

Such velocity changes (acceleration) have been considered concerning the feeling of thrills [3], which is typically observed in sophisticated games. However, it is unclear whether such a phenomenon can also be kept in a real-world situation, especially in the context of ride comfort. The extent of the accelerated changes (jerk) was also previously explored, which relates to motivation retention [46]. Thus, the thrilling experience is regarded as the bridge between motion in the real world and motion in mind.

3.3 Methodology

3.3.1 Ride Comfort in Physics

Motion control applications include passenger elevators and machining tools. Limiting vertical jerk is considered essential for elevator riding convenience. ISO 18738 specifies measurement methods for elevator ride quality and rules that specify acceptable or unacceptable ride quality levels. It is reported that most passengers rate a vertical jerk of 2.0 m/s^3 as acceptable and 6.0 m/s^3 as intolerable. As for human body capacity, 0.7 m/s^3 is the recommended limit [54].

In motion control, the design focus is on straight, linear motion, with the need to move a system from one steady position to another (point-to-point motion). Meanwhile, the design concern from a jerk perspective is the vertical jerk, where the jerk from tangential acceleration is virtually zero since linear motion is non-rotational. The primary design goal for motion control is to minimize the transition time without exceeding speed, acceleration, or jerk limits, and the third-order motion-control profile with quadratic ramping and deramping phases in velocity.

Because the human body feels acceleration, when a coaster car is speeding up, the actual force acting on the body is the seat pushing the body forward. However, the force is felt in front of the body because of the body's inertia, pushing into the seat. The force of accelerated push was always felt coming from the opposite direction of the actual force accelerating the body. This force (for simplicity's sake, called the acceleration force) feels the same as the force of gravity that pulls you toward Earth.

The main principle of a roller coaster ride is that it can reach the highest height through the conveying machinery, but when the highest point is reached, there is no power output, and the roller coaster entirely relies on the potential energy of gravity to move. Such an acceleration force is measured in G-force, where 1G is equal to the acceleration force due to the gravity of the Earth's surface (9.8 m/s^2, or 32 ft/s^2).

3.3.2 Data Collection on The Physics of Roller Coasters

The acceptable limit of force applied to the human body is typically up to about 6G, based on the top 11th high G-force roller coaster in the world (Table 3.2). For this study, the data from the top 11th high G-force roller coaster are adopted, which are also categorized as the top 50 most popular roller coasters for 2020 (Table 3.4) voted by Theme Park insider [55].

Table 3.2: The top 11th high G-force roller coaster

Rank	***g***	**Velocity**	**ΔHeight**	**Length**	**Duration***	**Name**	**Year**
1st	6.3	95.0	50.0		3:34	Tower of Terror	2001
2nd	5.9	97.0	35.4	1097.3	2:00	Shock Wave	1978
3rd	5.2	81.0	30.1	844.0	2:20	Euro-Star	2008
3rd	5.2	96.5	38.7	1279.6	1:13	Mindbender	1985
3rd	5.2	76.0	35.5	285.0	1:48	Speed of Sound	2000
4th	5.0	109.9	54.6	381.0	2:02	Diving Machine G5	2000
4th	5.0	206.0	127.4	950.4	0:28	Kingda Ka	2005
4th	5.0	80.5	40.0	309.0	1:30	invertigo	1998
4th	5.0	112.0	61.0	971.7	2:20	SheiKra	2005
4th	5.0	91.7	24.4	1037.2	1:22	Rock n Roller Coaster	1999
4th	5.0	72.0	31.0	787.0	1:50	Suspended Looping	2003
4th	5.0	80.0	25.7	670.0	1:30	Typhoon	2016
4th	5.0	72.0	31.0	787.0	1:50	Vortex	2007
4th	5.0	105.0	46.0	150.0	0:50	X Coaster	2006
4th	5.0	90.0	25.8	996.0	1:15	Xpress	2000
4th	5.0	144.8	91.4	1554.5	3:00	Intimidator 305	2010
5th	4.9	80.0	32.0	823.0	2:00	Batman (Model)	1999
5th	4.9	89.0	34.4	1053.7	2:12	Revolution	1976
6th	4.8	240.0	52.0	2000.0	1:32	Formula Rossa	2010
6th	4.9	101.0	50.9	891.2	2:52	The Odyssey	2002
7th	4.5	150.0	91.4	2010.2	2:20	Millennium Force	2000
7th	4.5	148.0	93.3	1672.1	3:28	Leviathan	2012
7th	4.5	161.0	126.5	376.4	0:28	Superman	1997
7th	4.5	160.9	115.0	376.4	0:28	Tower of Terror II	1997
8th	4.4	110.0	53.6	1341.1	1:42	El Toro	2006
9th	4.3	129.0	65.5	1644.1	2:20	Nitro	2001
10th	4.1	117.0	64.0	1488.0	2:15	Apollo's Chariot	1999
11th	4.0	153.0	97.5	2012.3	3:00	Fury 325	2015

g: G-force; $\star$: minutes:seconds.

3.3.3 Excitement in Roller Coaster Data Collection

Data collected from the real-world roller coaster has included some physics indexes. However, some of the roller coasters are very old, and it is challenging to compare the player's excitement level solely based on such data. As such, it is necessary to simulate how the physics settings reflect the excitement. Hence, the RollerCoaster Tycoon game was adopted to deal with this situation.

RollerCoaster Tycoon Classic is a construction and management simulation video game developed by Origin8 Technologies and published by Atari. The game combines features that were first seen in RollerCoaster Tycoon and RollerCoaster Tycoon 2, both amusement park management simulators created by Chris Sawyer for the PC [56]. The game was released worldwide for iOS and Android in December 2016 [57], while a version for Microsoft Windows and macOS was released in September 2017 [58].

Among the many game's goals (i.e., improving the park, managing guests, and others), the goal that prominently aligned with this study is the ride's data metric that maximizes excitement without making the ride too intense or nauseating. Furthermore, the data set includes both the player excitement and physics data [59]. In this study, the game was adopted to redesign the real-world roller coaster where the results concluded from the ride statistics, such as excitement rating and other physics indexes (velocity, maximum G-force, minimum G-force), were collected for further analysis. This condition assumes that the number of riders on roller coaster rides is always high (best-case scenario).

3.3.4 Experimental Setups

The experiment was designed in two stages. Firstly, the data of the roller coaster rides collected from all around the world were analyzed from the perspective of real-world physics, where the potential energy (denoted as E_p), momentum (denoted as $\vec{p}$), and force (denoted as F) were computed by Equations (3.5)–(3.7), respectively. Secondly, three-dimensional roller coaster simulation data were collected via the statistical data obtained from the RollerCoaster Tycoon game through the recreation of the real-world roller coaster rides by approximating the data available from Table 3.2.

$$E_p = mgh \tag{3.5}$$

$$\vec{p} = mv \tag{3.6}$$

$$F = ma. \tag{3.7}$$

These two experiments aimed to establish the relationships between potential energy, momentum, and force of real-world physics and the simulated one. Furthermore, those relationships are then analyzed further based on the concept of motion in mind to extend the understanding of the physical and mental comforts in ride using roller coasters (both real and simulated) as the bridge for excitement and thrill experience, from the perspective of information sciences. It is important to note that real-world roller coaster data is adopted into the Roller Coaster Tycoon game as the simulation environment for further analysis.

3.4 Experimental Results and Discussion

3.4.1 Evolution of Roller Coaster and Physics of Motion

People deeply love roller coasters as a popular entertainment facility since 1885. The roller coaster development changed between 1976 and 2016, in which the results have been shown based on the top 11th high G-force roller coaster, and their respective physic measures were computed and given in Table 3.3 and illustrated as in Figure 3.1. It can be observed that energies in this period are linearly rising, which shows that the ride experience requires tremendous energy as the year progresses. Also, roller coaster development paid much attention to providing users with an immersive experience based on the momentum that does not change and stabilizes around 150 kg/m/s, which was found to be the momentum that was the greatest since more users possess the ability to enjoy such a roller coaster ride. Overall, the roller coaster design has not changed too much from 1976 to 2016.

From the perspective of force, it can be found that the force is decreasing as the year progresses. It was observed that the latest roller coaster rides pursue the sense of thrill from the ride and pursue enrichment of the play experience. Observing the G-force changes throughout the years, it was found that G-force tends to decrease. In the early time of building the roller coaster, the only thing designers focused on is the thrilling feeling.

Table 3.3: The top 11th high G-force roller coaster

Name	$\boldsymbol{F}$	$\vec{\boldsymbol{p}}$	$\boldsymbol{E_p}$	**Length (m)**	**Duration***	**Year**
Tower of Terror	6.3	95.0	50.0		3:34	2001
Shock Wave	5.9	97.0	35.4	1097.3	2:00	1978
Euro-Star	5.2	81.0	30.1	844.0	2:20	2008
Mindbender	5.2	96.5	38.7	1279.6	1:13	1985
Speed of Sound	5.2	76.0	35.5	285.0	1:48	2000
Diving Machine G5	5.0	109.9	54.6	381.0	2:02	2000
Kingda Ka	5.0	206.0	127.4	950.4	0:28	2005
invertigo	5.0	80.5	40.0	309.0	1:30	1998
SheiKra	5.0	112.7	61.0	971.7	2:20	2005
Rock 'n' Roller Coaster	5.0	91.7	24.4	1037.2	1:22	1999
Suspended Looping Coaster	5.0	72.0	31.0	787.0	1:50	2003
Typhoon	5.0	80.0	25.7	670.0	1:30	2016
Vortex	5.0	72.0	31.0	787.0	1:50	2007
X Coaster	5.0	105.0	46.0	150.0	0:50	2006
Xpress	5.0	90.0	25.8	996.0	1:15	2000
Intimidator 305	5.0	144.8	91.4	1554.5	3:00	2010
Batman (Model)	4.9	80.0	32.0	823.0	2:00	1999
Revolution	4.9	89.0	34.4	1053.7	2:12	1976
Formula Rossa	4.8	240.0	52.0	2000.0	1:32	2010
The Odyssey	4.9	101.0	50.9	891.2	2:52	2002
Millennium Force	4.5	150.0	91.4	2010.2	2:20	2000
Leviathan	4.5	148.0	93.3	1672.1	3:28	2012
Superman: Escape From Krypton	4.5	161.0	126.5	376.4	0:28	1997
Tower of Terror II	4.5	160.9	115.0	376.4	0:28	1997
El Toro	4.4	110.0	53.6	1341.1	1:42	2006
Nitro	4.3	129.0	65.5	1644.1	2:20	2001
Apollo's Chariot	4.1	117.0	64.0	1488.0	2:15	1999
Fury 325	4.0	153.0	97.5	2012.3	3:00	2015

g: G-force; *: minutes:seconds.

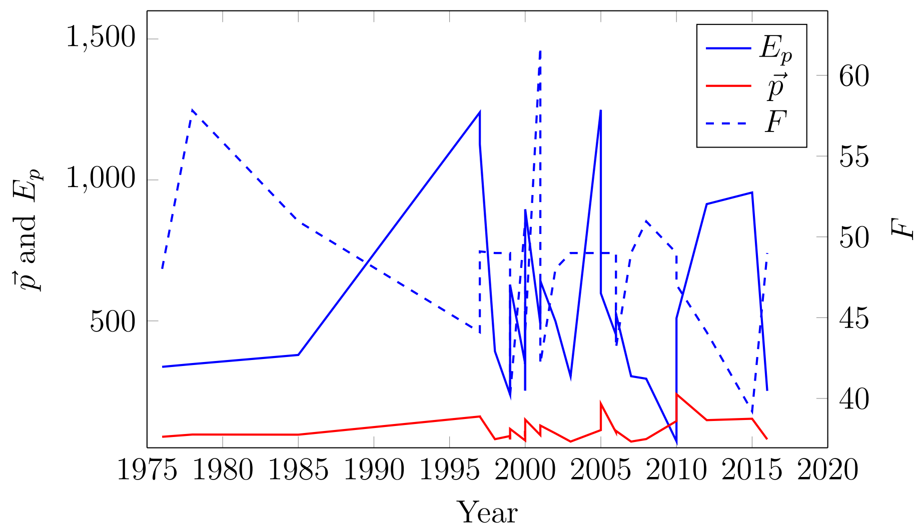

Figure 3.1: Motions changes of the roller coaster ride during different periods.

Indeed, roller coaster design has evolved significantly over the years, with a greater focus on providing a more immersive and entertaining experience for riders. The inclusion of theme design, role-playing, and immersive plot elements is a prime example of this trend. These aspects of the ride can help to create a more memorable and engaging experience for riders, beyond just the physical sensations of the ride itself.

Additionally, roller coaster rides with longer lengths and durations (length $\geq$ 1000 meters and duration $\geq$ 3:00 minutes). can offer a different type of experience, providing riders with a more sustained thrill over a longer period. These rides may also incorporate more twists, turns, and drops, as well as slower sections and scenic views, to create a more varied and engaging experience.

Overall, the recent variations in roller coaster design demonstrate the industry's commitment to innovation and creativity in providing riders with new and exciting experiences.

3.4.2 Comparison of Physical Roller Coaster and Roller Coaster in Mind

According to the previous section, it is found that the thrilling feeling is reflected by acceleration, but the thrill felt does not directly relate to player engagement. In the following sections, the link between the thrill feeling and player engagement in the roller coaster is established with real-world physics and the concept of motion in mind.

Here, we list the Top 50 most popular roller coasters in the appendix of this section.

Table 3.4: Top 50 most popular roller coasters

Name	g	**Velocity***	**ΔHeight***	**Length***	**Duration****	**Year**
Fury 325	4.0	153.0	97.5	2012.3	3:00	2015
El Toro	4.4	110.0	53.6	1341.1	1:42	2006
Steel Vengeance	1.0	119.1	61.0	1749.6	2:30	2018
Outlaw Run		109.4	49.4	895.2	1:27	2013
Superman The Ride	3.6	123.9	67.4	1645.9	2:35	2000
Top Thrill Dragster		193.1	128.0	853.4	0:30	2003
Iron Rattler	3.6	112.7	52.1	995.5	1:52	2013
Thunderbird	1.0	96.6	42.7	925.1	1:18	2015
Wicked Cyclone	1.0	88.5	33.2	1011.9	1:37	2015
Nitro	4.3	130.0	66.0	1644.0	2:20	2001
Phoenix		72.4	21.9	975.4	2:00	1985
Twisted Timbers	1.0	86.9	33.8	1024.4	2:00	2018
Twisted Cyclone	1.0	80.5	30.5	731.5	1:48	2018
Copperhead Strike		80.5	25.0	992.1	2:24	2019
Manta	3.7	90.1	34.4	1023.8	2:35	2009
Dragon Khan	4.3	104.6	49.1	1269.5	1:45	1995
Millennium Force	4.5	149.7	91.4	2010.2	2:20	2000
Space Mountain	3.7	48.3	27.4	974.1	2:30	2005
Mystic Timbers		85.0	30.0	995.0	2:00	2017
Mako		117.5	61.0	1450.8		2016
Leviathan	4.5	148.1	93.3	1672.1	3:28	2012
Tatsu		99.8	33.8	1097.9	2:00	2006
Montu	3.8	96.6	39.0	1214.0	3:00	1996
Space Mountain		71.0	32.0	1051.0	2:15	2005
Blue Fire	3.8	100.0	38.0	1056.0	2:30	2009
Time Traveler		81.0	27.4	920.5	1:57	2018
De Vliegende Hollander	3.0	70.0	22.5	420.0	3:45	2007
Diamondback	4.2	128.7	65.5	1610.0	3:00	2009
Nemesis	3.5	80.5	31.7	716.0	1:20	1994

Continued on next page

Table 3.4 continued from previous page

Name	g	**Velocity***	**ΔHeight***	**Length***	**Duration****	**Year**
Jurassic Park The Flying Dinosaur		99.8	37.8	1124.0		2016
Apollo's Chariot	4.1	117.0	64.0	1488.0	2:15	1999
Intimidator 305	5.0	144.8	91.4	1554.5	3:00	2010
GhostRider	3.1	90.1	32.9	1381.7	2:40	1998
Xcelerator	4.0	132.0	62.5	671.2	1:02	2002
Cheetah Hunt	4.0	96.6	39.6	1350.0	4:00	2011
Lightning Racer	3.6	82.2	27.4	1034.2	2:20	2000
Afterburn	4.5	99.8	34.4	901.0	2:47	1999
Big Thunder Mountain		65.0	12.0	1500.0	3:56	1992
Mamba	3.5	120.7	62.5	1706.9	3:00	1998
The Voyage	4.0	107.8	46.9	1963.5	2:45	2006
SheiKra	4.0	112.7	61.0	971.7	2:20	2005
Storm Runner	4.2	120.7	54.9	792.5	0:50	2004
Expedition Everest	3.0	80.5	24.4	1348.4	2:50	2006

According to the data from Table 3.2, the physical motions with an increase of excitement are illustrated as in Figure 3.2 to Figure 3.4. It can be observed that potential energy, force, and momentum were increasing at varying degrees. Among the three physical measures, the potential energy showed significant increases with the increasing excitement based on the linear data regression (Figure 3.3). This trend was followed by momentum, albeit lower in magnitude (Figure 3.4), while the force was much lower (Figure 3.2). Nevertheless, the overall directions of all the physical measures are directly proportional to the excitement (Excitement $\propto E_p > \vec{p} > F$).

Meanwhile, considering the concept of motion in mind in the framing of a roller coaster ride, the player is expected to experience a sense of thrill in the game-playing process. Based on the player satisfaction model [60], a method to express the thrill feeling in game-playing can be elicited where the N in roller coasters was found, which corresponds to the drops in the ride. The player's feelings will be stimulated at each reversal. Based on this situation, the motions in mind measures are illustrated in Figure 3.5 to Figure 3.7. It can be observed that the amount of potential energy in mind and the momentum in mind similarly decreases while having a high fluctuation when the excitement is between five and eight (x-axis). Concurrently, force in mind was observed with an increasing trend with some fluctuation, which increased further when excitement rises.

Such situations demonstrate the differences between natural physics and the physics of the mind, where motion in the mind had a different sense of "gravity" [61] that impacted the potential energy in mind and momentum in mind measures. In essence, the "gravity" may be associated with the player's perceptions of the current situation (i.e., reward or pleasure). Establishing a reliable measure of "gravity" in mind may be a game-changer in promoting a comfortable playing experience.

It is also worth noting that the player satisfaction model mentioned in the text can be a useful tool for game designers to understand and improve the player's experience. By identifying the drops in the ride that correspond to the player's feelings, game designers can create a more engaging and exciting gameplay experience. Additionally, the observations regarding the relationship between physical measures and excitement can inform the design of more realistic roller coaster simulations in games, which can enhance the player's immersion and enjoyment.

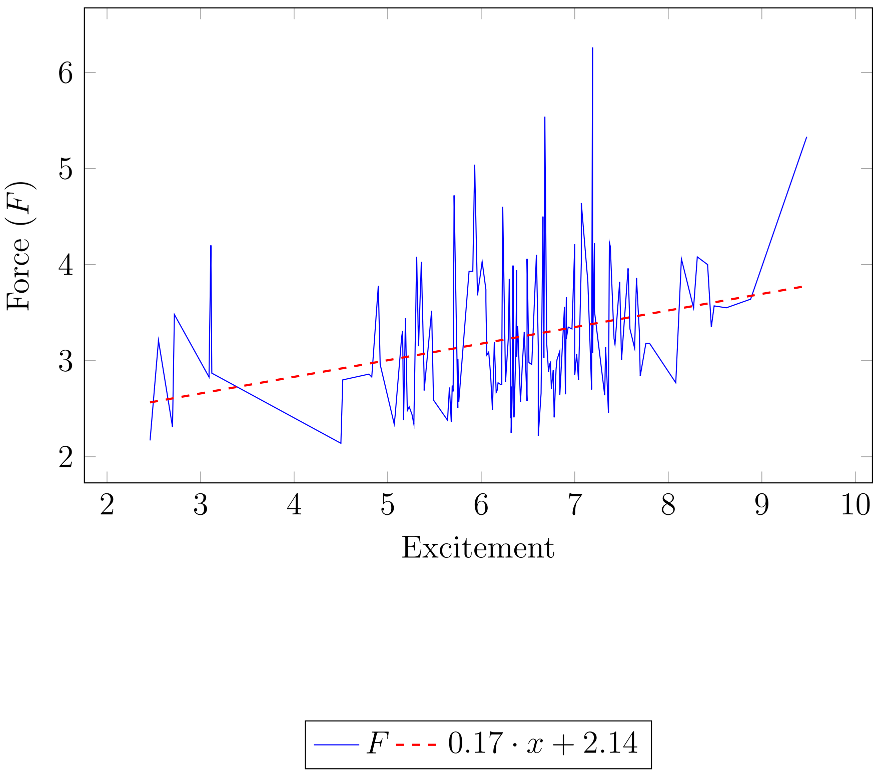

Figure 3.2: Excitement and force

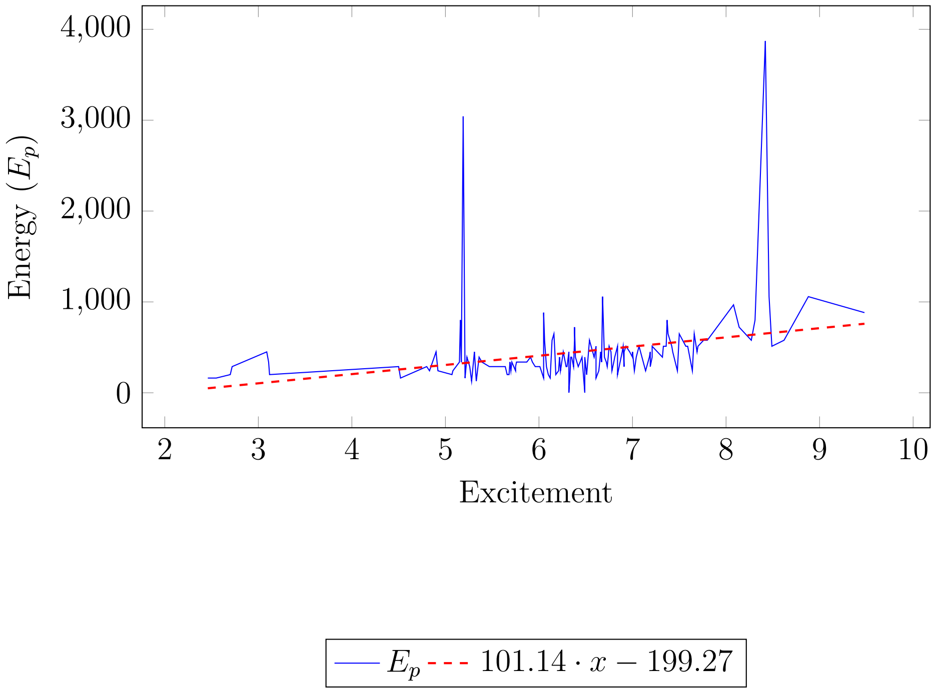

Figure 3.3: Excitement and potential energy

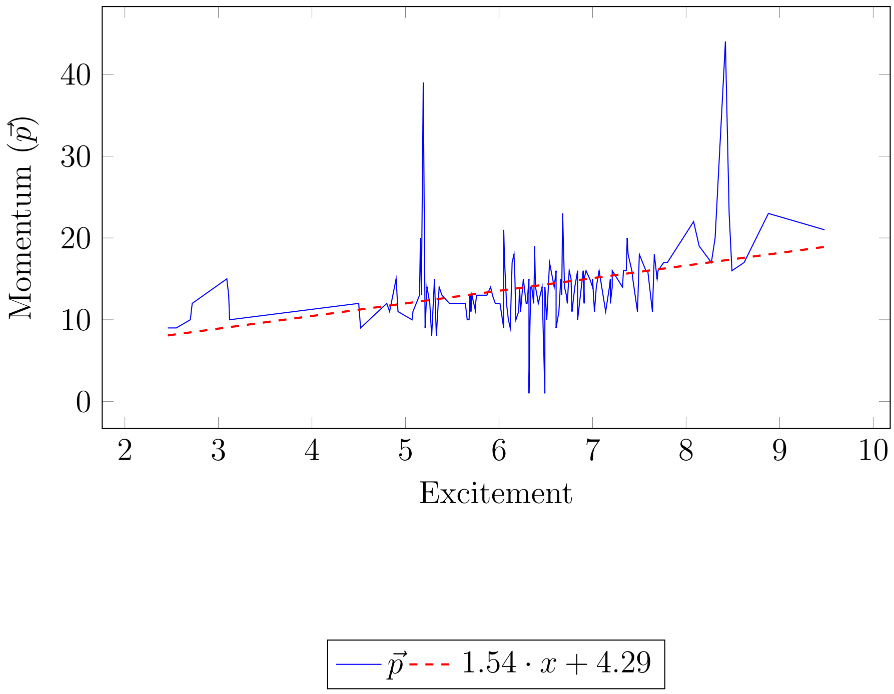

Figure 3.4: Excitement and momentum

The list figure are the dynamics of computed physical roller coaster based on increasing excitement and Figure 3.5 Force in mind, Figure 3.6 Energy in mind, and Figure 3.7 Momentum in mind.

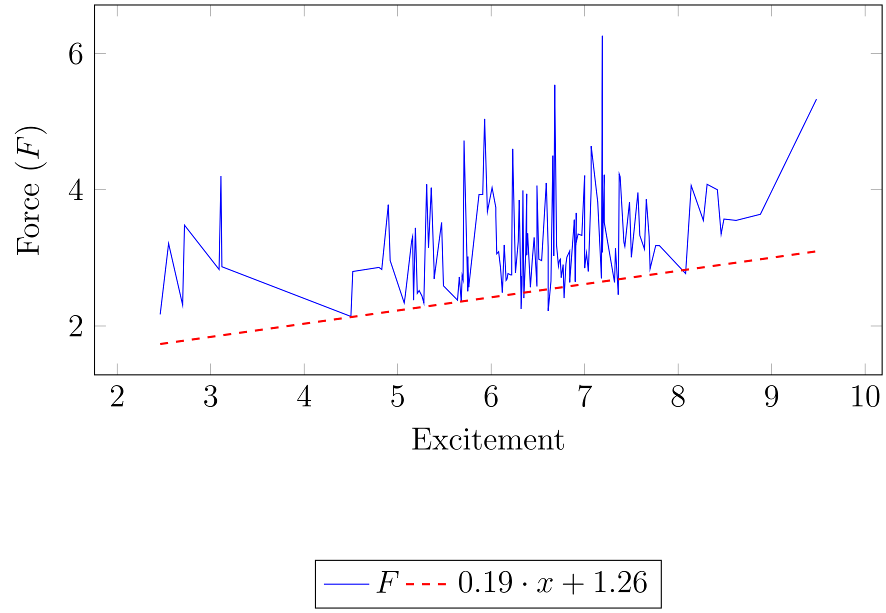

Figure 3.5: Excitement and force in mind (force)

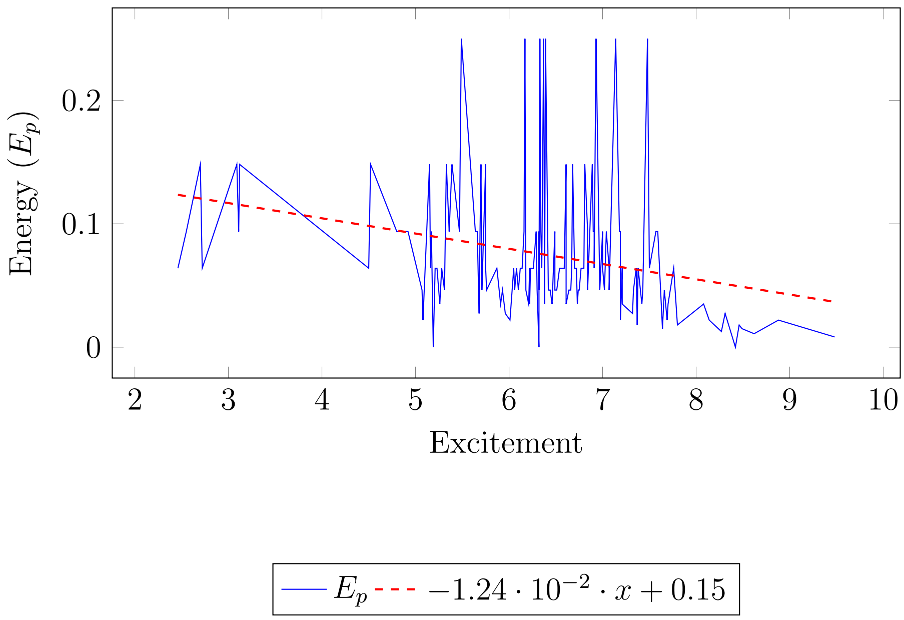

Figure 3.6: Excitement and energy in mind (energy)

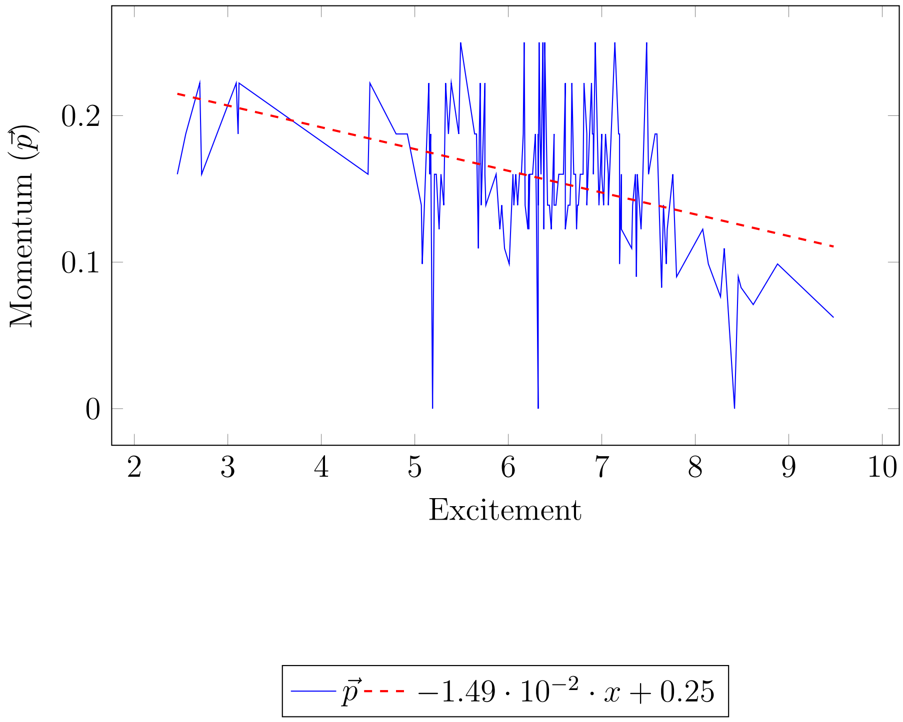

Figure 3.7: Excitement and momentum in mind (momentum)

3.4.3 The Link Between Natural Physic and Physic of The Mind

The initial riding on the roller coaster involves reaching the highest height through the conveying machinery. However, when the roller coaster reaches the highest point, there is no power output, and the roller coaster relies entirely on the potential energy of gravity to move. Thus, a physical roller coaster moves by gravity from high to low while having increasing velocity ($v = gt$). In other words, a physical roller coaster relies on unidirectional velocity change.

In contrast, the roller coaster in mind moves by tackling uncertainty from an unstable state to a stable one, where the frequency rate of seesaw turnover or up-down of the uncertainty played a crucial role in making the ride experience exciting. As such, a roller coaster in mind has both increased and decreased velocity (bidirectional). This situation describes the rate of uncertainty change that corresponds to acceleration, which relates to the thrilling sense that a player felt (concurrent with what a rider felt) due to the rapid evolution of pace between advantageous and adverse conditions throughout the play (or ride) experience.

Motions in natural physic were based on the real velocity and acceleration, whereas the motions in mind were mainly based on the parameter defined as the turnover frequency (N). According to the data, the relationship between both sides was established, as shown in Table 3.5. According to Iida and Khalid [3] and Xiaohan *et al.* [60], $F(N)$ corresponds to the player's effort to move in the game (work), $\vec{p}(N)$ corresponds to fascination or seesaw in the game (play), and $E_p(N)$ corresponds to the difficulty of entrancement and player satisfaction.

Here, it is conjectured that $F = F(N)$ when the user's effort is equaled to the force given upon by the game and the user can comfortably enjoy it. The user and the game synchronize their rhythm, where the user experiences an equal force with the force expressed by the game. From the results illustrated in Figures 3.2 and 3.5, it can be seen that there is an interval overlap between F and $F(N)$ at excitement value $\in [5, 8]$ where $F - F(N) \simeq 0 \pm 0.44$ (Figure 3.8). Further inspection of the $F(N)$ revealed that the jerk at excitement value of about five and eight was observed to be the highest, whereas the fluctuation is the most frequent at excitement value between five and eight (Figure 3.9). Such a moment demonstrates that the experience in both ride and play is considered comfortable by the user.

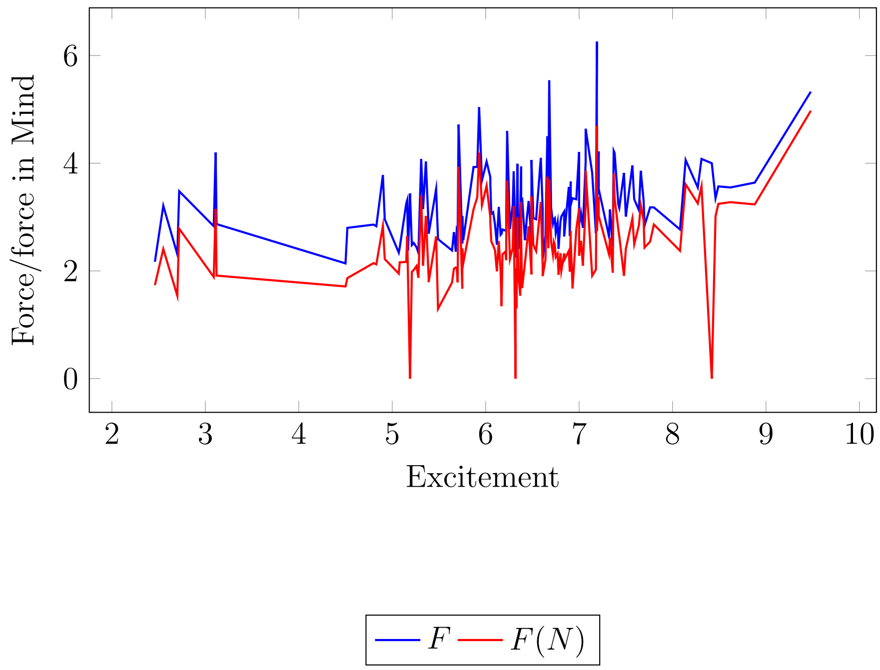

Figure 3.8: Force and force in Mind

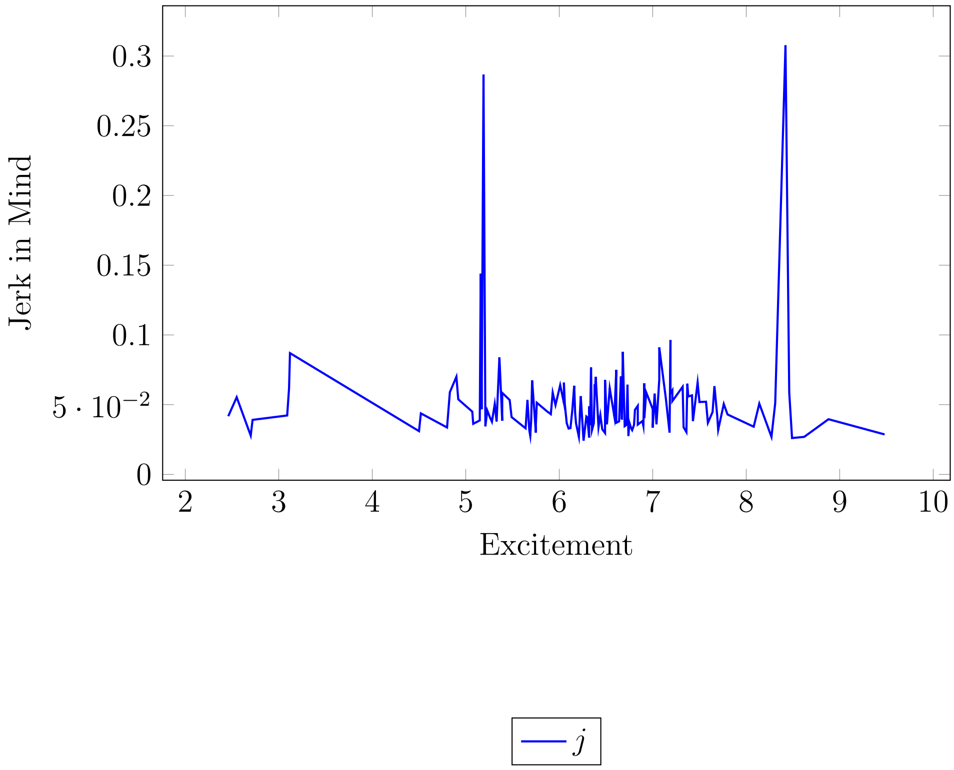

Figure 3.9: Jerk in Mind

Table 3.5: Analogical link between motions in mind and physics

		Energy		**Momentum**		**Force**	
		Low	High	Low	High	Low	High
$E_p(N)$	High	$\Updownarrow$	$\Downarrow$	$\Updownarrow$	$\Downarrow$	$\Updownarrow$	$\Downarrow$
	Low	$\Uparrow$	$\Updownarrow$	$\Uparrow$	$\Updownarrow$	$\Uparrow$	$\Updownarrow$
$\vec{p}(N)$	High	$\Updownarrow$	$\Downarrow$	$\Updownarrow$	$\Downarrow$	$\Updownarrow$	$\Downarrow$
	Low	$\Uparrow$	$\Updownarrow$	$\Uparrow$	$\Updownarrow$	$\Uparrow$	$\Updownarrow$
$F(N)$	High	$\Uparrow$	$\Updownarrow$	$\Uparrow$	$\Updownarrow$	$\Uparrow$	$\Updownarrow$
	Low	$\Updownarrow$	$\Downarrow$	$\Updownarrow$	$\Downarrow$	$\Updownarrow$	$\Downarrow$

$\Uparrow$: high excitement; $\Downarrow$: low excitement; $\Updownarrow$: unstable.

However, there were moments where $F - F(N) > 0$, which demonstrates the situation where the force expected to be felt by the user is overwhelming and could make the user feel uncomfortable, due to "surprise" (sudden change of j). In contrast, there was no moment where $F - F(N) < 0$, which implies that the ride's force experience is comfortable, and the player's ability to perceive such a force is acceptable, making the ride experience to be perceived as boring or dull.

Based on the results of $F = F(N)$, it can be inferred that there is a close approximation of the natural force (F) and the force in mind ($F(N)$), where the difference can be observed based on the occurrence of the jerk (j). According to the findings, some excitement levels are associated with frequent fluctuating measures, demonstrating that the changes in acceleration (thrills) and jerk (surprise) were expected to some extent. Interestingly, those results implied that bridging between physical and mental comfort existed, and jerk played an essential mental comfort element.

3.5 Chapter Summary

This study expanded the research that bridges ride comfort and play comfort, where roller coasters are utilized to establish the links between physical performance and mental experience (called the motion in mind). It was found that the roller coaster from 1976 to 2016 had evolved from being a pure thrill ride into an exciting ride experience, which was demonstrated by the changes in the potential energy, momentum, and force of such a ride experience. Such an experience was achieved by considering the trade-off between the physics indexes and the rides' physical properties.

Furthermore, the link between ride comfort and play comfort relative to the natural physic's motion and motion in mind was established according to the changes in ride speed (and direction), which can be reflected by the overlapping of the physical force and force in mind. The measure of $F \simeq F(N)$ was an essential indicator of the comfort expected, both in the ride's physical and mental aspects. Additionally, analogical links based on its excitement stability were tabulated to determine the comfort trade-off expected from a ride. Finally, it was found that jerk is an element that existed within the comfort of the play experience and should be avoided in the physical ride's comfort. Such a condition implies that the play experience had a different influence on the ride's comfort when compared to the physical ones.

However, further investigation is needed to explore the extent of the jerk's influence on the ride's comfort and experience. Potential future directions can be explored in defining the settings of a comfortable ride in various types and modes of transportation and applying the riding comfort in autonomous vehicles in conjunction with other state-of-the-art algorithms.

Chapter 4

Action Games Evolution Analysis: A Case Study Using the God of War Series

This chapter is based on the integration, update, and abridgment of the following publications:

- Zhang, Z., Gao, N., Li, S., Khalid, M. N. A., Iida, H., Action Games Evolution Analysis: A Case Study Using the God of War Series. IEEE Access, 10, 123697-123710, 2022.

4.1 Chapter Introduction

The defining characteristic of action games has depended substantially on their historical development. From many players' perspectives, they are straightforward: controlling a single game character passing levels can be called an action game (i.e., Super Mario series). Sometimes, the game character may do a series of movements and passes several levels. In the view of electronic video games, action games have no strict border. For example, fighting games can be seen as one branch of action games [62] and [63]. However, fighting games focus on competition and are programmed by rounds. As such, a clear definition of an action game is a challenging question [64].

So what are action games? As the name implies, action games take "action" as the primary means of expression to be called action games. Such a situation is what exactly makes an action game's definition complicated. Before 2005, simple action games became harder and more challenging to enter the gaming market [65]. The fast pace of technological invention has allowed electronic video games to have a vast capacity, so the elements a game contains can be unlimited. As a result, action games now may also include a good deal of different fighting-like game factors, shooting, and even puzzle-solving elements [66] and [67]. In addition, multiplayer online battle arenas or real-time strategy games are also considered part of action games.

With the development of new graphic technology, action games also made many improvements. In addition to the typical action-based gameplay, they may sometimes contain a significant proportion of other fast-paced game factors throughout the whole game series, such as shooting (i.e., Uncharted series [68]), fighting (i.e., Assassin's Creed series [69]), or both (i.e., God of War series [70]). These condition increases the games' tension and makes them more attractive. In essence, action games are challenging to define due to their multifaceted play packed into a single game, compared to simple and monotone action games a decade earlier. Furthermore, the choice and storytelling provided by the action games, which is movie-like, immerse players in a flow-like state due to having the freedom of making their "own story," such as different endings, consequences of choices, and interconnected narratives. Action games are sorted into two types; one pays attention to beautiful, exaggerated movements, while the other is realistic. Some action games appeal to players with their gorgeous combos and the manipulation of players (i.e., fighting games [67]). Other action games combine exciting storytelling, background music, and optical effect incongruity while becoming the means to express themselves. In both instances, action games involve learning and gaining experience, where players must think to pass through specific challenges while enjoying the game. While an action game includes necessary physical factors to overcome challenges (such as precise aim and quick response times), other factors such as competitions, puzzle-solving, collecting objects, strategy, planning, and exploration challenges were also important. However, such factors were catered toward the pressure of time running out, which uniquely represents a challenge in action games [65].

As an electronic video game, action games generally represent one title or story [63]. It emphasizes the ability of players' hand-eyes coordination and players' reactions. Action games are typically played by game consoles, assisted by computing units and graphic processing, and driven by compelling storytelling and narrative, forwarding the leading line of games while adding high tension in completing the whole game's story. Players usually manipulate the protagonist or avatar, allowing the players to choose and immerse themselves in various game elements, such as leveling up, collecting objects (utility or generally), avoiding obstacles or enemies, and engaging [71] in various actions (i.e., battling enemy, find treasure, build items, etc.). At the end of a level or group of levels, the players always have to beat against a "boss enemy" character, which becomes the biggest challenge for them [72].

Although boss battles were a significant part of any modern action game, studies on its evaluation metric and efficiency on such battle scenes or level(s) were scarcely investigated. To the best of our knowledge, the only study that focuses on the boss battle in an action-like game was the study by [25]. The study showed that specific game metrics could quantify critical insights into game entertainment. In this study, data from the God of War (GoW) series were collected, and analysis of these data was conducted to identify the underlying entertainment aspects of the game. In addition, the evolution of the GoW between the main series and additional releases, based on the changes, specifically on the boss battles, which influenced the entertainment of such titles, were investigated.

4.2 Analysis of Action Games

4.2.1 Game Refinement Model and Its Extension

Revisiting the game refinement (GR) theory, the original formulation of the outcome uncertainty from the game progress model is based on early work by [45]. It was applied to measure the design sophistication in domains of business [73] and education [74] while acting as a tool for exploring the evolution of popular board games [45] and [75]. The GR values for most popular games were situated within a reasonable zone of $GR \in [0.07, 0.08]$.

Considering the players' viewpoint, the information on the game result is an increasing function of time (the number of moves in board games) t. Here, the information on the game result is defined as the amount of solved uncertainty (or information obtained) $x(t)$, as given by (4.1). The parameter n (where $1 \leq n \in N$) is the number of feasible options and $x(0) = 0$ and $x(T) = 1$. $x(T)$ stands for the normalized amount of solved uncertainty. Note that $0 \leq t \leq T$, $0 \leq x(t) \leq 1$. (4.1) implies that the rate of increase in the solved information $x'(t)$ is proportional to $x(t)$ and inverse proportional to t. Solving (4.1), (4.2) is obtained.

$$x'(t) = \frac{n}{t}\ x(t) \tag{4.1}$$

$$x(t) = \left(\frac{t}{T}\right)^n \tag{4.2}$$

It is assumed that the solved information $x(t)$ is twice derivable at $t \in [0, T]$. The second derivative of (4.2) indicates the accelerated velocity of the solved uncertainty along with the game progress, which is given by (4.3). Accelerated velocity is the difference in the rate at which information is gathered as the game progresses. Then (4.5) gives the acceleration or "free-fall" motion in mind (denoted as a). a is estimated in the domain of board games as (4.4), where B and D denote the average number of possible moves and game length, respectively.

$$x''(t) = \frac{n\ (n-1)}{T^n}\ t^{n-2}\ |_{t=T}\quad = \frac{n\ (n-1)}{T^2} \tag{4.3}$$

$$a = \frac{n\ (n-1)}{T^2} \approx \frac{B}{D^2} \tag{4.4}$$

In the context of sports (or shooting games), the game information [76] progress was created by the number of attempts (T) and the total number of goals (G); it can analyze different game-playing mechanisms revealed in each state; given by their velocity (v), acceleration (a), and jerk (j) during their game processes (see (4.5)). In physics, mass determines the difficulty of changing the state of motion when an object is stressed. Thus, mass is a physical quantity that describes the inertia of an object, which describes the "heaviness" and the difficulty of holding an object [77]. In games, the risk factor is the reason that determines the difficulty of progression and; thus, the difficulty of obtaining scores. Therefore, assuming the mass as the risk rate, then the mass is given by $m = 1 - v$, where velocity (v) of information progress is the speed of getting goals, described by (4.6).

$$x(t) = \frac{G}{T} = \frac{1}{2}at^2 = \frac{1}{6}jt^3 \tag{4.5}$$

$$v = \frac{G}{T} \tag{4.6}$$

Since the possible attempts or moves for one goal, (N) is defined as (4.7), which was based on the definition of variable reward schedule of reinforcement rewards. Solving (4.5), the solutions of acceleration and jerk are (4.8) and (4.9). Correspondingly, it is known that GR and AD values measure entertainment and quantify unpredictability by (4.10) and (4.11). It was found that both GR and AD measures played an important role in retaining players' interest and enjoyment [78]. Table 4.1 shows the measures of game refinement for board games. For sophisticated board games such as Chess, Shogi, and Go, it is assumed that there exists a reasonable zone for the acceleration ($\sqrt{a} = GR$) and jerk ($\sqrt[3]{j} = AD$), which is between $GR \in [0.07, 0.08]$, and $AD = [0.045, 0.06]$, respectively.

$$N = \frac{1}{v} = \frac{T}{G} \tag{4.7}$$

$$a = \frac{2G}{T^2} \tag{4.8}$$

$$j = \frac{3G}{T^3} \tag{4.9}$$

$$GR = \sqrt{a} \tag{4.10}$$

$$AD = \sqrt[3]{j} \tag{4.11}$$

Table 4.1: Measures of game refinement for popular board games, adopted from [3].

	B	D	$\sqrt{a} = GR$	$\sqrt[3]{j} = AD$
Chess	35	80	0.074	0.059
Shogi	80	115	0.078	0.054
Go	250	208	0.076	0.044

In the motion in mind model, momentum in mind ($\vec{p}$) is among the analogy of physic measures that were adopted, given by (4.12). Based on its first derivative, where $\vec{p}' = 1 - 2v = 0$, and $v = \frac{1}{2}$ and $\vec{p} = \frac{1}{4}$, the peak of $\vec{p}$ can be identified. At $v = \frac{1}{2}$, the probabilities of win and loss are halved, and so do the risk rate ($m = 1 - v = \frac{1}{2}$). In addition, $\vec{p}$ is the difficulty to stop moving objects and the tendency of moving objects to keep moving. Also, $\vec{p}$ is an instantaneous variable that measures the momentary trend based on the current velocity. Finally, concerning the game process, $\vec{p}$ describes players' tendency to maintain the game's state and continue to focus on the game. In other words, when their success rate is constant, their tendency to keep playing the game is the highest. Hence, the $\vec{p}$ measures the players' tendency to keep playing the game in different velocity situations [79].

$$\vec{p} = m \cdot v = (1 - v) \cdot v \tag{4.12}$$

Potential energy ($\vec{E_p}$) is the energy stored at an initial position and related to the expectation of the specific state. For different winning rates, there are different energy and different expectations in our minds. $\vec{E_p}$ given as (4.13), in the context of a game, is defined as the amount of the required game information a player needs in progressing the game [3] which implies the anticipation of the player in finishing the game. As a game progresses, the game's potential energy reflects the anticipation the game may give the player (degree of winning comfort). More importantly, this helps the game designer determine the stability of a sophisticated game.

$$\vec{E_p} = 2mv^2 \tag{4.13}$$

The notion of energy conservation provided a deeper knowledge of games' engagement and addictive mechanisms by differentiating the perspective of objectivity and subjectivity [37]. The momentum ($\vec{p_1}$) is regarded as half of a combination of potential energy in the mind (E_p), then based on the conservation of energy in mind, given by (4.16), the momentum in mind ($\vec{p_2}$) can be derived, associated with the player's engagement, given by (4.17). Applying (4.17) by assuming the formulation of $\vec{p_2} = mv_2$ where the subjective reward v_2 is given by (4.18).

$$\vec{p_1} = mv \tag{4.14}$$

$$E_p = 2mv^2 \tag{4.15}$$

$$E_p = \vec{p_1} + \vec{p_2} \tag{4.16}$$

$$\vec{p_2} = E_p - \vec{p_1} = 2m^3 - 3m^2 + m \tag{4.17}$$

$$\vec{v_2} = 2m^2 - 3m + 1 = (1 - 2m)(1 - m) \tag{4.18}$$

Then, the velocity (v relabelled as v_1) and its subjective one (v_2) are established, where v_0 is the reward function over various masses of the perfect player. As such, the objectivity is given by (4.19). By generalization, $v_k(m)$ is the reward function over various m for a player with ability parameter (k), given by (4.20). k corresponds to the strength of players in the competitive game context or error tolerance in the social or non-competitive context (i.e., there is no error tolerance for the perfect player v_0).

$$v_0 = 1 - m, \quad \text{where} \quad 0 \leq m \leq 1 \quad \text{and} \quad 0 \leq v_0 \leq 1 \tag{4.19}$$

$$v_k = (1 - km)v_0, \quad \text{where} \quad 0 \leq k \in \mathbb{R} \tag{4.20}$$

Generalizing the notion of reward frequency (denoted as N) and the concept of reinforcement schedule (denoted as $VR(N)$). The objective reinforcement (E_0) refers to the potential energy in mind of the perfect player (v_0). Otherwise, the subjective reinforcement (E_k) refers to the potential energy in the minds of other players (v_k). A game would produce its potential energy in the field of play (hence, called potential energy of play) where players would experience engagement or "reinforcement" (Figure 4.1) relative to the enhancement of behavior in behavioral psychology. Such a term was used as a positive interpretation, where greater reinforcement gives people a greater interest in staying on the event under consideration.

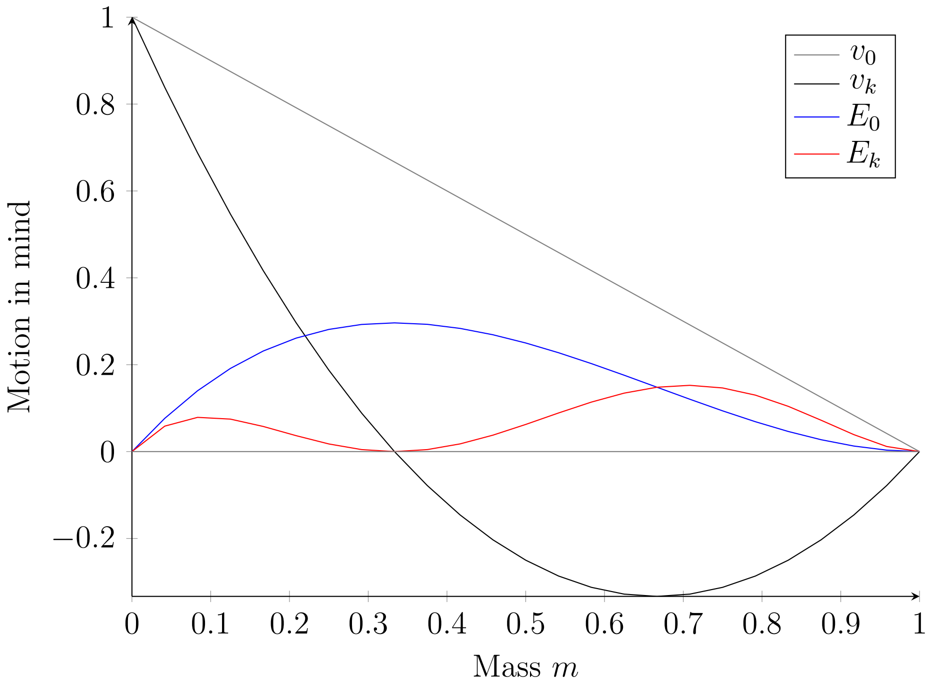

Figure 4.1: Objective and subjective reinforcement when $k = 3$

The notion of reinforcement relies on the player's ability in the game context, where the reward function (v_k) represents the model of the sense of the value of the players. When $k > 3$, $v_k < 0$ holds at $m = \frac{1}{3}$ where the objective reinforcement is maximized. This condition implied that most comfort point (peak of E_0) is not included in the learning context. Therefore, it is highly expected to have $k \le 3$. Since the Go game ($m = 0.42$) is still not yet solved, then it is expected that $2.38 < k$ holds. As mass (m) becomes larger, at $0 \le m \le \frac{1}{3}$, Δ_k increases (Figure 4.2). Meanwhile, Δ_k decreases at $\frac{1}{3} \le m \le \frac{2}{3}$.

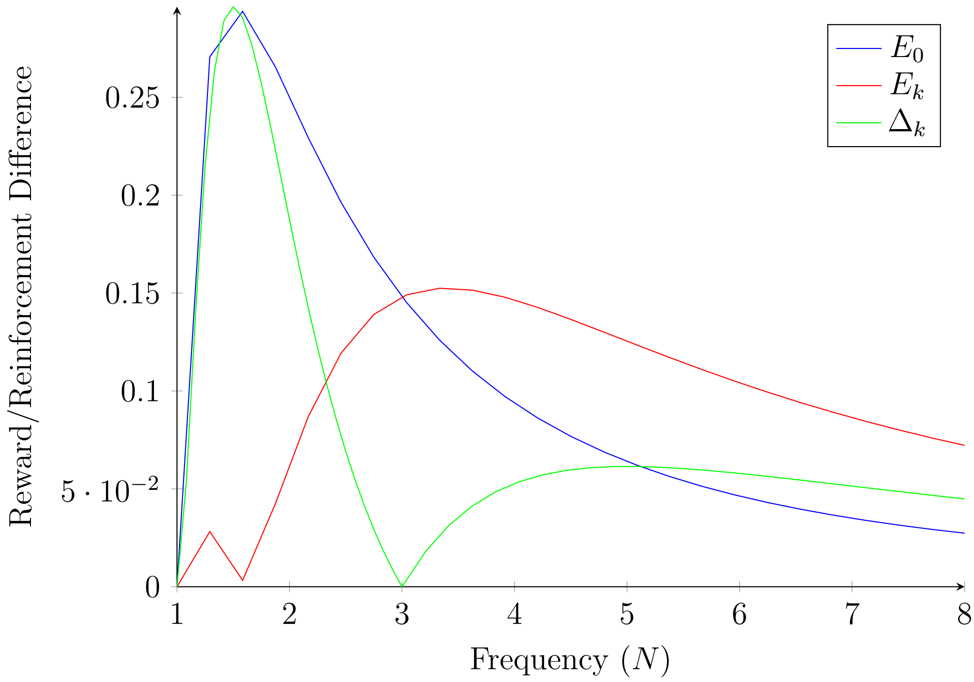

Figure 4.2: Objective and subjective reinforcement difference Δ_k when $k = 3$

Additionally, subjective reinforcement $\left(E_k \; ; m = \frac{1}{4k}\right)$ was maximized at its peak in the non-competitive gaming context (such as puzzle solving or solving comfort). This condition implied that puzzle solving or solving comfort is highly engaged at the success rate of $v_k\left(\frac{1}{4k}\right) = \frac{3}{4} - \frac{3}{16k} \mid_{k=3} = \frac{11}{16} = 0.6875$. Meanwhile, Δ_k is maximized at its peak at $m = \frac{4}{5}$ when $k = 3$, which implies the game under consideration is extremely engaged due to its high competition level (called competitive comfort).

[Learning and competitive comfort] Δ_k is maximized at its peak $m = \frac{1}{3}$ when, $k = 3$ where learning comfort is optimized. Meanwhile, Δ_k is maximized at its peak $m = \frac{4}{5}$ when $k = 3$ where the game under consideration is extremely engaged due to its high competition level.

4.2.2 Analyzing God of War Series

Table 4.2 provided all the GoW series releases, based on Greek mythology, according to their time of release, including replicas and original versions. The newest version of the God of War series was released on the PlayStation 4 (PS4) platform in March 2018, focusing on modern Norse mythology. However, the newer version was excluded due to significantly different game mechanics, play experience, and narrative design. The series consists of seven single-player-only games and one that includes multiplayer. God of War: Ascension is the first in the series to feature online-only multiplayer for competitive and cooperative play. GoW games featured a third-person, fixed cinematic camera (except for GoW: Betrayal, the only installment to feature a 2D side-scrolling view). Meanwhile, a first-person camera is featured in God of War III and GoW: Ascension. Throughout the series, the player controls the character Kratos in a combination of hack-and-slash combo-based[1] combat, platforming, and puzzle elements to achieve goals and complete the game's narrative.

The GoW series was primarily developed in most of the major PlayStation platforms (PlayStation 2, PlayStation 3, PlayStation 4), including the portable and console versions and the mobile phone. This condition showed that the GoW series was a versatile medium for various game mechanic experimentation (design of the quick time events, side-scroller play), control schemes (changes from the controller of the console into a portable version), and mode of interfaces (i.e., stereoscopic 3D of GoW: Origins collection). Furthermore, different marketing schemes (collections of high-definition remastered GoW releases) and business model development (downloadable contents) were also explored, which provided eudaimonic experiences and narrative engagement of the play [80]. Such situations were due to the well-blend mechanics' support and key narrative themes provided by the series. In addition, the interface design was essential to drive significant impression [81], which was integrated into part of the series. On the one hand, it could enhance the immersion of the play (adapted control between different platforms), while on the other, it may break the game's narrative flow (cutscenes not in 3-dimension while the gameplay does).

Action games were known for extended gameplay and sometimes complex narrative [82]. Naturally, this implies that players will spend more time on an action game. Such a condition is especially true when fighting against a boss, which can range from 10 minutes up to half an hour. Therefore, The GoW series was adopted

[1] A set of actions performed in sequence, usually with strict timing limitations, that yield a significant benefit or advantage, typically found in fighting games.

Table 4.2: History of God of War

Version	Year	Platform	Publisher	Description (Added Feature)
GoW	2005	PS2	SCE	The first game (combo-based combat, puzzles, platforming, QTEs)
GoW II	2007	PS2	SCE	The second game (enhanced puzzles and bosses)
GoW: Betrayal	2007	M-Phone	SPD	A only mobile phones game with 2D side-scroller
GoW: Chains of Olympus	2008	PSP	SCE	The first game for the PSP (reconfigured control scheme)
GoW Collection	2009	PS3	SCE, Capcom	A HD reissue of first and second games with remote play function
GoW III	2010	PS3	SCE	The best game in the series (enhanced control system, enemies, DLC)
GoW: Ghost of Sparta	2010	PSP	SCE	The second game for the PSP (25% more content)
GoW: Origins Collection	2011	PS3	SCE	A 2011 reissue of two PSP game with Stereoscopic 3D
GoW: Saga	2012	PS3	SCE	Reissue of five games in the series, except for GoW: Betrayal
GoW: Ascension	2013	PS3	SCE	The last game for this series (enhanced quick time events)
GoW Collection	2014	PSVA	SCE, Capcom	A PlayStation Vita reissue of first and second games
GoW III: Remastered	2015	PS4	SCE	A 2015 HD reissue of God of War III (DLC)

Remote play: transmit video and audio output to another device; DLC: downloadable content; M-Phone : Mobile Phone; SCE: Sony Computer Entertainment; SPD: Sony Pictures Digital; Quick time events (QTEs): complete game controller actions in a timed sequence;
2D: Two dimensional; HD: high-definition; Stereoscopic 3D: enhanced illusion of depth in image; PS 2/3/4: PlayStation 2/3/4; PSVA:PlayStation Studios Visual Arts;PSP:PlayStation Portable;

as the representative of the action game because the crucial part of this study focuses on the fight against the boss. Although action games such as the GoW series were classified as action-adventure games [65], with the advancement of graphics from both hardware and software, this kind of game involves a lot of factors and decision-making while having continuous movement games. Such a concept emerged in the 70s but fell short in design and innovation in the game-playing experience [83]. With decades of advancement in action games, the gameplay standards have soared and become more complex. Therefore, another aspect of our study is to analyze the historical differences between the GoW series.

In action games, boss battles were influential elements that were not well-studied. Game bosses can be generally defined as a significant computer-controlled enemy that must be defeated to reach a goal or ensure continued progression [84]. As battling a boss can be regarded as overcoming insurmountable odds, it depicts a universal conflict at the core of the human psyche, which drew the player, as the main protagonist, to participate actively [30]. While the developer meant the boss battle to be there, it also offers a new experience, or somewhat related to the emotional height, compressed into a single point or moment, which to some extent, breaks the established rules of the game and makes it exciting and engaging. As such, the boss battle remains highly popular in most developers' retrospection and design philosophies. Therefore, such reasons motivate this study to explore in-depths, from the perspective of game informatics, the entertainment aspects that arise from the boss battles, specifically in the GoW series. Adopting GR theory relative to the considered GoW series, two types of information in each round of boss battle were recorded. The first one is the sum of attack numbers completed by Kratos against the in-game boss battle, denoted as the game length (T). The second one is the sum of the successfully attacked adversary, also called successful attacks or instruction attempts, denoted as (G).

4.3 Computational Data and Result Analysis

This study collected data on the GoW battles with the boss for six games of the GoW series. Excluding the replica, re-edition versions, and the one released in the mobile phone version, there are six productions in total in the GoW series. These six productions were analyzed in this research, focusing on the boss battle. In any modern action game, the battle with the boss is a crucial inflection point in the game narrative, influencing the overall game outcome and providing the means to natural progression [85], [30] and [25].

As one of the most renowned action game series, there are many commentaries on the internet and many videos made for the GoW series, especially those which have completed the whole series. These videos facilitate the collection process by obtaining valuable data where only the recorded videos that passed all six chapters were observed to ensure quality and consistency. The data collection was conducted with five people with different levels of play experience in the GoW series. The participants were five males of varying ages (between 20 and 40) and educational levels (between bachelor's degrees or above, up to doctorate graduate levels). These players were considered to have some experience in action games (considered beginner players) to the ones that frequently played action games (considered expert players). They have explicitly agreed to participate in the data collection and were briefed on its purpose.

The statistics and average of the data collected were compared with a well-known Chinese game blogger (called Heigutongge[2]). The typical time for each boss fight is about five minutes. According to the game refinement theory, two data in each round of the boss battle were recorded for the video. The first data is the sum of attack numbers completed by Kratos against the in-game boss battle, denoted as the game length (T), representing all attacks (successes and failures). The second data is the sum of the successfully attacked adversary, also called successful attacks or instruction attempts, denoted as (G). This quantity is counted by adjusting the recorded video's speed to be played at half the normal speed (50% slower) to reduce the possibility of miscounts or errors.

4.3.1 Analysis of GoW Series Based on Sophistication (GR) and Challenge (m)

The player controls the protagonist (Kratos) in this fighting game to attack the boss; some attacks are efficient while others are not. Meanwhile, every single attack is an attempt, whether successful or not. In addition, the main GoW series was also unique because it has all the characteristics of simple fighting games but also decides the winner and loser in one round, like board games. However, players must undergo two or three rounds to defeat a boss and later be accompanied by a boss transformation. Such transformation changes the attacking style, game scenes,

[2]Example gameplay recording by the Heigutongge YouTube channel on GoW I: https://youtu.be/mlgjNpsZDj0

and interludes of cinematic storytelling. This situation makes the game experience fresh, adds amusement value, and allows the player to relax, calm their nerves, and concentrate on the boss battle.

The values of G and T of the six productions of the GoW series were recorded, where the GR value was calculated (Table 4.6 to Table 4.11). It provides the results of the computed GR values and the associated motion in mind measures (v, m, N, $\vec{p}$, and $\vec{E_p}$) of the boss battle scene, where each table corresponds to one game production of the GoW series. To visualize such findings, the trend of the GR and m of each GoW series, based on the sequence of bosses, were plotted (Figure 4.3 to Figure 4.8).

Tendencies of GR and m for Figure 4.3 GoW I, Figure 4.4 GoW II, Figure 4.5 GoW: Chains of Olympus, Figure 4.6 GoW III, Figure 4.7 GoW: Ghost of Sparta, and Figure 4.8 GoW: Ascension.

Table 4.6 shows the basic data of God of War I, and based on Table 4.6 we got Figure 4.3 to show more details intuitively. We can easily to see the tendency of GR and m of God of War I.

Table 4.7 shows the basic data of God of War II, and based on Table 4.7 we got Figure 4.4 to show more details intuitively. We can easily see the tendency of GR and m of God of War II in Figure 4.4.

Then, we are going to explore the next version, Table 4.8 shows the basic data of God of War: Chains of Olympus, and based on Table 4.8 we got Figure 4.5 to show more details intuitively. We can easily see the tendency of GR and m of God of War: Chains of Olympus in Figure 4.5.

As for the God of War III version, Table 4.9 shows the basic data of God of War III, and based on Table 4.9 we got Figure 4.6 to show more details intuitively. We can easily see the tendency of GR and m of God of War III in Figure 4.6.

Next, we will analyze the God of War: Ghost of Sparta version, Table 4.10 shows the basic data of God of War III, and based on Table 4.10 we got Figure 4.7 to show more details intuitively. We can easily see the tendency of GR and m of God of War III in Figure 4.7.

Finally, we will analyze the last version. God of War: Ascension, Table 4.11 shows the basic data of God of War III, and based on Table 4.11 we got Figure 4.8 to show more details intuitively. We can easily see the tendency of GR and m of God of War III in Figure 4.8.

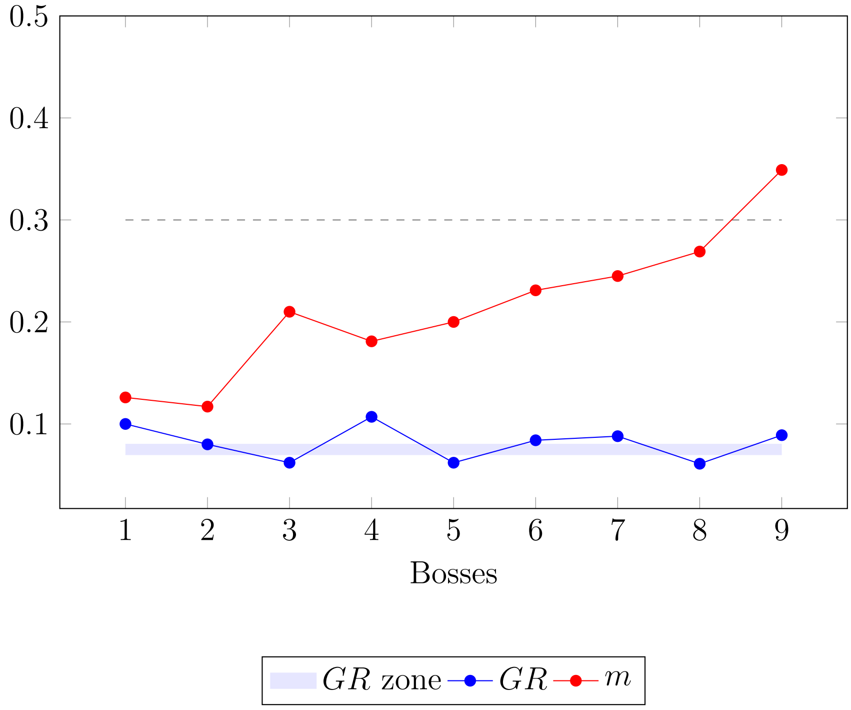

Figure 4.3: Tendency of GR and m of GoW I

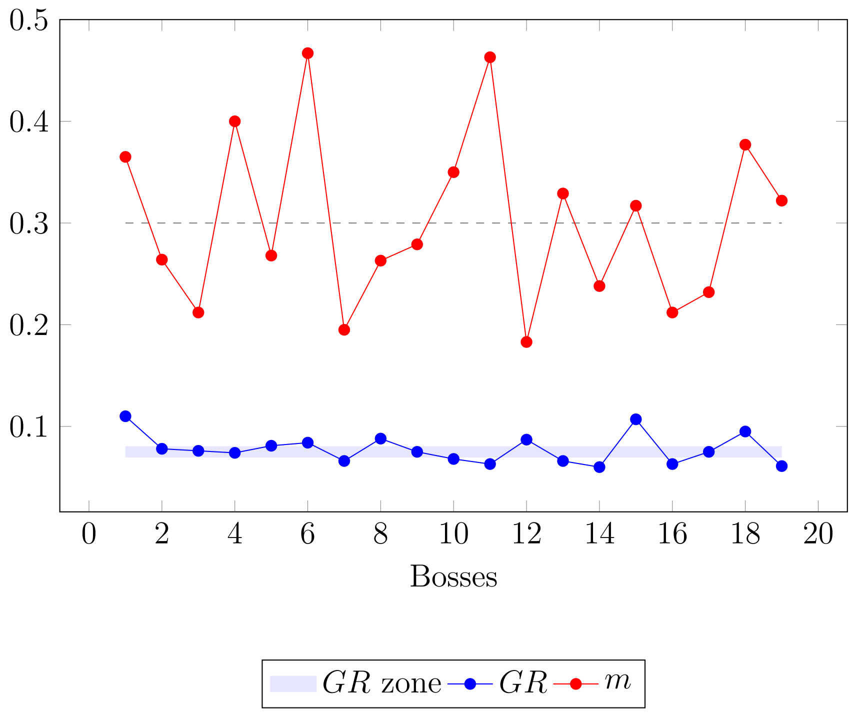

Figure 4.4: Tendency of GR and m of GoW II

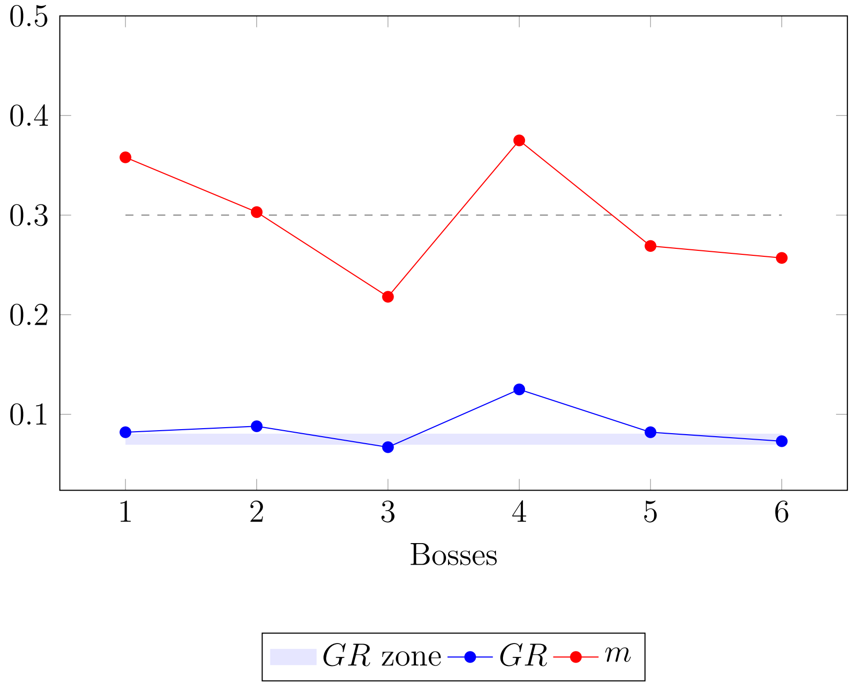

Figure 4.5: Tendency of GR and m of GoW: Chains of Olympus

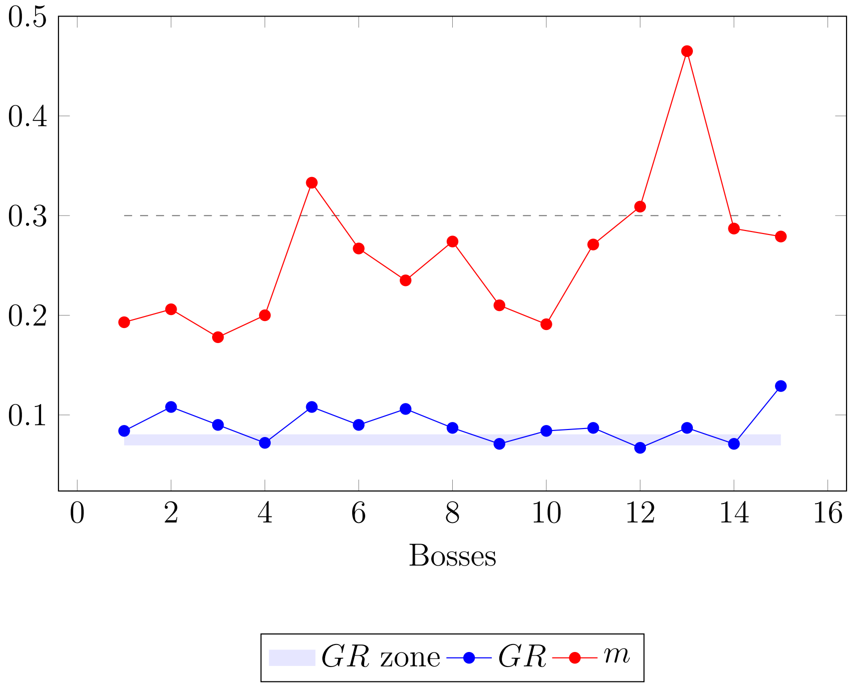

Figure 4.6: Tendency of GR and m of GoW III

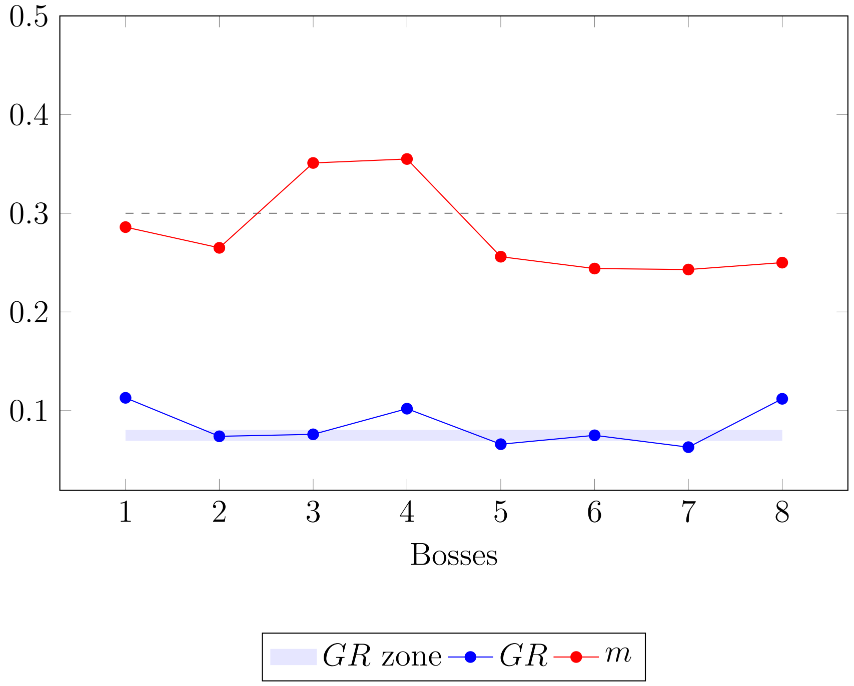

Figure 4.7: Tendency of GR and m of GoW: Ghost of Sparta

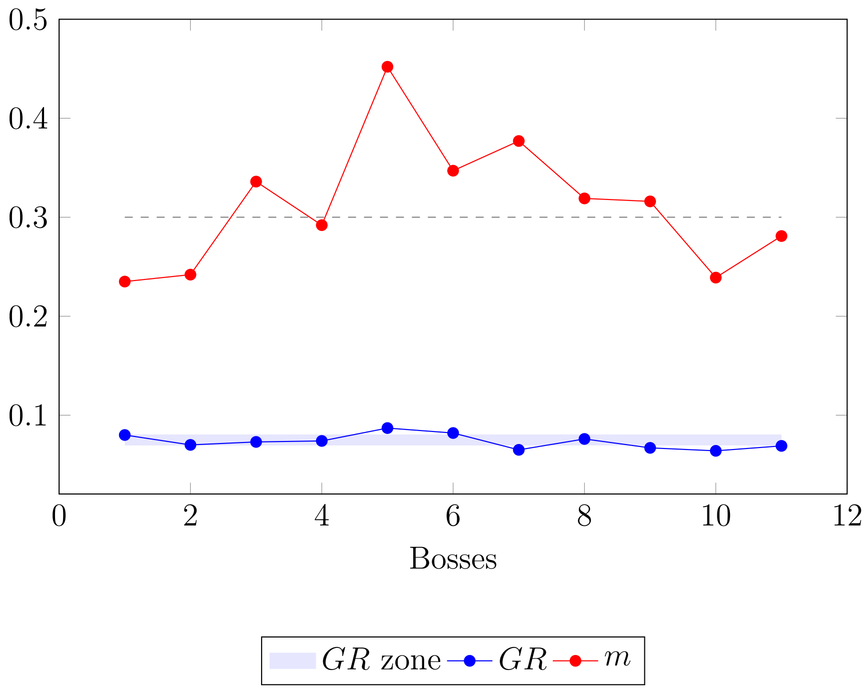

Figure 4.8: Tendency of GR and m of GoW: Ascension

Based on Figure 4.3, Figure 4.4, and Figure 4.6, the main GoW series were different from one another in terms of the boss challenges relative to the game progression. GoW I and GoW III shared a similar pattern where the challenge peaked (high m, GR in the zone) around the final three boss battles. At the same time, GoW II was more inconsistent for the boss challenge (rapid change of m) but still attractive relative to GoW I and GoW III (approximately similar GR values for the three main GoW series). Meanwhile, Figure 4.5, Figure 4.7, and Figure 4.8 showed that the peak of the challenge was roughly in the middle of the overall progression of the boss battle. However, this boss battle was more difficult since the GR value was higher than the sophistication zone ($GR > 0.08$).

From the data analysis of the average boss battle of each GoW series (Table 4.3), it can be observed that the GR and AD values were located within the sophisticated zone ($GR \in [0.07, 0.08]$ and $AD \in [0.05, 0.06]$). This condition implied that these different GoW versions were sophisticated with enough complexity, making them popular and highly attractive. However, with the subsequent GoW series, the G value was reduced while maintaining roughly similar v. Such a trend indicates that the game increases in difficulty and becomes more challenging to overcome by the players as the series progresses.

Table 4.3: The tendency of average motions in mind of different GoW series

Version	G	T	GR	AD	v	m	N	$\vec{p}$	$\vec{E}_p$
GoW I	104.11	132.44	0.081	0.056	0.79	0.21	1.28	0.16	0.25
GoW II	90.37	127.05	0.078	0.055	0.70	0.30	1.46	0.20	0.28
GoW: Chains of Olympus	77.83	107.67	0.086	0.063	0.70	0.30	1.43	0.21	0.29
GoW III	76.07	101.67	0.089	0.064	0.74	0.26	1.37	0.19	0.27
GoW: Ghost of Sparta	83.75	115.13	0.085	0.061	0.72	0.28	1.40	0.20	0.29
GoW: Ascension	92.27	132.37	0.073	0.050	0.69	0.31	1.47	0.21	0.29

4.3.2 Analysis of GoW Series Based on Challenge (m) and Anticipation (E_p)

The success of action games depended on the pace and plot of the stories behind the gameplay, emphasizing engagement and attractiveness in conjunction with the in-game actions. Such settings were visible in the GoW series. Relative to the boss battles in the series of GoW, the battle scene is divided into two to three rounds before it can conclude the outcome. This condition is necessary for the action game that concluded within minutes to be prolonged into some number of hours, increasing satisfaction and fulfilling the game's narrative.

Figure 4.9-Figure 4.14 depicted the measure of challenge (m) and anticipation ($\vec{E_p}$) of the considered GoW series. Observing the trend and pattern of the figures, the specific bosses were divided further to highlight the pattern of each of the GoW series. GoW I (Figure 4.9) and the rest of the non-main series of the GoW (Figure 4.11, Figure 4.13, and Figure 4.14) shared an approximately similar pattern of anticipation building up before the greatest challenge ($\vec{E_p}$ value being high just before the highest m). However, GoW I was a more typical 'ground-up' building than the other non-main GoW series, making anticipation higher after or in between the greatest boss battle (highest m).

Tendencies of GR and $\vec{E_p}$ for Figure 4.9 GoW I, Figure 4.10 GoW II, Figure 4.11 GoW: Chains of Olympus, Figure 4.12 GoW III, Figure 4.13 GoW: Ghost of Sparta, and Figure 4.14 GoW: Ascension. The dashed line separates the bosses' battle within the progression of the GoW game, while the green dotted line is the trend of the m values.

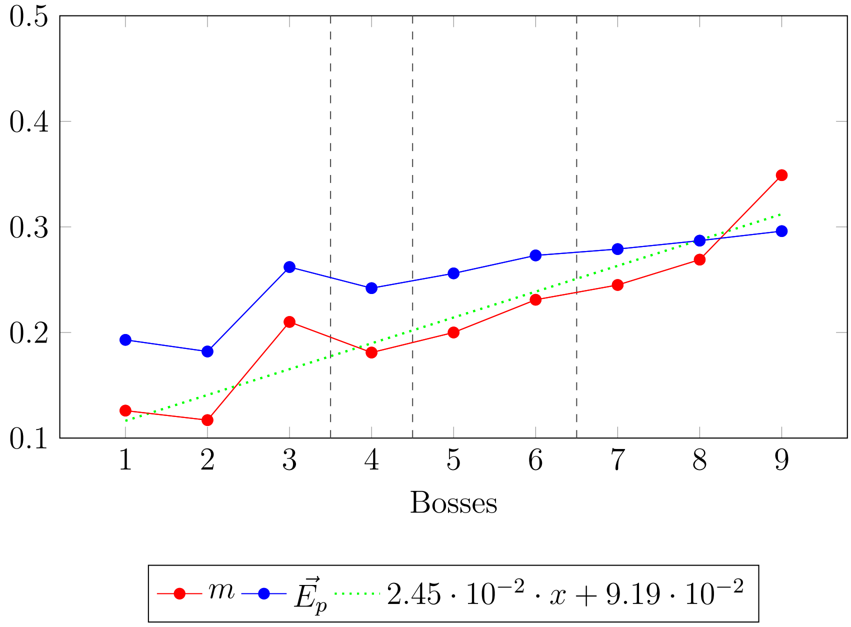

Figure 4.9: Tendency of m and $\vec{E_p}$ of GoW I

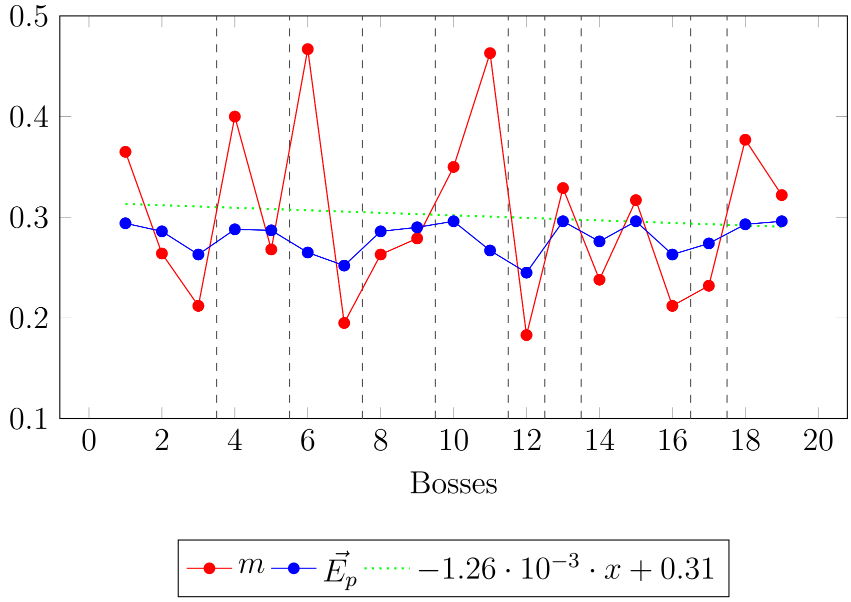

Figure 4.10: Tendency of m and $\vec{E}_p$ of GoW II

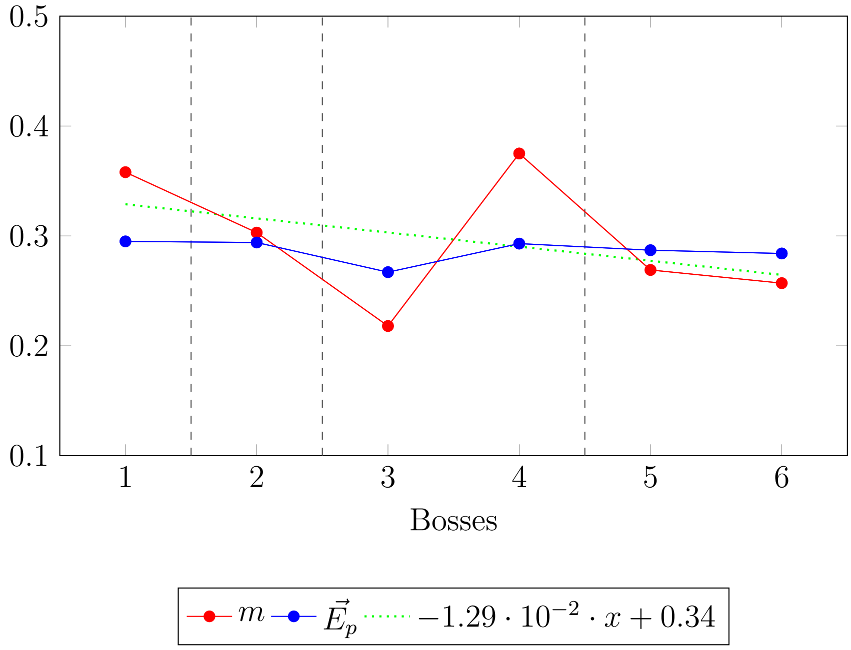

Figure 4.11: Tendency of m and $\vec{E}_p$ of GoW: Chains of Olympus

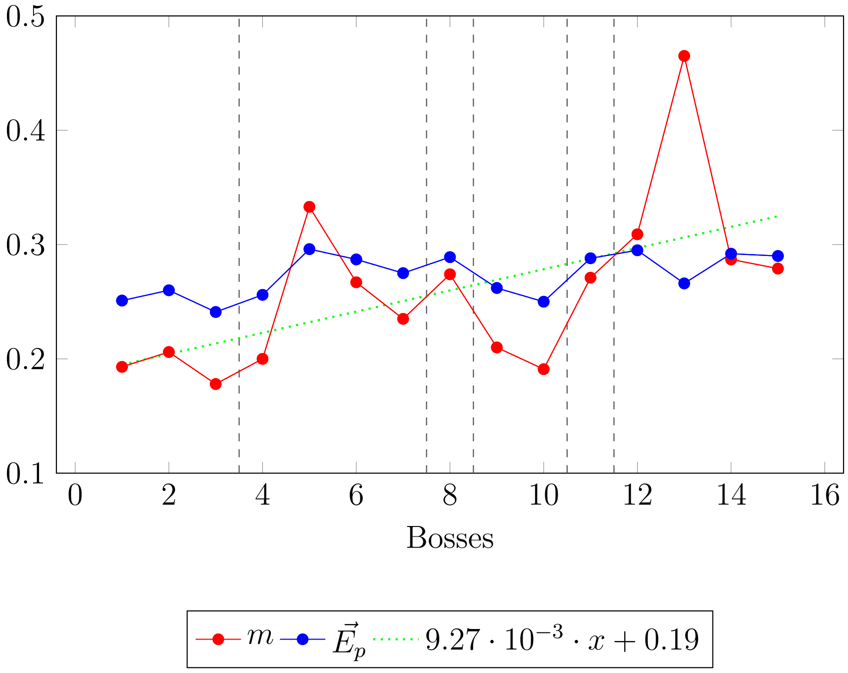

Figure 4.12: Tendency of m and $\vec{E}_p$ of GoW III

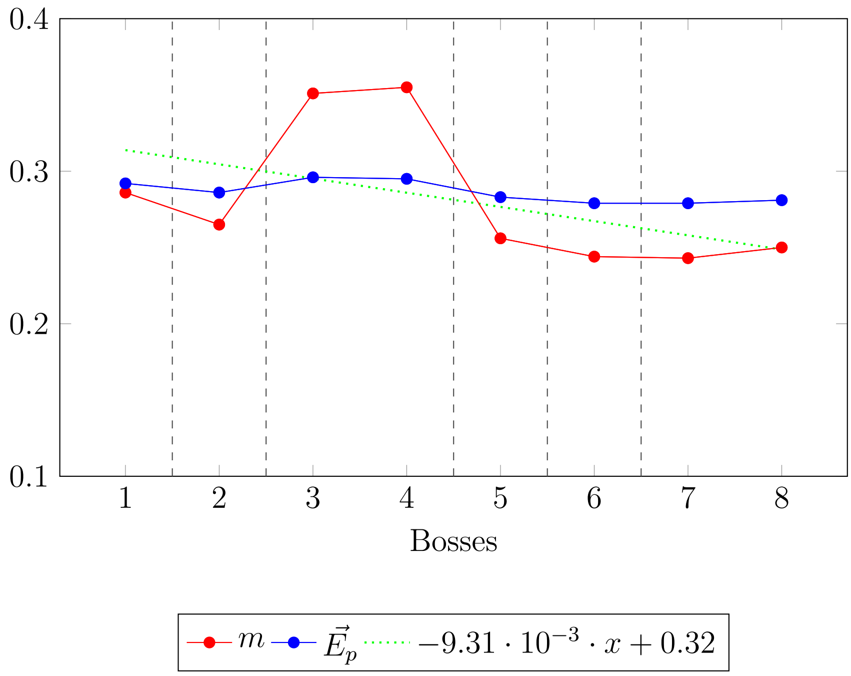

Figure 4.13: Tendency of m and $\vec{E}_p$ of GoW: Ghost of Sparta

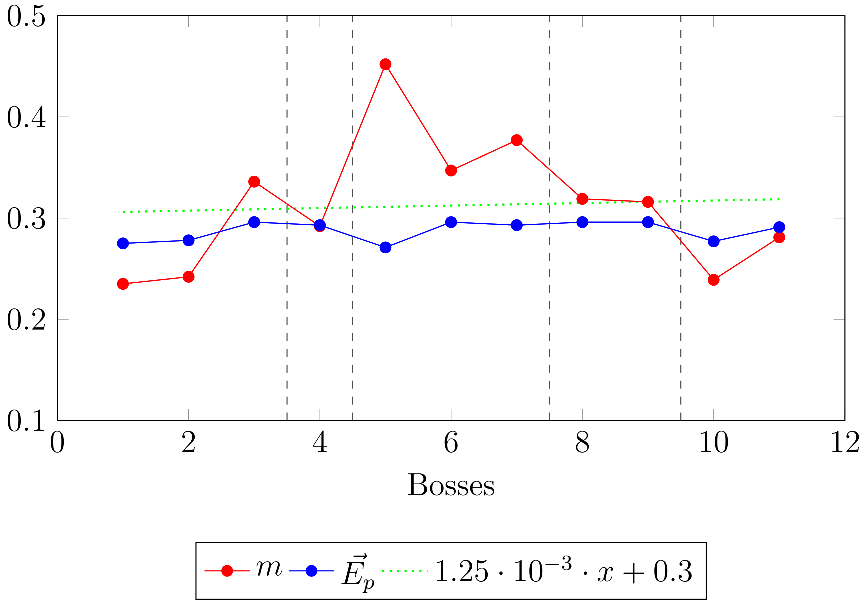

Figure 4.14: Tendency of m and $\vec{E_p}$ of GoW: Ascension

Meanwhile, the pattern observed for GoW II (Figure 4.10) and GoW III (Figure 4.12) were somewhat inconsistent, with intermittent exchanges between anticipation level (high $\vec{E_p}$ compared to the m) right before the high level of challenge (highest m throughout the overall boss battles). Interestingly, the more minor bosses (such as Euryale, Kraken, and Clotho in GoW II; Hermes and Hercules in GoW III) in between the greater bosses (such as Barbarian King and Perseus in GoW II; Hades and Helios in GoW III) provided the needed anticipation before reaching the most significant challenge (Zeus in GoW II and GoW III). Based on these results, it is clear that the GoW series experimented with different intervals of a boss battle and a different number of rounds allotted to each of the bosses to determine their impact on the entertainment of the battle itself.

Considering the ending or the last (strongest) boss of the GoW game, along the subsequent GoW series (Table 4.4), it can be observed that the average of the battle stages typically within the sophistication zone ($GR \in [0.07, 0.08]$), while $m \to 0.3$ and $\vec{E_p} \to 0.29$. Such a condition implies that the final boss battle of the GoW game was designed to have sufficient complexity that could cater to expert and beginner players, requiring objective reinforcement to overcome the challenge of the battle, and the challenge itself induces learning comfort that warrants the player to learn the mastery of the battle.

Table 4.4: Challenge (m) and anticipation (E_p) of the final strongest boss of each GoW series

Boss Name	GR	m	$\vec{E_p}$
GoW I-Ares1	0.088	0.245	0.279
GoW I-Ares2	0.061	0.269	0.287
GoW I-Ares3	0.089	0.349	0.296
GoW II-Zeus1	0.095	0.377	0.293
GoW II-Zeus2	0.061	0.322	0.296
*GoW: CO-Persephone1	0.082	0.269	0.287
*GoW: CO-Persephone2	0.073	0.257	0.284
GoW III-Zeus1	0.067	0.309	0.295
GoW III-Zeus2	0.087	0.465	0.266
GoW III-Zeus3	0.071	0.287	0.292
GoW III-Zeus4	0.129	0.279	0.290
†GoW: GoS-Thanatos1	0.063	0.243	0.279
†GoW: GoS-Thanatos2	0.112	0.250	0.281
‡GoW: A-Alecto1	0.064	0.239	0.277
‡GoW: A-Alecto2	0.069	0.281	0.291

*GoW: CO - GoW: Chains of Olympus;
†GoW: GoS - GoW: Ghost of Sparta;
‡GoW: A - GoW: Ascension;

Finally, observing the trend of m dynamics of the GoW series (Figure 4.9 to Figure 4.14), there were positive trends visible for GoW I, GoW III, and GoW: Ascension. However, GoW III had more intense changes of m dynamics, implying that the latest version of the GoW series incorporates high unpredictability and makes the experience feel roller-coaster-like. Such a situation was also similar in GoW II, but the trend of the m dynamic was negatively inclined. This condition meant that the boss battle was less challenging towards the end. While similar situations were also observed for GoW: Chains of Olympus and GoW: Ghost of Sparta, the m dynamic was predictable with apparent seesaw turnover between decreasing (or increasing). As such, the m dynamic was an essential element emphasized by the GoW developers to balance the levels of anticipation and predictability, where players enjoyed the experience of playing or solving in the moments between the m changes.

4.4 Experimental Results and Discussion

This study analyzed most of the GoW series, except the GoW IV, due to the differences in gameplay (failed combination of action and role-playing [86]) and unable to fit the same model to be discussed with other GoW series. However, it was found that there was a distinction between different boss battles throughout the GoW series. One of the distinctions was because of the game's medium, where overall boss battles of the game released on a PSP were shorter (see Table 4.8 and Table 4.10) than those released on the PS console. Besides, the first GoW also showed that the number of rounds of boss battles was somewhat limited, making it less celebrated than the latter GoW series. Nevertheless, variations in the number of boss battle rounds make the game exciting and the play experience attractive to the players.

Such a situation can be observed in the first series of the GoW, where the only boss battle with a single round was the Medusa. The battle was designed to regain the power of the protagonist, Kratos, and had no impact on the main narrative and overall gameplay. The $GR = 0.107$ and $m = 0.181$, indicating that the battle was relatively straightforward and short since the number of successful attempts (G) needed was low. In contrast to the final boss, the second round was $GR = 0.061$ and $m = 0.269$, where the battle was the toughest, likely due to the need for fast-paced hand-eye coordination since the successful attempts (G) were higher compared to other boss battles. Therefore, the GR value provides a viable measure of the complexity and sophistication of the boss battle of the GoW game.

In GoW II, the number of boss battles was the highest compared to all other GoW series. Interestingly, the boss battle against the Sparta soldiers was entirely rendered as a two-dimensional fighting game. It was found that the final boss battle had $GR = 0.061$ and $m = 0.322$, implying that the battle requires some comfort in learning to outmaneuver the final boss while requiring a high number of successful attempts. It also explained why GoW II was among the most complex and challenging throughout the GoW series. GoW III is the third main release of the series with enhanced graphics, exciting narratives based on Greek mythology, and supported on the PS3 console, which makes it the most popular and attractive version in the GoW series. However, based on the GR value of its last boss battle (see Table 4.9), the complexity is less likely to be a challenge where it relaxes the player by making the battle more manageable and more accessible than in the previous GoW series. In addition, its sanguinary scenes were made deliberately at the end to make the experience movie-like and immersive.

Table 4.5 summarized the findings of this study, where the entertainment aspects of the GoW series were extracted and the potential implications. It includes six potential entertainment aspects, where the change in the m, E_p, GR, and AD impacted the level of challenge posed based on the rounds/intervals of the boss battle. Increasing (or decreasing) m provides the necessary obstacle for the player, but tied with fluctuation of E_p and AD zone makes it a good condition for the training/practice environment, given the rounds/intervals is small since it provides some unpredictability yet highly expected. However, when m fluctuates, the GR zone would provide challenges that can either be progressive or unstable given the state of E_p and AD. Since E_p and AD influence expectation and unpredictability, it would be left to the developers' imagination to experiment with a different configuration that best suits their intended design of the game flow and narrative—for instance, balancing more or fewer rounds/intervals relative to player expectation towards a more difficult boss (unstable challenge) or allowing for the play experience to be aligned with a more complex narrative (progressive challenge). Subsequently, higher GR and AD, with fluctuating E_p, could make the play experience very difficult or require some level of mastery, which typically requires more rounds/intervals to be engaging (or fair). At this point, the risk of character death is generally acceptable, since the player would associate it with an obstacle that requires some overcompensation to overcome it.

Nevertheless, the reader should take the findings with a grain of salt, as the study may be exposed to some threats to the validity of the findings. Firstly, the collected data may be exposed to human error, as the data collection procedure involves intervention from multiple participants of different educational backgrounds and biases towards the action game. Secondly, the data collection procedure was conducted from a recording of gameplay posted on a public video-based website, in which the play experience may be lost or excluded from the video recording due to other external motivations. Nevertheless, future works can address the such threat by collecting the data either via external programs (i.e., game-specific application programming interface or API), in-game metrics (i.e., scores, achievements, time spent), game telemetry (remote data monitoring, measurement, or recording), or psycho-physiological means (i.e., heart rate and skin conductance), in which the considered GoW series lacks in the first place.

Table 4.5: Summary of entertainment aspects identified from the GoW series boss battles and potential implications

Entertainment Aspect	m	E_p	GR	AD	**Rounds/Intervals**†	**Implication**
Impactless obstacle	$\nearrow$	$\searrow$	$>$	$>$	Single	No challenge
Small "bumps"	$\searrow$	$\updownarrow$	$<$	zone	Little	Practice/Training challenge
Ground-up	$\nearrow$	$\nearrow$	zone	zone	Little $\rightarrow$ Medium	Progressive challenge
Erratic incline	$\updownarrow$	$\nearrow$	zone	$>$	Medium $\rightarrow$ Little	Unstable challenge
Erratic decline	$\updownarrow$	$\searrow$	zone	$>$	Medium $\rightarrow$ Little	Unstable challenge
Hard obstacle	$\updownarrow$	$\searrow$	$>$	$>$	Medium $\rightarrow$ Many	Mastery challenge
Risky obstacle	$\updownarrow$	$\updownarrow$	$>$	$>$	Medium $\rightarrow$ Many	Ultimate challenge

$\nearrow$: positive increase; $\searrow$: negative increase; $\updownarrow$: fluctuating; $\rightarrow$: up to; $>$: more than zone value; $<$: less than zone value; †: recommended estimation based on corresponding entertainment aspect; Little: 2–3; Medium: 3–4; Many: 4 or more;

4.5 Chapter Summary

This study analyzed the GoW series via the GR theory and its extension, called motion in mind, based on the actions of the boss battles available in each of the series of the GoW considered. From the analysis, the evolutionary trend of the GoW series was identified not only in the challenge increases, insights into the narrative design, levels of predictability, and balances the experience of play for beginner and advanced players.

From the findings ((Figure 4.3 to Figure 4.8). And Table 4.3), it can be concluded that the boss battle of the GoW series was designed with sufficient sophistication to be entertaining to diverse players ($GR \in [0.07, 0.08]$) while applying enough unpredictability and retain the interest of the player ($AD \in [0.045, 0.06]$) to allow the experience repeatable. Additional features identified include the learning comfort imposed by the developers, where the player is expected to learn and master the battle when reaching the final boss for each GoW series. In addition, the m dynamics of the game imply a roller-coaster-like gameplay experience, where the uncertainty makes it enjoyable to the player.

The study also found that the game's platform indirectly related to different GoW series experiences. As different platforms had different interfaces (diegetic or non-diegetic) [87] and new media technology [88], it could significantly influence the play experience. As the findings of this study showed, the GoW series had demonstrated parallel development of human-computer interfaces and measures of information delivery. The developer encouraged players to learn and adapt not only to in-game challenges but also to involve rapid reactions and excellent hand-eye coordination, thus, making the expected experience from the play much more holistic and enjoyable.

As action games are rich with other game-playing elements, future work may want to consider those other elements to enhance the analysis. For instance, the inclusion of puzzle-solving stages, building and/or crafting, character skill combination and/or balancing meta-gaming elements (user interface, mini-games, and in-game progression and/or badging), and narrative structure. These elements also measured and determined their roles relative to the expected enjoyment and entertainment of the intended game-playing experience of the players by the developers. Finally, having a unified view of the game design (inclusive of the aforementioned elements) would provide insights that were beneficial to the developers and publishers of the games alike.

Figure 4.6 to Figure 4.11 was listed below.

Table 4.6: Measures of GR and Motion in Mind for God of War I

Boss Name	G	T	GR	AD	v	m	N	$\vec{p}$	$\vec{E_p}$
Hydra (part1)	76	87	0.100	0.070	0.874	0.126	1.145	0.110	0.193
Hydra (part2)	121	137	0.080	0.052	0.883	0.117	1.132	0.103	0.182
Hydra (part3)	162	205	0.062	0.038	0.790	0.210	1.265	0.166	0.262
Medusa	59	72	0.107	0.078	0.819	0.181	1.220	0.148	0.242
Guardian (part1)	164	205	0.062	0.039	0.800	0.200	1.250	0.160	0.256
Guardian (part2)	83	108	0.084	0.058	0.769	0.231	1.301	0.178	0.273
Ares (part1)	74	98	0.088	0.062	0.755	0.245	1.324	0.185	0.279
Ares (part2)	144	197	0.061	0.038	0.731	0.269	1.368	0.197	0.287
Ares (part3)	54	83	0.089	0.066	0.651	0.349	1.537	0.227	0.296
Average	104	132	0.081	0.056	0.786	0.214	1.283	0.164	0.252

Table 4.7: Measures of GR and Motion in Mind for God of War II

Boss Name	G	T	GR	AD	$\vec{v}$	$\vec{m}$	N	$\vec{p}$	$\vec{E_p}$
Colossus of Rhodes (part1)	33	52	0.110	0.089	0.635	0.365	1.576	0.232	0.294
Colossus of Rhodes (part2)	89	121	0.078	0.053	0.736	0.264	1.360	0.195	0.286
Colossus of Rhodes (part3)	108	137	0.076	0.050	0.788	0.212	1.269	0.167	0.263
Theseus (part1)	66	110	0.074	0.053	0.600	0.400	1.667	0.240	0.288
Theseus (part2)	82	112	0.081	0.056	0.732	0.268	1.366	0.196	0.287
Barbarian King(part1)	40	75	0.084	0.066	0.533	0.467	1.875	0.249	0.265
Barbarian King(part2)	149	185	0.066	0.041	0.805	0.195	1.242	0.157	0.252
Euryale (part1)	70	95	0.088	0.063	0.737	0.263	1.357	0.194	0.286
Euryale (part2)	93	129	0.075	0.051	0.721	0.279	1.387	0.201	0.290
Perseus (part1)	91	140	0.068	0.046	0.650	0.350	1.538	0.228	0.296
Perseus (part2)	73	136	0.063	0.044	0.537	0.463	1.863	0.249	0.267
Sparta Soldier	89	109	0.087	0.059	0.817	0.183	1.225	0.150	0.245
Kraken	104	155	0.066	0.044	0.671	0.329	1.490	0.221	0.296
Sisters of Fate (part1)	160	210	0.060	0.037	0.762	0.238	1.313	0.181	0.276
Sisters of Fate (part2)	41	60	0.107	0.083	0.683	0.317	1.463	0.216	0.296
Sisters of Fate (part3)	156	198	0.063	0.039	0.788	0.212	1.269	0.167	0.263
Clotho	106	138	0.075	0.049	0.768	0.232	1.302	0.178	0.274
Zeus (part1)	43	69	0.095	0.073	0.623	0.377	1.605	0.235	0.293
Zeus (part2)	124	183	0.061	0.039	0.678	0.322	1.476	0.218	0.296
Average	90	127	0.078	0.055	0.698	0.302	1.455	0.204	0.280

Table 4.8: Measures of GR and Motion in Mind for God of War: Chains of Olympus

Boss Name	G	T	GR	AD	$\vec{v}$	$\vec{m}$	N	$\vec{p}$	$\vec{E_p}$
Persian King	61	95	0.082	0.060	0.642	0.358	1.557	0.230	0.295
Basilisk	62	89	0.088	0.064	0.697	0.303	1.435	0.211	0.294
Charon (part1)	136	174	0.067	0.043	0.782	0.218	1.279	0.171	0.267
Charon (part2)	25	40	0.125	0.105	0.625	0.375	1.600	0.234	0.293
Persephone (part1)	79	108	0.082	0.057	0.731	0.269	1.367	0.196	0.287
Persephone (part2)	104	140	0.073	0.048	0.743	0.257	1.346	0.191	0.284
Average	78	108	0.086	0.063	0.703	0.297	1.431	0.206	0.287

Table 4.9: Measures of GR and Motion in Mind for God of War III

Boss Name	G	T	GR	AD	$\vec{v}$	$\vec{m}$	N	$\vec{p}$	$\vec{E_p}$
Poseidon (part1)	92	114	0.084	0.057	0.807	0.193	1.239	0.156	0.251
Poseidon (part2)	54	68	0.108	0.080	0.794	0.206	1.259	0.163	0.260
Poseidon (part3)	83	101	0.090	0.062	0.822	0.178	1.217	0.146	0.241
Hades (part1)	124	155	0.072	0.046	0.800	0.200	1.250	0.160	0.256
Hades (part2)	38	57	0.108	0.085	0.667	0.333	1.500	0.222	0.296
Helios (part1)	66	90	0.090	0.065	0.733	0.267	1.364	0.196	0.287
Helios (part2)	52	68	0.106	0.079	0.765	0.235	1.308	0.180	0.275
Hermes	69	95	0.087	0.062	0.726	0.274	1.377	0.199	0.289
Hercules (part1)	124	157	0.071	0.046	0.790	0.210	1.266	0.166	0.262
Hercules (part2)	93	115	0.084	0.057	0.809	0.191	1.237	0.155	0.250
Cronos	70	96	0.087	0.062	0.729	0.271	1.371	0.197	0.288
Zeus (part1)	105	152	0.067	0.045	0.691	0.309	1.448	0.214	0.295
Zeus (part2)	38	71	0.087	0.068	0.535	0.465	1.868	0.249	0.266
Zeus (part3)	102	143	0.071	0.047	0.713	0.287	1.402	0.205	0.292
Zeus (part4)	31	43	0.129	0.105	0.721	0.279	1.387	0.201	0.290
Average	76	102	0.089	0.064	0.740	0.260	1.366	0.187	0.273

Table 4.10: Measures of GR and Motion in Mind for God of War: Ghost of Sparta

Boss Name	G	T	GR	AD	$\vec{v}$	$\vec{m}$	N	$\vec{p}$	$\vec{E_p}$
Scylla	40	56	0.113	0.088	0.714	0.286	1.400	0.204	0.292
Callisto	100	136	0.074	0.049	0.735	0.265	1.360	0.195	0.286
Erinys (part1)	72	111	0.076	0.054	0.649	0.351	1.542	0.228	0.296
Erinys (part2)	40	62	0.102	0.080	0.645	0.355	1.550	0.229	0.295
Piraeus Lion	128	172	0.066	0.042	0.744	0.256	1.344	0.190	0.283
Deimos	102	135	0.075	0.050	0.756	0.244	1.324	0.185	0.279
Thanatos (part1)	143	189	0.063	0.040	0.757	0.243	1.322	0.184	0.279
Thanatos (part2)	45	60	0.112	0.085	0.750	0.250	1.333	0.188	0.281
Average	84	115	0.085	0.061	0.719	0.281	1.397	0.200	0.286

Table 4.11: Measures of GR and Motion in Mind for God of War: Ascension

Boss Name	G	T	GR	AD	$\vec{v}$	$\vec{m}$	N	$\vec{p}$	$\vec{E_p}$
Aegaeon (part1)	91	119	0.080	0.055	0.765	0.235	1.308	0.180	0.275
Aegaeon (part2)	116	153	0.070	0.046	0.758	0.242	1.319	0.183	0.278
Aegaeon (part3)	83	125	0.073	0.050	0.664	0.336	1.506	0.223	0.296
Manticore	92	130	0.074	0.050	0.708	0.292	1.413	0.207	0.293
Pollux Castor (part1)	40	73	0.087	0.068	0.548	0.452	1.825	0.248	0.271
Pollux Castor (part2)	64	98	0.082	0.059	0.653	0.347	1.531	0.227	0.296
Pollux Castor (part3)	91	146	0.065	0.044	0.623	0.377	1.604	0.235	0.293
The Furies (part1)	81	119	0.076	0.052	0.681	0.319	1.469	0.217	0.296
The Furies (part2)	104	152	0.067	0.045	0.684	0.316	1.462	0.216	0.296
Alecto (part1)	143	188	0.064	0.040	0.761	0.239	1.315	0.182	0.277
Alecto (part2)	110	153	0.069	0.045	0.719	0.281	1.391	0.202	0.291
Average	92	132	0.073	0.050	0.688	0.312	1.468	0.211	0.287

Chapter 5

Psychological changes when people play roller coasters

5.1 Chapter Introduction

Roller coasters have been a source of excitement and thrills for people of all ages [89]. However, not all roller coasters are created equal. Some people prefer the heart-pounding drops and high-speed twists of a roller coaster, while others prefer a more relaxed and scenic ride, as people have different preferences in terms of ride intensity and theme. The lack of standardized scales or questionnaire instruments for measuring roller coaster comfort in the previous literature created a gap in understanding. It required the development of detailed questionnaires based on specific topics.

To fill this gap, this study developed its own survey tool aimed at understanding roller coaster riders' preferences for various design elements, such as drops, turns, turns, and dips that are commonly included in roller coaster designs. The authors collected data using a combination of focus groups and surveys.

As a first step, we conducted focus group sessions to gather participants' opinions and feelings about the roller coaster experience. The themes that emerged from these sessions were analyzed to narrow down roller coaster preferences. In the second step, survey questions corresponding to the themes identified by the focus group analysis were designed.

Overall, this study utilized a questionnaire designed to explore elements of people's preferences for roller coasters and the importance of understanding people's preferences for specific design elements in roller coasters in creating a more satisfying experience for riders.

The focus groups were composed of a diverse group of 20 individuals who had varying levels of experience with roller coasters. The participants were asked about their favorite roller coasters, what makes them enjoyable, and what factors they consider when choosing a roller coaster. The discussions were recorded and later analyzed to identify common themes and patterns in the participants' responses.

Based on the roller coaster preference themes identified in the first-step focus group analysis, this survey questionnaire was designed with relevant questions related to the themes to collect more detailed and specific information about roller coaster preferences. The questionnaire includes questions about the demographic information of participants, their experiences riding roller coasters, and their preferences for specific roller coaster features such as height, speed, and inversion. The survey questionnaire was distributed to roller coaster enthusiasts by a professional data company, and the answers were collected and analyzed to gain a comprehensive understanding of roller coaster preferences. A total of 533 valid responses were collected.

The results of the focus group discussions and the questionnaire provide valuable insights into what roller coaster enthusiasts value most and what factors they consider when choosing a roller coaster. These insights are important for theme parks and roller coaster manufacturers, as they can use this information to create roller coasters that better meet the needs and preferences of their customers. This chapter will present the findings of the roller coaster preferences research, including both the qualitative data from the focus group discussions and the quantitative data from the questionnaire. The chapter will conclude with a discussion of the implications of these findings for the roller coaster industry and future research in this area.

5.2 Focus group Interview

5.2.1 Focus Group Participants

The current research on the preferences of roller coaster enthusiasts is mainly summarized from the most popular roller coaster reports in the world, which is inferential research. In order to gather information and opinions about roller coasters from a diverse group of individuals. The following two-step methods were used in this study. The focus group method and questionnaire method. Firstly, The data collected from the focus group will be used to gain a better understanding of what people like and dislike about roller coasters and to help determine what factors are important in creating a successful and enjoyable roller coaster experience. Secondly, the focus group data designed questionnaire questions, which are used to collect data from larger populations. A focus group is a qualitative research method used to gather information and feedback from a group of people about a particular topic or product. The focus group method is commonly used in market research to understand consumer preferences, attitudes, and behaviors [90]. Focus groups are utilized by professionals in various fields, including sociology, psychology, communication studies, education, political science, and public health, for research purposes [91].

This study entrusted WENJUANXIN Company to recruit participants by distributing questionnaires online. This is the company website : [92].WENJUANXIN has rich experience, and advanced technology, and is committed to providing customers with accurate and actionable data, which is an excellent choice for questionnaire survey companies. And cooperate with many famous universities, such as Tsinghua University, and Peking University. The world-famous company Huawei and McKinsey are also their client.

Recruit people from different backgrounds to include and hear different opinions. Eligibility criteria for participation include

- (1) Love roller coasters and having 2 or more rides.
- (2) Age range from 16 and 40 at the time of recruitment.
- (3) Having access to the internet and a computer or tablet.

Potential participants are asked to submit an interest form. Finally, 20 roller coaster enthusiasts were recruited. These 20 participants signed informed consent with the entrusting company and agreed to participate in the following focus group interviews. Table 5.2.4 shows the information of 20 participants.

5.2.2 Focus Group Procedure

The focus group interview is held online via Zoom, and Zeliang Zhang as the moderator leads the discussion. Participants are encouraged to share their experiences and opinions about roller coaster rides. The discussion is recorded for later analysis. During the focus group, The moderator (Zeliang Zhang) prepares a set of questions and discussion topics related to roller coaster rides.

- 1. “What is your favorite type of roller coaster ride?”

- 2. “What factors influence your decision to ride a roller coaster?”
- 3. “Explain Why you love roller coasters?”

Participants were asked to answer a series of topical questions about their experiences with roller coasters and to provide feedback on various aspects of roller coasters, including design, safety, and overall enjoyment. The focus group meeting lasted 1.5 hours.

5.2.3 Focus Group Data Analysis

The moderator (Zeliang Zhang) and the research team analyzed data from the completed focus group to identify roller coaster preferences and attitudes. This involves transcribing audio recordings, coding data, identifying common themes, analyzing trends, and interpreting results. In this focus group, we aim to gather in-depth insights from participants about participants' preferences and attitudes toward roller coasters.

5.2.4 The Result of Focus Group Data Analysis

During the focus group conversations, participants repeatedly mentioned the thrill of riding a roller coaster and feelings of excitement and fear in expressing their love for roller coasters. It is particularly worth noting that during the discussion, the participants mentioned that the feeling of stimulation brings about two experiences of excitement and fear simultaneously, so this analysis extracted one of the themes of stimulation separately. After extracting these keywords, we finally summarized three themes excitement, fear, and stimulation. These emotions and feelings are crucial to the roller coaster experience. Respondents were found to describe riding a roller coaster as both excitement and fear, both of which brought them pleasure and enjoyment. And when the roller coaster reaches the highest point and the lowest point, it most obviously expresses the enjoyment of riding a roller coaster brought about by fear and excitement. The Exciting themes were extracted keywords: Rising, Descent, Highest point, Before departure, Loops, Swoops, and Descents to the Lowest point. The Fear/Scared theme included the Highest point, Loops, Swoops, High Speed, and Time. The third one Stimulation included the following sub-themes which are Rolling, Turns, Drops, Diving, Gravity, and Height.

Table 5.1: Basic information of Participants

Participants.ID	Gender	Age	Number of rides on the roller coaster
1	Female	26	5
2	Female	18	6
3	Male	35	9
4	Female	32	15
5	Male	22	6
6	Male	25	9
7	Female	38	15
8	Female	35	6
9	Female	25	7
10	Female	21	5
11	Female	40	10
12	Male	42	8
13	Male	34	7
14	Female	26	4
15	Male	37	7
16	Male	34	5
17	Male	27	5
18	Female	29	8
19	Female	29	3
20	Female	20	4

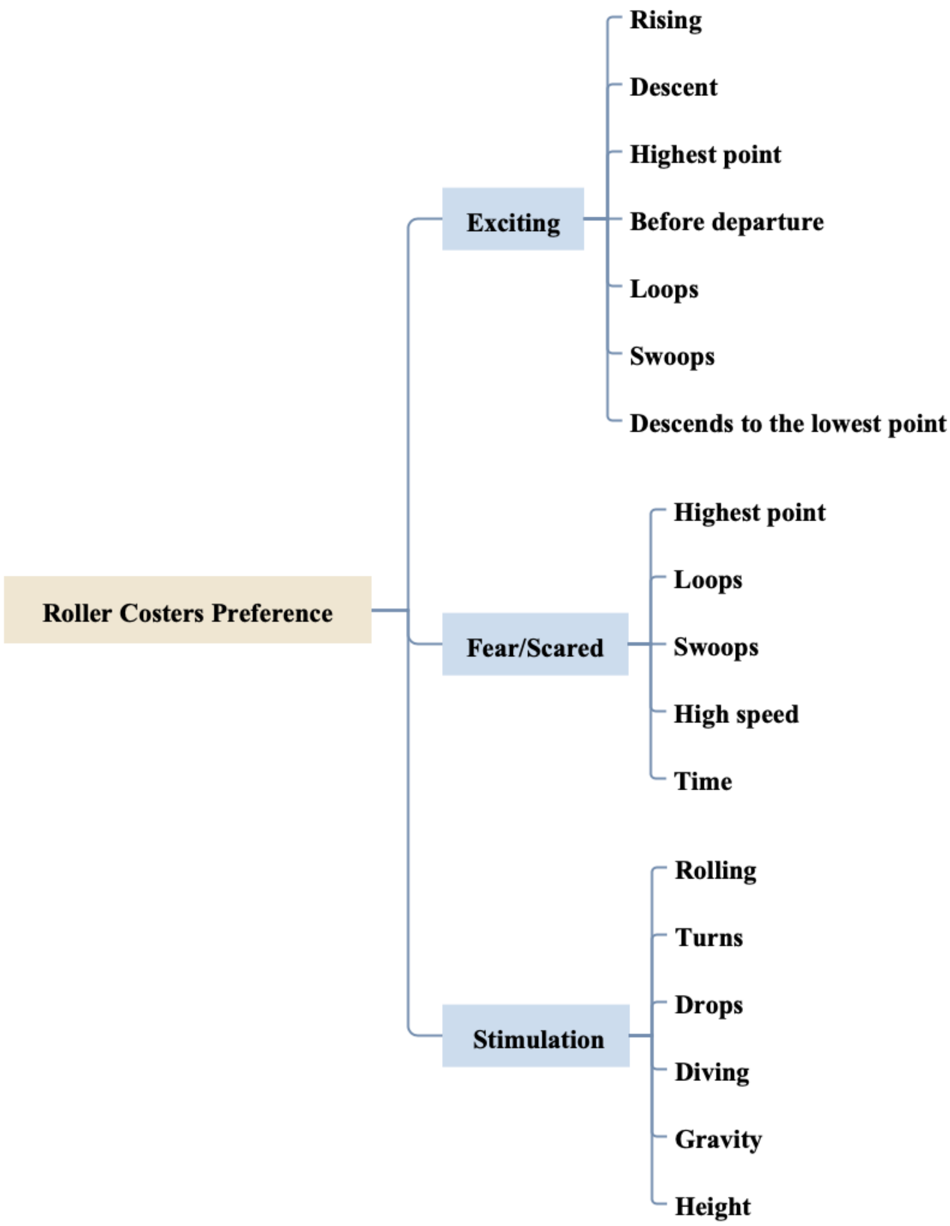

Figure 5.1: Focus group Theme

5.3 Questionnaire Investigation

5.3.1 Questionnaire Design

Questionnaire investigation is an important tool in research that allows for efficient and standardized data collection while minimizing bias and increasing objectivity. It is particularly useful when dealing with a large and diverse population, and can provide valuable insights into people's attitudes, opinions, and behaviors [93]. Within social science research and practice, questionnaires are most frequently used to collect quantitative data, In order to understand the greatest preference of roller coaster enthusiasts, this research involves frequency analysis of data analysis, so it is the best choice for a questionnaire survey.

Under the three themes ground in the focus group, there are keywords about the topic described by the participants. This research uses each keyword to further establish a complete questionnaire to collect more sample data. When constructing the questionnaire questions, this study combines the keyword discussions of the participants to formulate questions related to the topic to gain an in-depth understanding of the participants' views and feelings. According to the 3 themes of the data results of the focus group, a questionnaire with 15 questions was made. Including 3 demographic questions and 12 roller coasters questions.

For example, keywords in the theme of excitement, involving the excitement brought by these elements such as ascending, descending, and surrounding the highest point", such as "How did you feel when the roller coaster reached the top point? etc. For fear topics, elements such as Time, loops Swoops, etc. are involved. Questionnaire questions "When you ride a roller coaster, what number of loops do you like?", etc.

5.3.2 Sample And Data Collection

This study entrusts the data sample company WENJUANXING to collect the necessary sample data. The WENJUANXING has been chosen for its reputation in the field of data collection and its ability to provide high-quality and accurate results. The company has a proven track record of successfully completing similar projects, making them the ideal choice for this study. With their assistance, this study will be able to produce meaningful insights and contribute to the advancement of the field. WENJUANXING Company conducted a data collection campaign, the questionnaire was distributed to the participants online and they were asked to complete it within a week. And Company was able to gather a total of 629 data points. Upon further analysis, it was found that 96 of the data points were invalid, while 533 were found to be valid.

5.4 Questionnaire Data Analysis

5.4.1 Ethical Consideration

The collected data were analyzed using descriptive statistics, including frequency distributions and percentages to determine the significant population preferences for roller coaster rides.

Participants signed an informed consent form with WENJUANXIN. Participants were informed about the purpose of the study and their right to withdraw at any time. Additionally, all data [1] collected was kept confidential and anonymous.

[1] The table data is complicated and divided into two pages, all data collected was kept confidential and anonymous

Table 5.2: Focus group Participants Information

No.	Questions	Options
1	Your Gender	Male Female
2	Your age group	Under 18 years old 18∼25 years old 26∼30 years old 31∼40 years old Over 40 years old
3	Please evaluate your physical condition	Very unhealthy Unhealthy Fair/not sure Healthy Very healthy
4	How many times have you ridden roller coasters?	Less than 5 times 5 to 9 times 10 to 14 times 115 to 19 times More than 20 times
5	Do you enjoy to ride roller coasters	Very dislike Dislike No sure Like Very like
6	what is your favorite roller coaster speed?	5070km/h 71∼90km/h 91∼110km/h 111∼130km/h 131∼150km/h
7	What is the maximum height of a roller coaster you can take?	20meters 40meters 60meters 80meters Over 100meters Any height is alright
8	What's your favorite ride time on a roller coaster?	1/1.5/2/2.5/3 minutes and above

No.	Questions	Options
9	What is your favorite gravity force when riding a roller coaster?	1/2/3/4/5g
10	What is the total distance (meters) of your favorite roller coaster?	700∼999m 1000∼1299m 1300∼1599m 1600∼1899m 1900∼2500m
11	When you ride a roller coaster, what number of loops do you like?	2 loops 4 loops 6 loops 7 loops 8 loops
12	Why do you find roller coasters enjoyable?	Too fast, fear Too fast, excitement Swooping, fear Swooping, excitement Rings, afraid Loops, excited The process of rising is scary Get excited about the process of rising
13	Which part of thrilling experiences do you like on a roller coaster?	Strong stimulation part (rolling, near vertical descent) The more exciting part (sharp turns, dives, acceleration) Gentle part
14	How did you feel when the roller coaster reached the top?	Feel very scared Feel a little scared Feel nothing Feel a little excited Feel very excited
15	What position do you find most exciting when riding a roller coaster?	Before departure Rising process Rise to the highest point Descent process Drop to lowest point

5.4.2 The Result of Questionnaire Data Analysis

The following figures are the specific content of the questionnaire and the results of the data analysis. A total of 533 valid questionnaires were received in this study, of which 263 points were valid for males and 270 points for females. In terms of age, we can notice that 26 to 40 years old are concentrated groups of people who like to play roller coasters. The survey on physical condition finds that people who like to ride roller coasters think they think they have good physical condition which is shown in Figure 5.4.

This study focuses on the preferences of roller coaster enthusiasts. In order to ensure the fairness and validity of the data, this study requires the data company to ensure a balanced ratio of male and female data when collecting information. But it is worth noting that when collecting male data, the questionnaire company collected data on male roller coaster riders was significantly more difficult and took longer to collect than data on female roller coasters. From this point of view, there are obviously more women than men who like to ride roller coasters. This is also the same as a study finds. The study investigated whether men tend to be less truthful in their ratings of common fears. The study investigated whether men tend to be less real in their ratings of common fears. A fear survey was designed in which men's fear ratings for rats, rats, and roller coasters increased significantly, while women's ratings remained the same. These findings suggest that male fear expression may be influenced by traditional gender role expectations [94]. The roller coaster is actually a kind of social interaction. It requires the participation of many people. Of course, it does not exclude people who like to ride the roller coaster alone. The roller coaster is actually a social activity that usually involves two or more people. Of course, there is also the phenomenon that people like to ride the roller coaster alone. This study only considers the situation of multiple people riding a roller coaster. A doctoral study in psychology found that women are more dependent on face-to-face contact and are more emotional in social activities, while men tend to prefer to be alone, which explains why they like to ride roller coasters. Women will be more than men [95].

The roller coaster is a very challenging project, which tests people's courage and endurance. In the process of riding a roller coaster, people will face various thrills and challenges, such as high-speed driving, steep climbs, and sharp turns. These extreme situations will cause huge impact and pressure on the human body, the most obvious of which is the effect of the G-force.

G-force is a kind of gravitational acceleration brought to people by the roller coaster, which will make the human body feel a strong downward pressure. This stress can cause lightheadedness, a racing heart, shortness of breath, and in some people, fainting. Therefore, riding a roller coaster requires certain physical and psychological qualities to be able to withstand these extreme stimuli and pressures.

Interestingly, according to a 2014 scientific study "Evolutionary optimality in sex differences of longevity and athletic performance" [96], we can find that more women than men like to ride roller coasters. This can be explained from a biological point of view. Studies have shown that females have a higher survival rate than males, however, males are more competitive than females, which is one of the reasons why males are more prominent in sports.

So, from this perspective, there is an explanation for the fact that more women than men like to ride roller coasters. Because females are more resilient and able to survive, they are better able to withstand the physical stress and challenges of roller coasters. Men are more inclined to compete and challenge more intense projects, so they perform relatively less on roller coasters and other projects. Generally speaking, the roller coaster is a very challenging project, which requires people to have certain physical and psychological qualities to be able to successfully complete it. At the same time, from a biological point of view, there is a reasonable explanation for the fact that more women than men like to ride roller coasters.

Based on the survey conducted on the number of rides taken by 533 people, it can be inferred that a significant proportion of the respondents had a penchant for roller coasters. Among them, the majority (i.e., more than half) took the roller coaster between five and nine times. This suggests that these people were not just trying out the ride once or twice but were keen on experiencing it repeatedly. What's even more interesting is that 8.82% of the respondents went beyond the typical range of rides and took the roller coaster more than 20 times. This indicates that there is a considerable group of people who are truly devoted to this ride and enjoy it immensely. The high number of rides taken by these respondents also reflects the reliability of the data gathered in the survey. It shows that the participants were willing to share their actual experiences and that the data collected is indicative of the true preferences of roller coaster enthusiasts. Overall, this survey highlights the popularity and appeal of the roller coaster ride among a significant group of people. It also underscores the importance of conducting surveys to understand the preferences and experiences of consumers, which can help businesses tailor their offerings to meet their customers' needs and desires.

During the focus group interview with roller coaster enthusiasts, it was discovered that the speed of the ride was a major concern for them. To better understand this, the focus group summarized the speed into five different ranges and conducted a questionnaire survey. The results showed that 38.2% of the respondents preferred a speed between 91-110 km/h, as they believed it was the speed range that allowed them to enjoy the ride the most. Further discussions in the focus group revealed that enthusiasts had different attitudes toward the height of the roller coaster. While some believed that higher heights, even up to 80m or more, created excitement and enjoyment, others thought that such heights induced fear and diminished their enjoyment. To understand these attitudes better, the questionnaire survey asked respondents to choose their preferred height from five different options: 20m, 40m, 60m, 80m, and 100m. The survey found that 26.08% of the respondents preferred a height of 80m, while 25.70% preferred a height of around 60m, which corresponded to a steep incline of about 60 degrees. These results indicated that, in general, a height of 60-80m was the most preferred by roller coaster enthusiasts at present.

In summary, the focus group interview and questionnaire survey provided valuable insights into the preferences of roller coaster enthusiasts regarding the speed and height of the ride. The findings revealed that the speed range of 91-110 km/h and the height range of 60-80m was the most favored by enthusiasts. Such insights could be used to design roller coasters that appeal to a broader audience and provide the best possible experience for roller coaster enthusiasts.

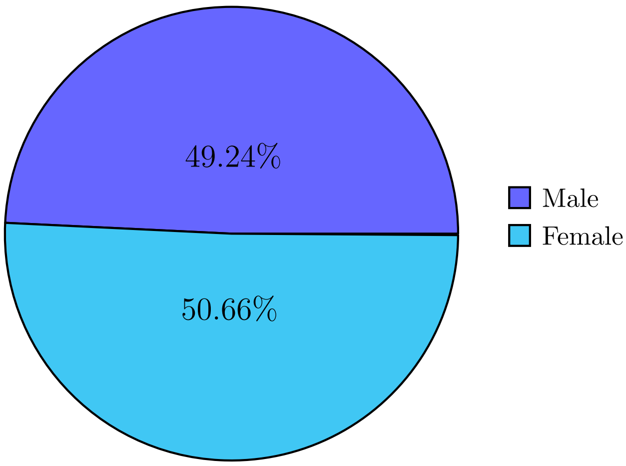

Figure 5.2: Gender Ration

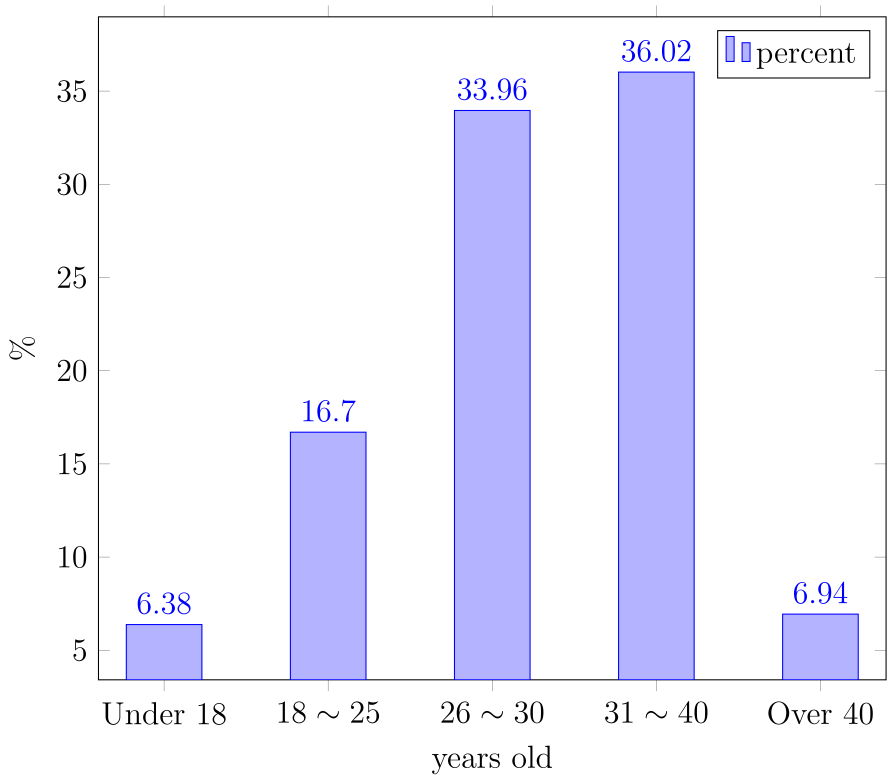

Figure 5.3: Age group

The data collected during the study revealed that individuals between the ages of 26 to 40 are the most experienced in riding roller coasters. This finding suggests that individuals within this age range may have a higher tolerance for the excitement and fear associated with riding roller coasters.

It is also possible that individuals who are too young or too old may find roller coasters too intense, causing them to feel scared or uncomfortable. Young children may not have developed the cognitive abilities to process the intense sensory input that roller coasters provide, leading them to feel overwhelmed or frightened. Conversely, older individuals may have physical limitations that make the intense movements and sensations of a roller coaster too uncomfortable or even painful.

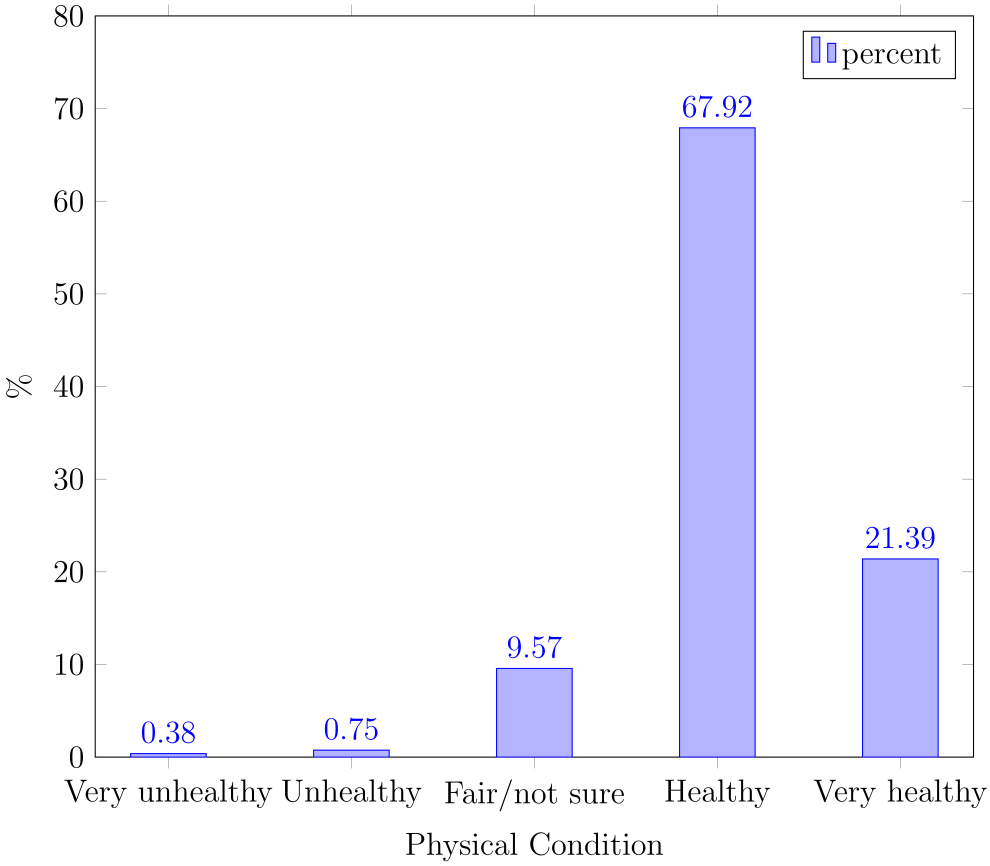

Figure 5.4: Physical Condition

It is obvious that riding roller coasters requires passengers to have a certain level of physical fitness and health. According to the collected questionnaire data, 67.92% of participants reported that they considered their physical health to be good. This suggests that the majority of participants have sufficient physical conditions to adapt to the physical impact and stimulation brought about by riding roller coasters.

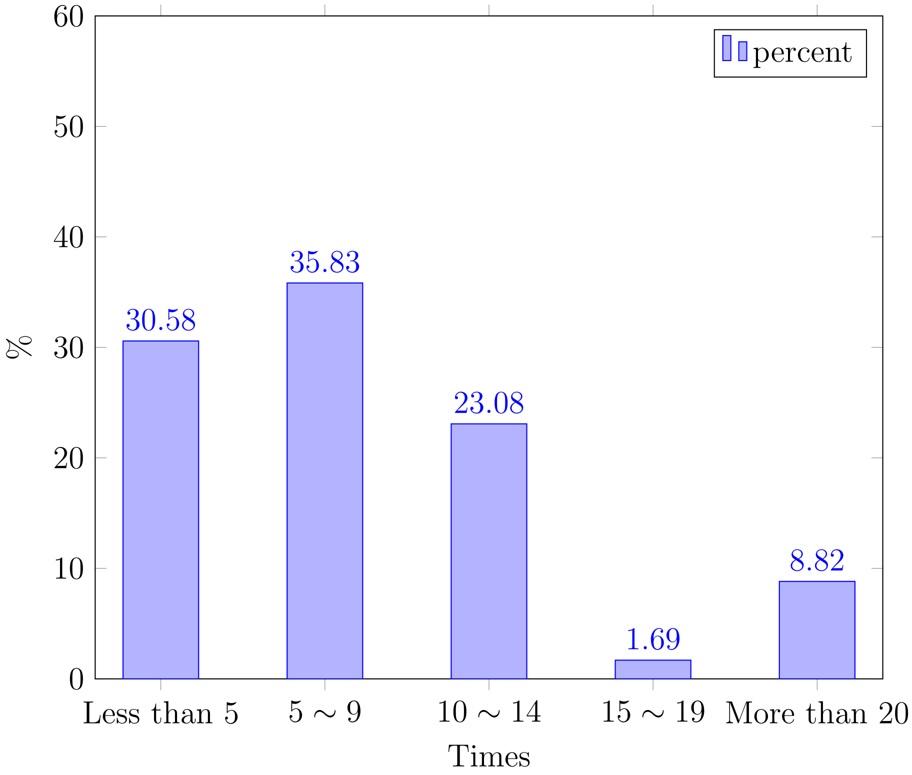

Figure 5.5: Times of Taken Roller Coasters

From the survey on the number of rides, it can be seen that most of the 533 people in this survey took the roller coaster five to nine times, and even a special point is that 8.82% of the people even took the roller coaster more than 20 times. At the same time, it can be seen that these people not only ride the roller coaster a lot and love to ride the roller coaster very, very much. It also fully proves the reliability of the data, representing the preference of most roller coaster enthusiasts.

According to a questionnaire survey conducted among individuals who have experienced riding a roller coaster, the majority of respondents reported enjoying the experience. Out of the total number of respondents, 62.85% reported feeling a high level of enjoyment during their ride.

This high level of enjoyment can be attributed to the unique combination of sensations and thrills that roller coasters provide. The feeling of anticipation before the drop, the rush of wind as the coaster accelerates, and the sense of weightlessness during drops and inversions are just a few of the elements that contribute to the excitement and enjoyment of the ride.

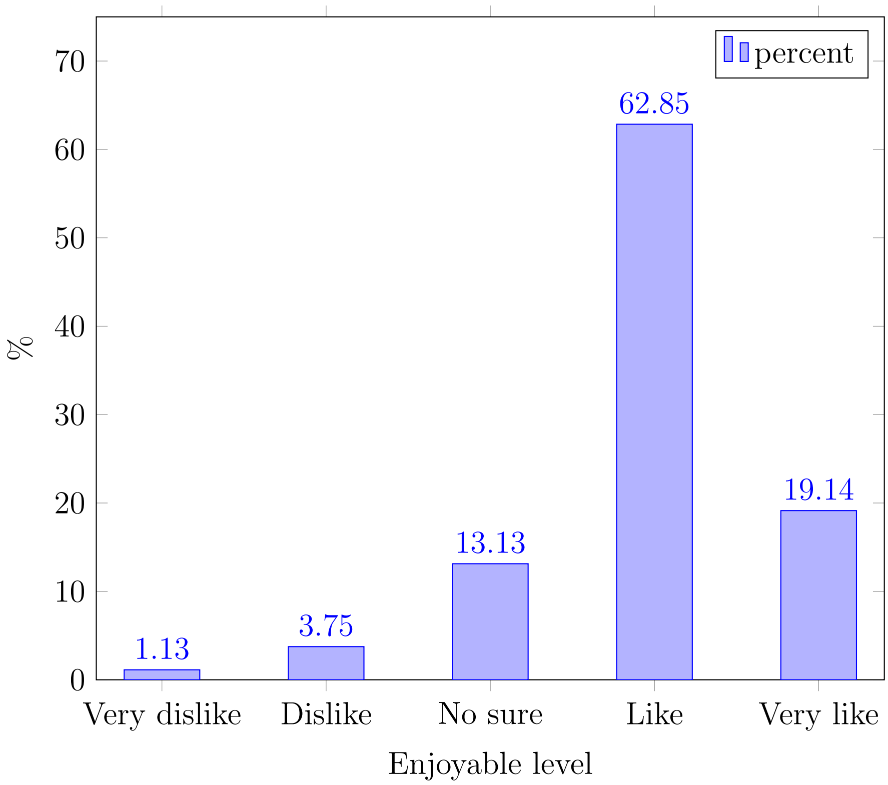

Figure 5.6: Enjoyable level

Roller coaster riders generally think of themselves as being in good physical health, because the roller coaster is an exciting activity, it requires good health conditions for players.

In the focus group interview, it was found that roller coaster enthusiasts are very concerned About the speed of the roller coaster. Therefore, five-speed ranges were summarized in the focus group. Based on this five-speed range, conducted a questionnaire survey found that 38.27% of the people selected between 91-110 km/h. At this speed, they think they can enjoy the most. In the discussion of the focus group, it can be found that roller coaster enthusiasts have different attitudes toward roller coasters of different heights.

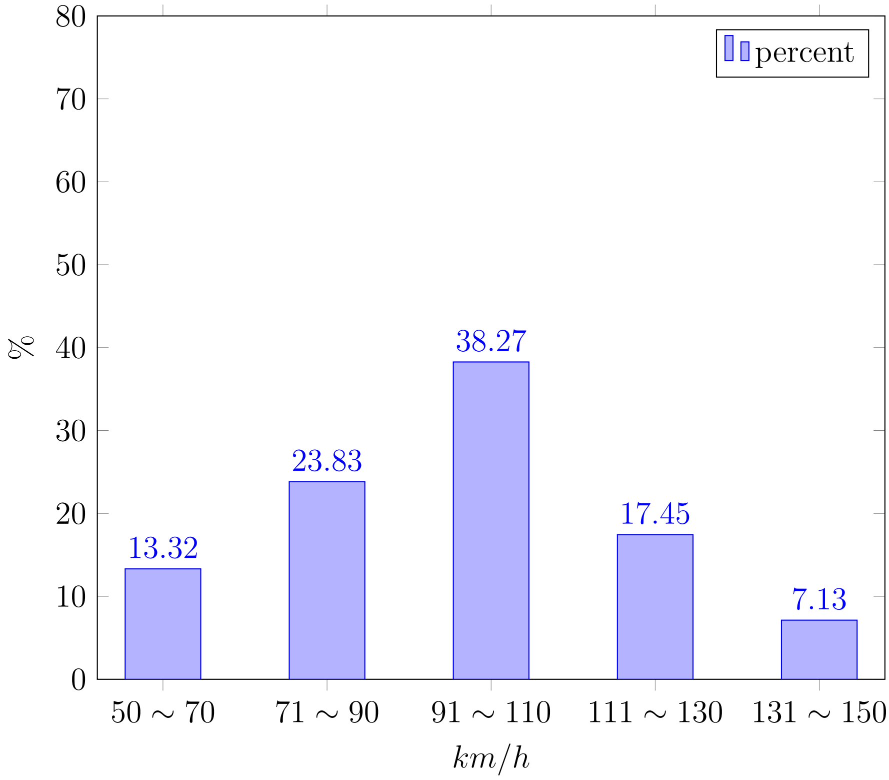

Figure 5.7: Favorite roller coaster speed

Some people think that when the height reaches a maximum of nearly 80m or even exceeds 100m, they can feel excitement and enjoyment, but some people think that it is too high. Higher heights will create a sense of fear and lower enjoyment. Therefore, in this question, we investigated the attitudes of roller coaster enthusiasts at different heights of 20 meters, 40 meters, 60 meters, 80 meters, and 100 meters. Finally, 26.08% of people and 25.70% of people like a high height of about 60 degrees like the roller coaster with a height of 80 meters, so in summary, the height of 60 meters and 80 meters is the height that people like most at present.

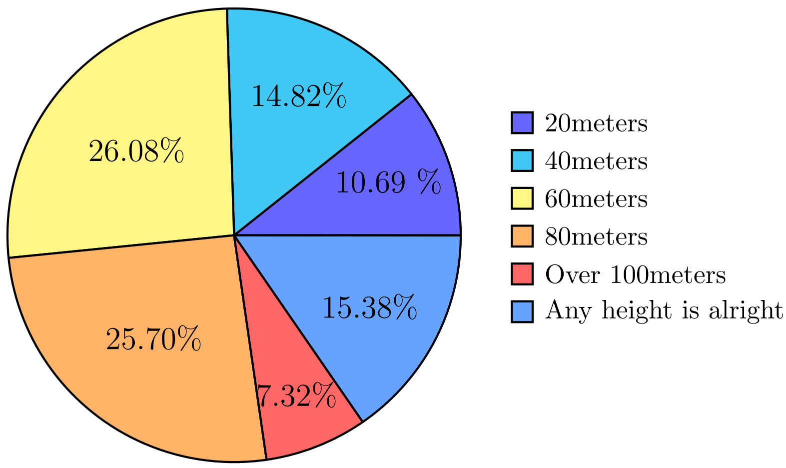

Figure 5.8: Favorite roller coaster height

Questions 8 to 11 of the questionnaire aimed to investigate the specific values associated with roller coasters. The 8th question focused on the duration of the roller coaster ride. Out of the 533 respondents, 32.65% and 31.52% of the respondents felt that roller coasters with durations longer than three minutes and two minutes, respectively, were the most enjoyable.

Gravity was the subject of the 9th question, and almost half of the respondents (49.48%) considered 3G to be the most suitable for roller coasters. 3G is the gravity level that is both tolerable for people and provides the necessary level of excitement and enjoyment. Gravity force is an important parameter in roller coaster design, which is used to describe the acceleration experienced by riders. In the design of roller coasters, gravity force can be used to control factors such as speed, height, and turn radius. The speed and height of a roller coaster are typically determined by gravity and kinetic energy, while turn radius is determined by both gravity and centrifugal force.

Therefore, in response to questions about gravity force, this survey of 533 participants showed that 45.03% of people chose 3G as their favorite gravity force value for roller coasters, which was also the most popular value. A single-sample T-test was conducted on this question to further verify the representativeness of the data. The final result showed: sample size=533; minimum value=1.000; maximum value=5.000; average value=3.038; standard deviation=1.036; p=0.404.

From the above data, it can be seen that none of them show significance ($p>0.05$) regarding the question "What is your favorite gravity force when riding a roller coaster?", which means that the average value of this item is close to 3.0 and there is no statistically significant difference. Therefore, 3G force shows representative.

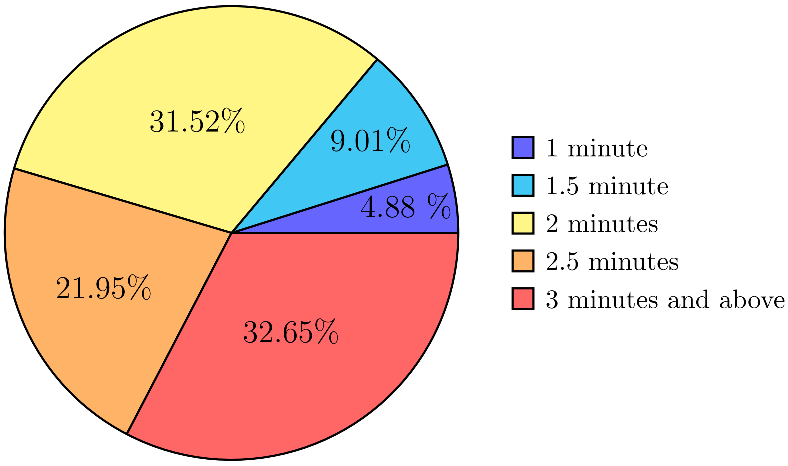

Figure 5.9: Favorite Ride Time

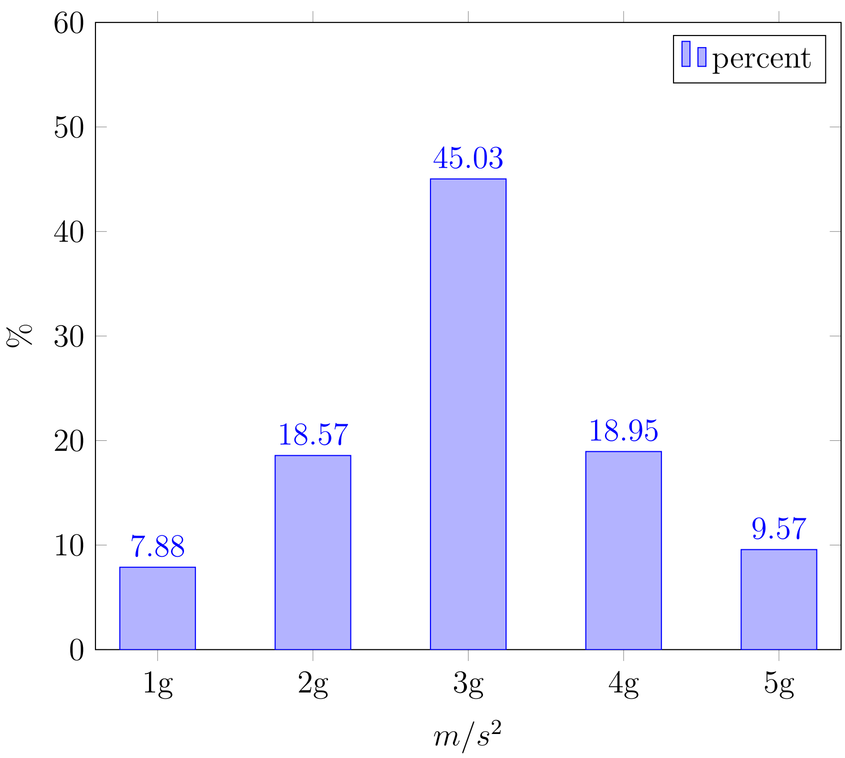

Figure 5.10: Favorite gravity force of roller coaster

The 10th question investigated the respondents' preferred length of roller coasters. It was found that most people did not prefer roller coasters that were either too short or too long. Instead, roller coasters that were 1300-1599 meters in length were preferred.

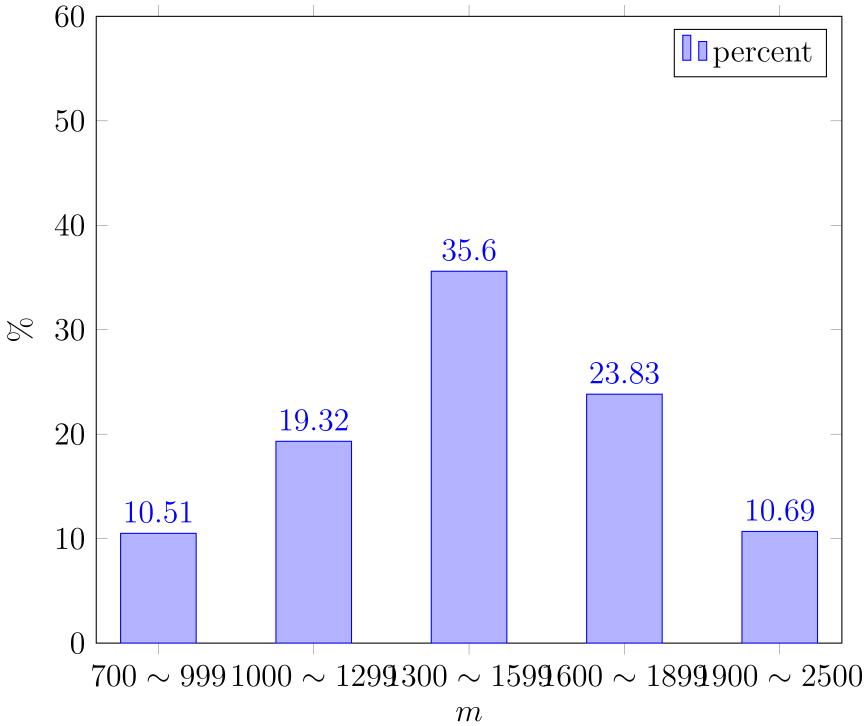

Figure 5.11: Favourite Total Distance

The final question, number 11, focused on the number of loops in a roller coaster ride. The survey found that more than six loops would result in a steep drop in enjoyment levels, and too many turns would make riders feel uncomfortable. Respondents preferred roller coasters with 2 to 8 loops, with six loops being the most preferred number.

In summary, the survey results showed that the duration of the roller coaster ride, the gravity level, the length of the ride, and the number of loops were all critical factors that impacted the enjoyment levels of roller coaster enthusiasts. Understanding these factors and their optimal values could help in the design of better roller coasters that cater to the preferences of riders and provide them with the best possible experience.

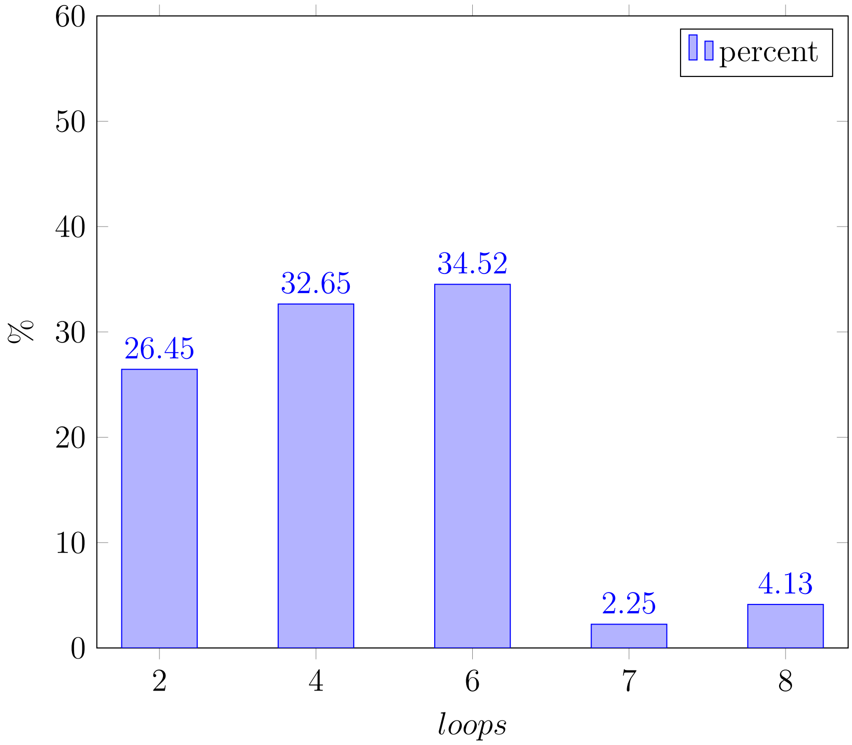

Figure 5.12: The Favorite loops of roller coaster

During the focus group, participants engaged in a lively discussion about the appeal of roller coasters. Many interviewees cited the coexistence of excitement and fear as the primary reason why people find roller coasters exhilarating. This observation prompted the group to pose a thought-provoking question: Which emotion is stronger on a roller coaster ride - excitement or fear?

To answer this question, the group conducted a survey among themselves, asking participants to rate their level of excitement and fear during the ascent and descent of a roller coaster ride. The results revealed that most people experienced a greater level of excitement than fear during both phases of the ride.

Upon analyzing these findings, the group concluded that roller coasters primarily provide an exhilarating experience that is punctuated by brief moments of fear. While fear is indeed a component of the roller coaster experience, it is not the dominant emotion. Instead, the excitement factor outweighs the fear and is the primary emotion that people associate with this type of amusement ride.

In the focus group, it is finding a very interesting topic. The interviewees often mentioned that the reason why roller coasters make people feel happy is that excitement and fear coexist. From this point, the following question was asked. On the roller coaster, is the excitement greater than the fear or the fear is greater than the excitement? In this question, it was found that most people actually felt more excitement than fear during the ascent or descent, so in conclusion, the roller coaster gives the excitement, and fear brought by people does coexist, but the excitement is greater than the fear after all.

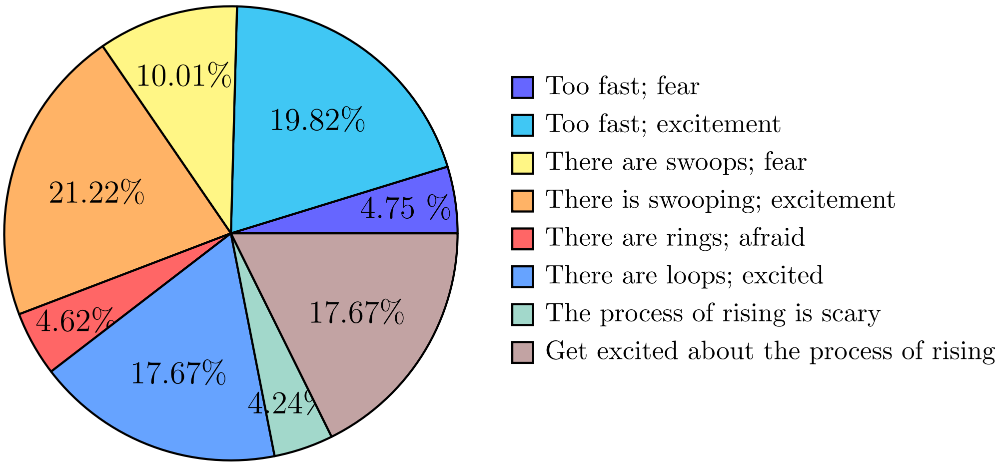

Figure 5.13: The reasons about feel Roller Coasters Exciting

During the focus group discussion, the respondents also mentioned different views about the thrill of the roller coaster. For example, the very exciting action in the roller coaster, the vertical descent and crazy rolling, and the relatively exciting parts, such as diving and sharp turns. All kinds of stimuli will always make the respondents feel different levels of pleasure. A survey was conducted on people in this aspect. The final results show that most people who like to ride roller coasters are more able to accept the relative stimuli, such as The roller coaster that dives, accelerates, and turns sharply can make them feel the greatest pleasure. It also tells us the truth that too much or too little can not improve people's pleasure.

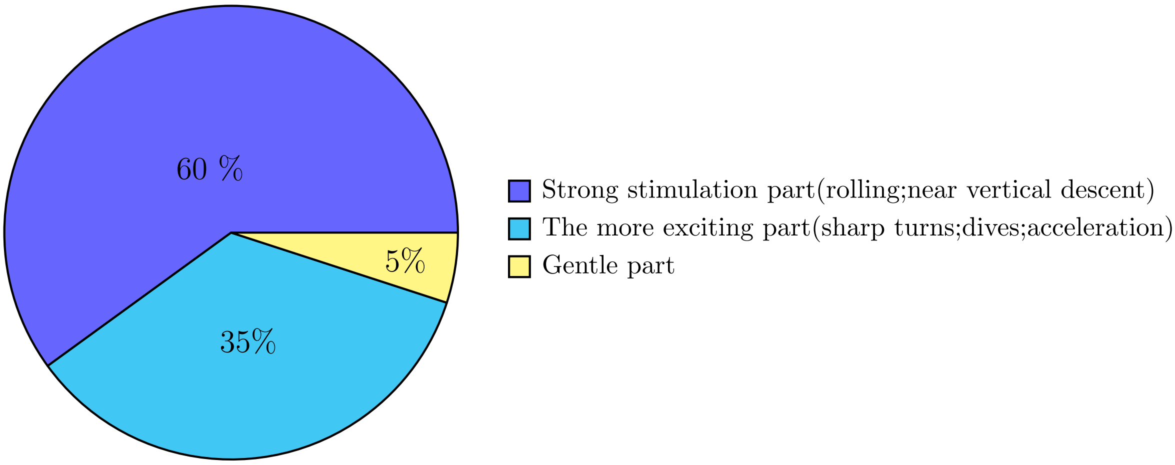

Figure 5.14: The part of the thrill of Roller coasters

Riding a roller coaster is a popular form of entertainment that can provide a thrilling experience for individuals seeking an adrenaline rush. However, the excitement and pleasure experienced during the ride can vary depending on the position of the rider on the roller coaster.

When riding a roller coaster, individuals experience different sensations as they ascend to the top of the ride. As the roller coaster reaches its peak, riders may feel a sense of anticipation and excitement, as they prepare for the drop that is about to come. According to a survey conducted among 533 roller coaster riders, 229 individuals reported feeling a mild sense of excitement when the roller coaster reached its peak, accounting for 42.96% of the total number of respondents. Additionally, 115 respondents reported feeling extremely excited, which accounts for 21.58%.

The sensation of excitement during a roller coaster ride is not only influenced by the position of the rider but also by the speed and movements of the roller coaster. Some riders may feel more excited during sharp turns or drops, while others may enjoy the feeling of weightlessness during moments of freefall.

Overall, the experience of riding a roller coaster can be highly entertaining and thrilling for individuals seeking an adventure. Whether it's the sense of anticipation before the drop or the rush of excitement during sharp turns, the roller coaster provides a unique form of entertainment that can be enjoyed by people of all ages.

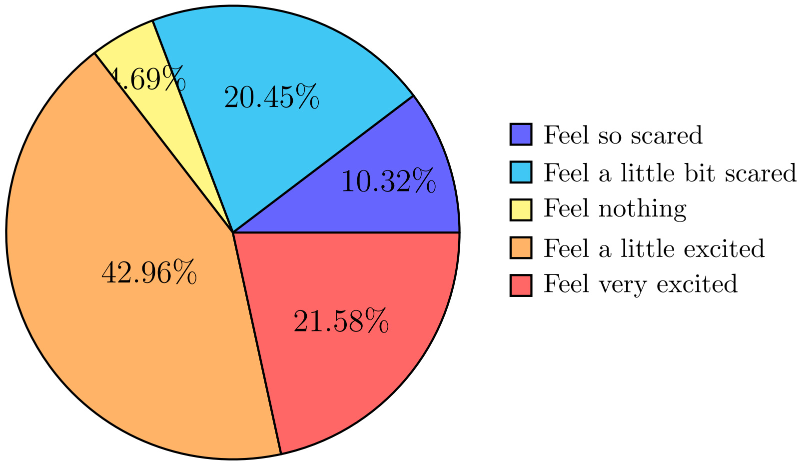

Figure 5.15: The feelings when the roller coaster reached the top

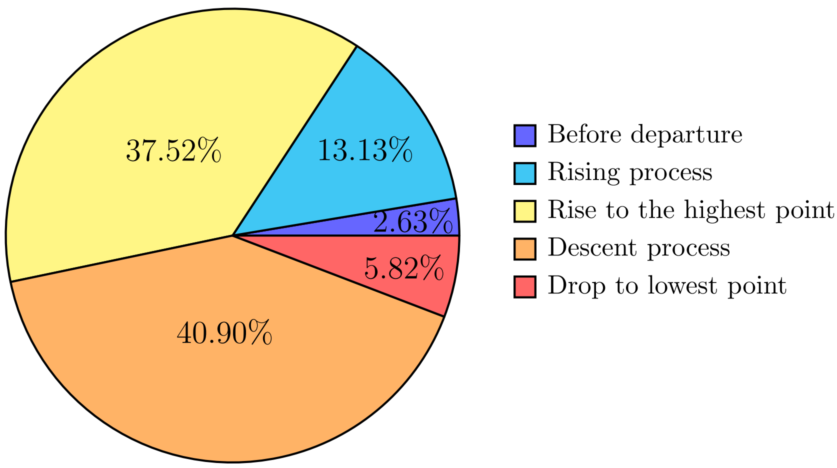

Figure 5.16: The position of most exciting when riding a roller coaster

During the focus group interview, an interesting topic emerged regarding the reason why roller coasters bring joy to people. Interviewees often mentioned that the combination of excitement and fear is the key to the roller coaster's appeal. Based on this idea, question 12 was asked to investigate whether excitement or fear was the dominant emotion experienced during the roller coaster ride.

The question asked whether the excitement or fear was greater during the ascent or descent of the roller coaster ride. The survey revealed that most people felt more excitement than fear during these moments. Therefore, it can be concluded that roller coasters generate both excitement and fear, but the excitement is greater than the fear.

The results of this question 12 suggest that the experience of riding a roller coaster is highly dependent on the combination of excitement and fear. It appears that the thrill of riding a roller coaster stems from the balance between these two emotions. This finding can be valuable to roller coaster designers and park operators who want to create the most enjoyable experience for their guests. By understanding the importance of balancing excitement and fear, designers can create roller coasters that generate the perfect amount of each emotion, resulting in a thrilling and unforgettable ride for all.

The focus group discussion provided valuable insights into the different aspects of thrill that roller coaster enthusiasts are interested in. The respondents shared various opinions on what they consider the most exciting part of a roller coaster ride. Some considered the vertical descent and crazy rolling to be the most thrilling part, while others felt that the diving and sharp turns were the most exciting. It was evident that different stimuli in a roller coaster ride can bring different levels of pleasure to people.

To gain more insight into this aspect, this questionnaire question 13 was conducted to determine the type of stimuli that people who like to ride roller coasters are most able to accept. The results of the question 13 showed that most people preferred relative stimuli that include diving, acceleration, and sharp turns. These types of stimuli gave them the greatest pleasure and satisfaction. The survey also highlighted the fact that too much or too little of these stimuli cannot improve the overall pleasure experienced by the riders. This information can be useful to designers and operators of roller coasters who seek to improve the ride experience for enthusiasts. The survey results suggest that incorporating relative stimuli that are not too extreme, but provide a sense of thrill and excitement, can lead to a more enjoyable ride experience for riders. It is important to note that finding the right balance between the different types of stimuli is crucial to ensure the safety and comfort of the riders.

The experience of riding a roller coaster is exhilarating and unique, as the various positions of the coaster cause riders to feel different degrees of excitement and pleasure. The top of the roller coaster, also known as the apex or peak, is a particularly thrilling moment for many people. The anticipation of the drop, combined with the feeling of being suspended in mid-air, creates a rush of adrenaline and a sense of excitement that is difficult to replicate.

In this survey (question 14) of 533 people who had ridden a roller coaster, 42.96% of them reported feeling a little excited at the peak of the ride, while 21.58% of them reported feeling super excited. This suggests that the apex of the ride is a particularly enjoyable moment for many riders, as the thrill and entertainment value are very high. In question 15 about the different positions of roller coasters, we found that approximately 41% of participants felt the most excitement during the downward phase, followed closely by approximately 38% who felt the most excitement during the ascent to the highest point. These survey results reveal the differences in emotional responses people have at different positions on a roller coaster and can help roller coaster manufacturers design and improve their products to provide even more thrilling and enjoyable experiences.

The unique sensations and feelings experienced while riding a roller coaster are due to a combination of factors, including the speed and intensity of the ride, the twists and turns, the height and position of the coaster, and the individual rider's physical and emotional response. Overall, the experience of riding a roller coaster is a thrilling and memorable one that leaves riders feeling exhilarated and energized.

In summary, the results of the study suggest that there are certain features that are particularly appealing to riders of roller coasters. Specifically, drops, inversions, sharp turns, and acceleration were identified as key elements that designers and developers should focus on when creating new roller coasters. Incorporating these features into roller coaster designs is likely to appeal to the preferences of most riders, and could lead to more successful and popular roller coasters in the future.

Moreover, the study also identified specific data on riders' favorite preferences. The best loops were found to be six laps, while the best speed range was between 90-100 km/h. The best height was 60 meters, while the best gravity value was 3G. The best time for a roller coaster ride was found to be three minutes and above, and the best distance range was 1300-1599 meters. This data provides valuable insights for roller coaster designers and developers, as it can help them to create rides that are tailored to the preferences of riders.

Overall, these findings have important implications for the design and development of roller coasters. By incorporating drops, inversions, sharp turns, and acceleration into their designs, and by paying attention to riders' preferences for specific features such as loops, speed, height, gravity, time, and distance, roller coaster designers and developers can create rides that are both thrilling and enjoyable for riders. This, in turn, is likely to lead to more successful and popular roller coasters in the future, and to the continued growth and development of the theme park industry.

- (1) The best loops are 6 laps;
- (2) The best speed range is 90-100km/h;
- (3) The best height is 60 meters;
- (4) The best gravity value is 3G;
- (5) The best time is around 3 minutes;
- (6) And the best distance range is 1300-1599 meters.

This data could lead to more successful and popular roller coasters in the future.

Table 5.3: One-sample t-test analysis results

Item	Sample Size	Minimum Value	Maximum Value	Average Value	Standard Deviation	t	p
favorite gravity force	533	1	5	3.038	1.036	0.836	0.404

$*p<0.05$
$**p<0.01$

Gravity force is a crucial parameter in roller coaster design as it determines the acceleration experienced by riders. It plays a role in controlling various factors such as speed, height, and turn radius in roller coaster design. The speed and height of a roller coaster are primarily influenced by gravity and kinetic energy, while the turn radius is determined by both gravity and centrifugal force.

In this survey involving 533 participants, respondents were asked about their preferred gravity force value for roller coasters. The results indicated that 45.03% of participants chose 3G as their favorite gravity force value, which was also the most popular choice. To further assess the representativeness of the data, a single-sample T-test was conducted on this question. The analysis yielded the following results:

sample size = 533, minimum value = 1.000, maximum value = 5.000, average value = 3.038, standard deviation = 1.036, and p-value = 0.404.

Based on the above data, none of the findings demonstrate statistical significance (p >0.05) concerning the question "What is your favorite gravity force when riding a roller coaster?" This implies that the average value for this item is close to 3.0, and there is no statistically significant difference. Therefore, a gravity force of 3G is considered representative according to the survey results.

The distance of roller coasters in mind can be described as:

$$y(t) = \frac{1}{2}at^2 = \frac{1}{6}jt^3 \tag{5.1}$$

Based on the specific data of favorite preferences, we knew that the $a = 3g$ and $t \approx 3$.

So we can solve the average jerk in mind [97],

$$j = \frac{9g}{t} \approx 3g \tag{5.2}$$

Here, we found that $a \approx j$, which means that the acceleration and jerk of roller coasters are the same, they locate in a balance zone.

If the jerk is too much higher than acceleration, the process is too unpredictable and discomfort, and it will make people feel dangerous.

Otherwise, if the jerk is too much lower than the acceleration, the roller coaster can not make sure enough thrill, it will make people feel bored.

Acceleration and jerk work together to provide enough entertainment and thrill and avoid danger and boredom.

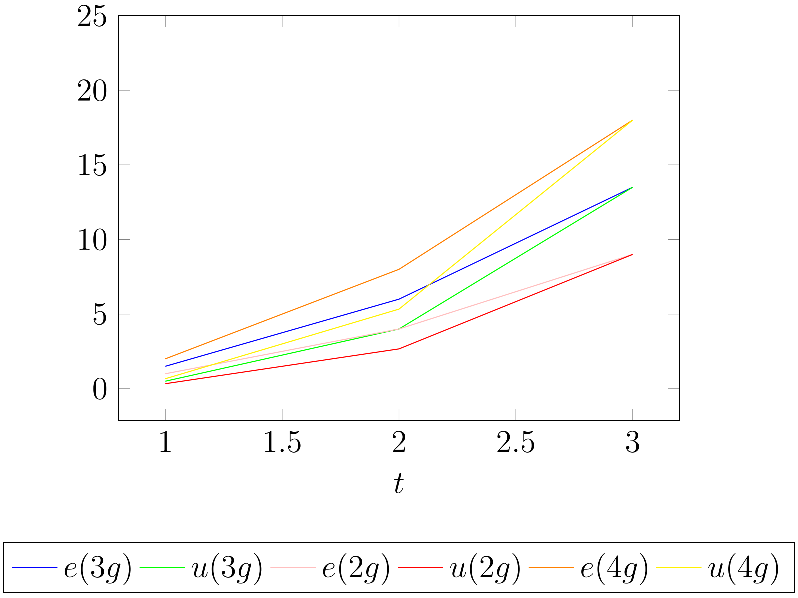

Figure 5.17: The tendency of entertainment and unpredictability in roller coasters

Our questionnaire fits perfectly with the speed, acceleration, number of loops, duration, etc. of the most popular roller coasters.

As Figure 5.17 shows, we can see the tendency of entertainment and unpredictability in roller coasters within 3 minutes, entertainment and unpredictability are strong correlations and work together to provide reasonable entertainment and excitement for roller coasters.

5.5 Chapter Summary

The chapter titled "Preferences of Roller Coaster Enthusiasts" explores the opinions and preferences of roller coaster enthusiasts through a focus group interview and a questionnaire investigation. The purpose of the study is to better understand what characteristics and features roller coaster enthusiasts value most in their favorite rides.

The chapter begins with an introduction to the topic, providing a brief overview of the popularity of roller coasters and the importance of understanding the preferences of enthusiasts. The authors then explain the methodology used in the study, including the recruitment of participants and the use of both focus groups and questionnaires.

The first section of the chapter describes the results of the focus group interview. The participants discussed a variety of factors that they value in a roller coaster, including ride intensity, duration, timing, and stimulation. They also discussed the importance of safety and the overall experience of riding a roller coaster. The authors provide a detailed analysis of these results and highlight the key themes that emerged from the focus group discussion.

The second section of the chapter presents the results of the questionnaire investigation. The questionnaire was completed by a larger sample of roller coaster enthusiasts and included questions about demographics, ride characteristics, and specific values during the roller coaster ride. The authors analyzed the data from the questionnaires and identified several important trends and preferences among the respondents. These included a preference for longer and more intense rides, a desire for unique timing, and immersive experiences.

The final section of the chapter summarizes the key findings of the study and discusses their implications for the amusement park industry and the design of a virtual roller coaster game. In roller coaster game designing, the value of the preference found in this study could improve the following three parts:

- (1)The gaming experience: By designing roller coaster games that closely match the preferences of the players, game developers can provide a more personalized and enjoyable gaming experience. This can increase player engagement and keep them coming back for more, resulting in better overall player satisfaction.

- (2)Targeting specific audiences: By understanding the preferences of different groups of players, game developers can create roller coaster games that are tailored to specific age groups, skill levels, and interests. This can help them reach a broader audience and appeal to a wider range of players.

- (3)Creating safer roller coasters: Understanding what riders find enjoyable and exciting can also help designers create safer roller coasters in real life. By incorporating popular and thrilling elements into the design, designers can create a ride that is both exciting and safe, ensuring that riders have a memorable experience without any unnecessary risks.

Overall, the chapter provides a valuable contribution to the literature on roller coasters and amusement parks, shedding light on the preferences and priorities of the most dedicated and enthusiastic riders.

Chapter 6

Conclusion

With artificial intelligence (AI) advancement, games are gradually regarded as an accessible way to simulate human society and explore more profound insights into human science. Iida et al. have discussed the link between work and play. From this perspective, can we blur the line between ride and play, or find the link between game and ride? As social animals, human beings inevitably take transportation in social activities such as going to work and going to school. Is it possible to relate this behavior to the game or play? The main work of this part is to analyze the different experiences that roller coaster brings to passengers under the influence of gravity at different heights and to connect it with people's behaviors in cars, airplanes, and other transportation vehicles. As long as the height of the roller coaster is low enough, the roller coaster and ordinary transportation can be regarded as the same in this case. This study is to explore the connection between ride comfort and play comfort (real physics and mental physics) that can comprehend the physical world in the human mind better. Through research activities such as blur games and physic, the world of thinking can be closely integrated with the physical world.

We expanded the research that bridges ride comfort and play comfort, where the roller coaster is utilized to establish the links between physical performance and mental experience (called the motion in mind). It was found that the roller coaster from 1976 to 2016 had evolved from being a pure thrill ride into an exciting ride experience, which was demonstrated by the changes in the potential energy, momentum, and force of such a ride experience. Such an experience was achieved by considering the trade-off between the physics indexes and the rides' physical properties.

Furthermore, the link between ride comfort and play comfort relative to the natural physic's motion and motion in mind was established according to the changes in ride speed (and direction), which can be reflected by the overlapping of the physical force and force in mind. The measure of $F \simeq F(N)$ was an essential indicator of the comfort expected, both in the ride's physical and mental aspects. Additionally, analogical links based on its excitement stability were tabulated to determine the comfort trade-off expected from a ride. Finally, it was found that jerk is an element that existed within the comfort of the play experience and should be avoided in the physical ride's comfort. Such a condition implies that the play experience had a different influence on the ride's comfort when compared to the physical ones.

We also discussed the tendency of GR value and motions when players go to the next stage, we used an action game to analyze when players go to the next stage, and how motions in mind will change. The GoW series via the GR theory and its extension, called motion in mind, is based on the actions of the boss battles available in each of the sequences of the GoW considered. From the analysis, the evolutionary trend of the GoW series was identified in the challenge increases, insights into the narrative design, levels of predictability, and balances the experience of play for beginner and advanced players.

From the findings ((Figure 4.3 to Figure 4.8). And Table 4.3), it can be concluded that the boss battle of the GoW series was designed with sufficient sophistication to be entertaining to diverse players ($GR \in [0.07, 0.08]$) while applying enough unpredictability and retain the interest of the player ($AD \in [0.045, 0.06]$) to allow the experience repeatable. Additional features identified include the learning comfort imposed by the developers, where the player is expected to learn and master the battle when reaching the final boss for each GoW series. In addition, the m dynamics of the game imply a roller-coaster-like gameplay experience, where the uncertainty makes it enjoyable to the player.

The study also found that the game's platform indirectly related to different GoW series experiences. As different platforms had different interfaces (diegetic or non-diegetic) [87] and new media technology [88], it could significantly influence the play experience. As the findings of this study showed, the GoW series had demonstrated parallel development of human-computer interfaces and measures of information delivery. The developer encouraged players to learn and adapt not only to in-game challenges but also to involve rapid reactions and excellent hand-eye coordination, thus, making the expected experience from the play much more holistic and enjoyable.

As action games are rich with other game-playing elements, future work may want to consider those other elements to enhance the analysis. For instance, the inclusion of puzzle-solving stages, building and/or crafting, character skill combination and/or balancing meta-gaming elements (user interface, mini-games, and in-game progression and/or badging), and narrative structure. These elements also measured and determined their roles relative to the expected enjoyment and entertainment of the intended game-playing experience of the players by the developers. Finally, having a unified view of the game design (inclusive of the aforementioned elements) would provide insights that were beneficial to the developers and publishers of the games alike.

The final part findings of this study shed light on the mood and feelings of roller coaster enthusiasts while riding a roller coaster and provide valuable insights into the factors that contribute to a satisfying and comfortable ride. By investigating and researching first-hand information on velocity, acceleration, distance traveled, travel time, and the optimal data range of roller coaster loops, the study has established a comprehensive understanding of the technical aspects of roller coaster design. Furthermore, the study has also explored the expression of participation and comfort of riders in different important driving positions, and thoroughly examined the psychological changes of the riders throughout the ride. foundation for establishing a mental model of users riding roller coasters in the future. These findings are highly relevant to game design, especially in the context of user game comfort design. By using this data, game designers can tailor the game experience to meet the needs and preferences of users, resulting in higher levels of engagement and satisfaction. The study's contribution to game design lies in its ability to provide a theoretical basis for future roller coaster game development that accurately simulates the thrill of riding a roller coaster while ensuring user comfort. In conclusion, the insights gained from this study have significant implications for both the amusement park industry and the game design industry. By using this data, developers can create roller coaster games that offer a realistic and enjoyable experience for users, while also addressing the need for comfort and safety. Ultimately, this study's contribution to game design, especially user game comfort design, is crucial for creating engaging and immersive experiences that keep players coming back for more.

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