Exploring the Effects of Dynamic Difficulty Adjustment Functions in Running Exergames on Player Experience and Physical Effort

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Abstract

Dynamic difficulty adjustment (DDA) in exergames uses player data to modify game challenges, balancing difficulty with player ability or fitness. DDA in exergames can be categorised into two types: exercise intensity (EI)-based and performance (P)-based. However, insight into how they impact players is limited.

This thesis investigates how different DDA functions influence player experience (PX) and physical effort using a bespoke running exergame as the case study. This was done using within-subject quantitative design with counterbalancing. The impact on PX was assessed using established questionnaires and physical effort was measured through average heart rate (AHR).

Experiment 1 (N = 26) explored two EI-based DDA types: continuous EI-based DDA (DDA1), aiming to maintain AHR in the aerobic zone, and interval EI-based DDA (DDA2), alternating between low and high intensity, compared to a no-DDA condition (nDDA). Both DDA1 ($p < .001, d = 1.00$) and DDA2 ($p = .011, d = .64$) significantly increased AHR compared to nDDA, with no difference between DDA1 and DDA2 ($p = 1.000, d = .18$). Perceived exertion was higher in DDA1 than in both nDDA ($p = .006, r = .54$) and DDA2 ($p = .015, r = .48$), while no significant difference was found between DDA2 and nDDA ($p = .323, r = .19$). However, EI-based DDA did not influence other PX.

Experiment 2 (N = 43) examined P-based DDA (DDA3), adjusting difficulty based on setback counts. DDA3 significantly improved challenge-skill balance ($p = .026, r = .34$), perceived competence ($p = .018, r = .36$), and AHR ($p = .036, d = .33$) compared to nDDA.

Experiment 3 (N = 36) compared DDA3 to a novel P-based DDA (DDA4), adjusting difficulty before setbacks occurred. DDA4 significantly enhanced challenge-skill balance ($p = .017, r = .40$), increased competence satisfaction ($p = .002, r = .51$), and reduced competence frustration ($p = .040, r = .34$) compared to DDA3.

This research provides insights into how DDA functions impact players, suggesting that different DDA functions influence players in distinct ways, opening opportunities for using this knowledge in designing exergames and DDA.

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"What we know is a drop, what we don't know is an ocean."
– Isaac Newton

May this research serve as a small yet meaningful contribution to the field of Human-Computer Interaction in Games.

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`Appamādena Sampādetā`, the final teaching of the Buddha, is a reminder I reflect on throughout my PhD journey. It teaches that nothing in this world is permanent, including our lives. We will grow old, and our bodies will decline. The Buddha urged his followers to act with diligence and mindfulness, completing tasks before we leave this world. By doing so, we can avoid recklessness, which may lead to failure.

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Declaration

I, Sittikrai Chorrojprasert, declare that this thesis is my own original work and that I am the sole author. This thesis has not been submitted, in whole or in part, for any degree or qualification at this or any other university. All sources of information, ideas, and quotations are fully acknowledged and properly cited in the References.

Parts of the research described in this thesis have previously published in:

- An overview of the research and the design of *ExerWitch* exergame were presented at the Doctoral Consortium at FDG '23: *Proceedings of the 18th International Conference on the Foundations of Digital Games* as "Player Experience in Exergames with Dynamic Difficulty Adjustment".

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[1] University of York, "Appendix 10: Thesis Submission and Examination," Research Degree Policy, [Online]. Available: click here to the reference source. [Accessed: 13-Mar-2025].

List of Abbreviations

AHR	Average Heart Rate During the Playtime Session
AI	Artificial Intelligence
BANGS	Basic Needs in Games scale
BPM	Beats per Minute
BRPE	Borg's Rating of Perceived Exertion
CORGIS	Challenge Originating from Recent Gameplay Interaction Scale
DDA	Dynamic Difficulty Adjustment
DDA1	Continuous Exercise Intensity-based Dynamic Difficulty Adjustment
DDA2	Interval Exercise Intensity-based Dynamic Difficulty Adjustment
DDA3	Reactive Performance-based Dynamic Difficulty Adjustment
DDA4	Proactive Performance-based Dynamic Difficulty Adjustment
EI-based	Exercise Intensity-based Dynamic Difficulty Adjustment
FSS	Flow State Scale
HCI	Human-Computer Interaction
HR	Heart Rate
ID	Identification
IMI	Intrinsic Motivation Inventory
IQR	Interquartile Range
MET	Metabolic Equivalent of Task
MHR	Maximum Heart Rate
nd.	No Significant Difference
nDDA	No Dynamic Difficulty Adjustment
NPC	Non-Player Character
P-based	Performance-based Dynamic Difficulty Adjustment
PA	Physical Activity
PX	Player Experience
SD	Standard Deviation
SDT	Self-Determination Theory
SEM	Standard Error of the Mean
SFSS	Flow Short Scale
sig.	Significant
vs.	versus

Chapter 1

Introduction

Video games are not limited to sedentary activities but they can also incorporate physical movement, encouraging physical activity while providing entertainment. Exergames, also known as exertion games, refer to a category of video games that require players to use physical movements to interact with the game, resulting in energy expenditure that is sufficient to contribute to fitness [1]. Despite having existed for decades, exergames remain an area of interest [2], [3], with early examples including the Power Pad (1988)[1] and Dance Dance Revolution (1990s)[2], where players stand on an interaction-input pad or stage and physically step on each button to interact with the games.

In recent years, with more advanced technology such as inertial game devices and virtual reality headsets, Ring Fit Adventure (released in 2019) and Beat Saber (released in 2019) are examples of exergames that have gained popularity among players. Ring Fit Adventure has an approximate average rating of 4 out of 5 stars based on around 46,000 reviews[3], while Beat Saber has received approximately 93% positive ratings from about 67,000 reviews[4].

One possible reason exergames continue to gain popularity among players is that they offer a unique way to engage individuals in physical activity. Unlike traditional exercise, which often depends on self-motivation, exergames incorporate interactive and immersive gameplay, making physical activity more engaging. Besides, by integrating goal-oriented challenges that provide a sense of accomplishment when overcome, as well as reward systems, competition, and a connection to an avatar [2], [4], [5], exergames can enhance player motivation and adherence to exercise routines [2]. Moreover, research by Kari [6] and Osorio *et al.* [7] indicates that exergames are generally perceived as more enjoyable than traditional exercise across different age groups.

[1]Power Pad, Nintendo Fandom [Online], Available: click here to the reference source. [Accessed: 24-Feb-2025]

[2]Dance Dance Revolution (1998), Dance Dance Revolution Fandom [Online], Available: click here to the reference source. [Accessed: 24-Feb-2025].

[3]Nintendo, Ring Fit Adventure [Online]. Available: click here to the reference source. [Accessed: 24-Feb-2025]

[4]Beat Games, Beat Saber [Online]. Available:click here to the reference source. [Accessed: 24-Feb-2025]

Exergames have been also explored for their potential benefits beyond entertainment. Research [1], [6], [8] suggests that exergames can promote light-to-vigorous exercise intensity in children and adults, comparable to traditional exercise. However, this effect depends on the type of physical activity incorporated into the games. In addition to encouraging physical activity, exergames have the potential to reduce sedentary behaviour, increase energy expenditure, and serve as a tool for combating obesity [7], [8].

In exergames, physical challenges—where players use their physical limitation to overcome in-game challenges with speed and accuracy [9]—are often used to engage players. A review by Bogost [2] identifies two types of physical challenges in exergames: (1) players quickly reacting physically after seeing something, such as striking a target in a Whack-a-Mole game, and (2) players executing movement patterns with precision and agility. The latter often requires transitioning between exercise movements accurately and quickly to deal with game challenges.

As physical challenges require players to move specific body parts or their entire bodies to overcome obstacles, they lead to energy expenditure, which is a primary goal of exergames. These challenges also demand quick and dexterous movements, fostering a sense of challenge. Moreover, setbacks and failure are common game mechanics that intensify the game experience [10], [11]. These elements are designed to enhance player engagement, encourage a desire for skill improvement or thrive to overcome, and create a more enjoyable experience when challenges are overcome [12].

Experiencing challenges, setbacks, and failure can shape various aspects of player experience (PX). One widely discussed theory related to challenge is *Flow*, introduced by Csikszentmihalyi *et al.* [13]. The key to achieving flow is *a balance between the challenge and the player's skill level* [14]. When the challenge is too difficult, it can lead to frustration and overwhelming *pressure or tension* [15], as players repeatedly fail to overcome game challenges. This can reduce *motivational effort* to keep trying. Moreover, an overly difficult challenge can prevent players from reaching *enjoyment*, as they struggle to fully focus and engage with the game [14]. On the other hand, when the challenge is too easy, players may find the game boring, which can negatively affect engagement.

Another relevant theory is Self-Determination Theory (SDT), as outlined by Ryan *et al.* [16], which identifies three key factors—autonomy, relatedness, and competence—that lead to intrinsic motivation when three are satisfied, as individuals tend to seek new challenges and growth once their basic psychological needs are met [17]. In particular, *competence satisfaction* plays a crucial role related to challenge, as overcoming challenges can enhance a player's sense of competence. However, if a challenge is excessively high, it may cause *competence frustration* due to repeated failure.

In exergames, challenges can have a greater impact on PX than in traditional video games, as different levels of physical challenges lead to varying exertion levels. So, they can impact *perceived exertion*, which refers to an individual's subjective perception of how hard their body is working during physical activity, and *physical effort*, often measured by heart rate (e.g. [18]). While increased physical effort can be beneficial in exergames, excessively intense and demanding challenges may cause players to perceive a high level of exertion, leading to severe fatigue and a negative experience [19]. This highlights the importance of balancing challenges in exergames.

Even though balancing between challenge and skill provides benefits to PX, it may not be ideal for all video games due to its potential limitations. For example, players might feel overly in control due to game difficulty adjustments, neglecting other aspects of the game [20]. However, in the context of exergames, the challenge level should be well-balanced, as it is further complicated by the physical exertion involved. Players must not only use their gaming skills to handle challenges but also exert physical effort to overcome them. Considering this balance helps exergames avoid being either too physically demanding or not demanding enough, supporting the aim of promoting physical activity alongside entertainment.

The dual-flow model [19], which extends traditional flow theory, also highlights two equilibria that should be considered when designing exergames: the balance between challenge and skill (referred to as attractiveness, which ensures that in-game challenges can sustain player engagement) and the balance between exercise intensity and the player's fitness level (referred to as effectiveness, which ensures that the activity remains physically beneficial). An excessive challenge can lead to severe exhaustion, while a very low challenge may fail to provide any benefits for physical activity.

To address the imbalance in challenge levels, two approaches are commonly adopted in video games: manual adjustment and dynamic difficulty adjustment (DDA) [21], [22]. Manual adjustment is a method where developers predefined static difficulty levels, such as easy, medium, and hard, from which players can choose before playing to match their preference or skill. Research suggests that this approach can promote a sense of control [22]. However, it has limitations. The preset difficulty levels may not suit all players, and it can interrupt the game flow as players are required to stop and adjust the level during gameplay [22]. Moreover, in exergames, where players continuously engage in physical activity, preset difficulty levels may not account for the player's changing physical state during the game. For instance, a player may become tired or more active at different points of time, or if the difficulty level is too low relative to their fitness, the game may become ineffective. On the other hand, if the difficulty level is set too high, it may cause excessive fatigue, potentially leading players to stop playing before the game session ends, which reduces the effectiveness of exergames.

These issues lead to the need for real-time adjustment using player data to modify the difficulty. DDA is another approach commonly adopted in video games. DDA is typically based on the challenge-skill balance from flow theory, using player data (e.g. performance data and physiological data) to assess and adjust the difficulty level [23], [24]. Even though some studies (e.g. [22], [25]) criticise DDA, if poorly designed, it may negatively impact game experience, for example, unrealistic difficulty shifts (e.g. rubber-banding in racing games), exploitation by players, or a loss of control. However, DDA remains highly relevant in the context of exergames.

Unlike preset difficulty settings, which rely on static levels (e.g. easy, medium, hard), DDA dynamically adapts to real-time player data, offering a more individualised experience. This is particularly important in exergames, where physical exertion fluctuates during play—unlike traditional sedentary video games, where physical effort is not a limiting factor. A player may feel energetic at one moment and fatigued the next, making real-time adjustments useful for maintaining both engagement (attractiveness) and effectiveness.

The potential of DDA to adjust difficulty in real time based on player data motivates an exploration of its impact on PX and physical effort, which the next section describes.

1.1 Research Motivation

DDA has been adopted in many exergame studies, primarily to promote players' exertion levels within a targeted exercise intensity zone (e.g. [18], [26]) and to balance game challenges with player skill (e.g. [23], [27], [28]). However, despite its widespread use, the impact of DDA functions on both physical effort and PX remains an area that needs further investigation.

In exergames, DDA can be categorised into two types based on the player data used: exercise intensity-based DDA and performance-based DDA. Exercise intensity (EI)-based DDA, grounded in the effectiveness of the dual flow model [19], adjusts difficulty based on player exertion levels during gameplay. One commonly used metric for this is heart rate (HR), typically measured in beats per minute (BPM) (e.g. [18], [26], [29]).

In this approach, the DDA function monitors the player's heart rate and compares it to predefined exercise intensity zones, which are often calculated using age-related maximal heart rate formulas (e.g. 220 - person's age [30]). If the player's heart rate falls below the target range, the function increases the difficulty level to induce higher energy expenditure. In contrast, if the player's heart rate exceeds the target range, the function reduces the difficulty level to lower intensity and allow the player to recover.

Previous studies (e.g. [31], [32]) suggest that DDA functions potentially increase heart rates to reach target zones. However, the literature reveals limited investigation into whether DDA leads to a higher average heart rate compared to no DDA, and the findings appear conflicting. For instance, an EI-based DDA [26] using heart rate in a cycling exergame found no difference in average heart rate, while another EI-based DDA [18] using heart rate in a pedalling game (which involves a similar physical activity but a different game theme) reported an increase in heart rate. Furthermore, a few studies (e.g. [18], [26], [33]) have examined the impact of EI-based DDA on PX.

Moreover, it seems that most existing research [18], [31], [32] using EI-based DDA commonly applies continuous-pattern physical activity, with some studies proposing interval-pattern physical activity, such as HIIT (High-Intensity Interval Training) [34]. However, how these two different types of DDA—continuous EI-based DDA and interval EI-based DDA—impact PX and physical effort remains under-explored as these two approaches seems to generate different physical activity patterns which may impact PX and physical effort differently.

There is another type of DDA, known as performance (P)-based DDA. This type of DDA, often based on the challenge-skill balance in Flow theory [13], uses player data to assess performance, which can be defined differently depending on the game, such as error or success rates, completion time, or the number of enemies killed. Existing research (e.g. [23], [24], [27], [28]) generally shares a similar concept of how P-based DDA functions work: player performance is evaluated, and if performance is poor, the DDA decreases the difficulty level to prevent negative experiences, such as frustration. Conversely, if performance is good, the DDA might increase the difficulty level to maintain the challenge (avoiding boredom) and foster player progress.

Existing exergame studies [23], [24], [27], [28] that adopt P-based DDA commonly use a reactive approach, where difficulty is adjusted while players are struggling with a challenge.

In this approach, players must first encounter setbacks or failure before receiving assistance from the DDA. This can create a sense of challenge and intensity that motivates players to overcome obstacles and improve their performance [12]. Some studies (e.g. [35]) further suggest that experiencing failure before succeeding can enhance enjoyment.

However, when players perceive these setbacks during extended gameplay as repeated failures, the outcome may instead be frustration [36], especially in exergames where physical exertion is required. Fatigue during gameplay may amplify this frustration, reducing the likelihood of sustained engagement [37]. In this context, a proactive approach could mitigate the problem by adjusting difficulty levels before players encounter likely failures. Nevertheless, such a strategy may also forfeit the advantages of the reactive approach in fostering an intense and engaging game experience.

Regarding the impact of P-based DDA on PX, research in this area remains limited. Besides, existing studies present mixed findings. For instance, some research (e.g. [24], [27], [38]) suggests that applying P-based DDA can potentially enhance PX, leading to positive experiences such as flow and enjoyment. However, other studies (e.g. [23], [28]) report no significant differences in PX when using P-based DDA. Furthermore, only a few studies have examined how P-based DDA influences physical effort. Also, in exergames, there appears to be limited research on incorporating the concept of a proactive approach into practice, and how proactive P-based DDA affects players compared to reactive P-based DDA remains under-explored.

Understanding these effects is important for both game designers (as creators) and players (as users who experience the game). For example, although EI-based DDA can help regulate player exertion levels within the target zone, if its adjustments negatively affect PX, it may discourage continued engagement with exergames. Also, the impact of P-based DDA on PX remains unclear, and its influence on physical effort has not been widely explored. While P-based DDA can enhance PX, if it fails to promote physical effort, it may reduce the effectiveness of exergames in encouraging physical activity. These gaps highlight the need to examine how different DDA functions affect PX and physical effort, providing insights for future development to create exergames that balance both attractiveness and effectiveness [19]. The next section outlines the gaps identified in existing research.

1.2 Research Gaps

Some related studies have reported a significant positive impact on PX when DDA was implemented compared to no DDA in the following cases:

- **Pong game (P-based DDA)** — Ajani *et al.* [27] and Goršič *et al.* [38]
- **Full-body game (P-based and EI-based DDA)** — Martin-Niedecken *et al.* [24] (no difference in average heart rate)

However, other studies found no significant impact on PX when DDA was applied compared to no DDA in the following cases:

- **Pong game (P-based DDA)** — Darzi *et al.* [28]
- **Cycling game (EI-based DDA)** — Wünsche *et al.* [26] (no difference in average heart rate)
- **Lower-body movement exergame (EI-based DDA)** — Schwarz *et al.* [33]
- **Full-body game (P-based and EI-based DDA)** — Martin-Niedecken *et al.* [23]
- **Pedal game (EI-based DDA)** — Ketcheson *et al.* [18] (but increased average heart rate)

These studies show research gaps in the following: these studies present mixed findings regarding PX and physical effort. Moreover, different types of physical activity in exergames involve varied exertion levels from low (e.g. Pong) to vigorous (e.g. full body). Some studies also have limitations, including small sample sizes [24], low-intensity physical activity in games like Pong [27], [28], [38] (which might limit the difficulty adjustment range of DDA because the lower intensity may not provide sufficient physiological variation to trigger significant changes in PX or physical effort by DDA), and non-fully automated DDA, where investigators manually adjusted difficulty [24]. These uncertainties and limitations highlight the need for further investigation into the impact of DDA in exergames on PX and physical effort.

Moreover, there is a lack of understanding of how various P-DDA strategies: proactive (anticipating failure) and reactive (responding to failure), influence PX and physical effort differently. Given these gaps, future research should address these issues by exploring a wider range of physical activities, incorporating fully automated DDA functions, and comparing proactive and reactive DDA approaches to better understand their effects on PX and physical effort.

1.3 Research Questions and Objectives

To address the research gaps in the under-explored effects of DDA in exergames on PX and physical effort, this research aims to investigate the following research questions:

Research Question 1: How do different DDA functions affect player experience in exergames?

Research Question 2: How do different DDA functions affect physical effort (as evaluated through average heart rates) during gameplay in exergames?

Research Question 3: How does proactive performance-based DDA impact player experience and physical effort compared to reactive performance-based DDA?

To answer these questions, this research aims to provide empirical evidence and quantitative data by:

- Examining the impact of EI-based DDA on PX and physical effort compared to a no-DDA condition.
- Examining the impact of P-based DDA on PX and physical effort compared to a no-DDA condition.
- Comparing two variations of P-based DDA: assisting the game difficulty level before (proactive P-based DDA) or after players experience game setbacks (reactive P-based DDA), to explore their different effects on PX and physical effort.

1.4 Methodology

Empirical within-subject experiments with counterbalancing were conducted to address the research questions, engaging participants in an exergame integrated with different DDA conditions. This approach (commonly used in related works, such as [23], [26], [32], [34], [39]) was adopted to examine the impact of EI-based DDA and P-based DDA in contrast to the no-DDA condition, as well as to compare the effects of proactive and reactive P-based DDA.

The impact of each DDA function and the no-DDA condition is examined through validated PX questionnaires and physical effort measurements, with heart rate (beats per minute) recorded throughout gameplay.

Additional details on the research methodology are provided in Chapter 3. Further details on the exergame are provided in Chapter 4, while details on each DDA function is explained in each experimental chapter.

1.5 Scope

This research investigates the effects of different DDA functions in an exergame on specific aspects of PX based on the literature review (i.e. intrinsic motivation, flow, perceived exertion, and perceived challenge) and physical effort. The research examines exercise intensity-based DDA, which adjusts game difficulty using heart rate in beats per minute based on age-related maximal heart rate, and performance-based DDA, which adjusts difficulty based on player performance. These DDA functions are explored within a single-player exergame where physical challenge (the main challenge commonly found in exergames) serves as the core gameplay element.

Physical activity in the related works ranges from low to high intensity. Therefore, (1) DDA functions should dynamically adjust game difficulty in response to a wide range of exertion levels, and (2) the types of physical activity should be linked to the cardiovascular system, as EI-based DDA uses heart rate for difficulty adjustment. Additionally, the experiments measured average heart rate (to describe physical effort) during the play sessions. Aerobic exercise is the type of physical activity focused on in this research (further details are provided in Chapter 4).

This research adopts a short-playtime-session experimental design, consistent with previous

studies (e.g. [18], [23], [24], [38]), to address the gaps in the under-explored immediate impacts of DDA (using a simple rule-based algorithm) on PX and physical effort. Unlike conventional video games, exergames involve physical activity, and prolonged play sessions can introduce both cognitive workload and physical fatigue [37]. To mitigate potential confounding effects of fatigue on PX measurements, a short playtime session was chosen.

Participants aged 18 or older who consider themselves to have no limitations in engaging in physical activity were included in the study, allowing for generalisability of the findings to a broader population that may engage with exergames incorporating light-to-vigorous exercise intensities.

1.6 Contributions

The primary outcomes of this research contribute to:

- HCI research in video games
  - This research addresses gaps in related works on how EI-based DDA and P-based DDA in exergames impact players. It shows that EI-based DDA potentially enhances physical effort, benefiting the effectiveness of exergames in promoting physical activity. Meanwhile, P-based DDA not only promotes physical effort but also enhances positive PX, supporting both the effectiveness and attractiveness of exergames.
  - This research addresses the work of Sinclair *et al.* [29], who proposed the dual flow model [19], and conducted a pilot study on applying EI-based DDA (based on heart rate during playtime) to exergames. However, its impact on PX remains unexplored. This research shows that while EI-based DDA enhances effectiveness, it does not improve attractiveness.
  - This research shows that P-based DDA, grounded in challenge-skill balance from flow theory, can support players' psychological needs by assisting them when their performance is poor due to struggles with game challenges. This support enhances competence and challenge-skill balance. In contrast, EI-based DDA, designed to maintain players' exertion levels within the targeted exercise intensity zone, fails to satisfy players' psychological needs, leading to no impact on PX compared to the no-DDA condition.
  - This research shows that challenge-skill balance-based DDA (e.g. P-based DDA), which focuses solely on a single physical challenge, may not induce other PX, such as enjoyment, pressure, motivational effort, overall flow, and perceived challenge.
  - This research demonstrates that although P-based DDA uses similar performance-based data, the timing of DDA actions—whether applied before players struggle with game challenges or while they are struggling—affects PX differently.
- DDA design in exergames
  - In cases where game developers aim to promote physical activity, EI-based DDA can be a suitable choice, as it monitors players' heart rates and adjusts game exertion levels to maintain intensity within the target zone.

  - In contrast, if game developers are not targeting exercise intensity zones, P-based DDA can be a suitable choice that potentially enhances both PX and physical effort.
  - This research highlights the importance of alternating between low and high-intensity phases during gameplay, rather than maintaining continuous exertion levels, as continuous exertion increases perceived exertion compared to no DDA and interval physical activity.

1.7 Thesis Structure

This thesis is structured as follows:

- **Chapter 2** provides background knowledge and reviews the relevant literature on exergames, including challenges, setbacks, and failures, as well as the impact of these challenges on PX. It discusses how DDA can address challenge levels, its application in exergames, and its effects on players. Finally, this chapter identifies the gaps in existing research regarding DDA in exergames.
- **Chapter 3** outlines the research methodology developed after reviewing the relevant literature to address the research questions. This chapter details the experimental design, participant selection, data collection methods, data analysis procedures, ethical considerations, and data management plans used in this research.
- **Chapter 4** details the background of the exergame used in this research, which integrates various DDA conditions for the subsequent experiments.
- **Chapter 5** details the study on how EI-based DDA in the exergame impact PX and physical effort compared to a no-DDA condition.
- **Chapter 6** details the study on how P-based DDA in the exergame impact PX and physical effort compared to a no-DDA condition.
- **Chapter 7** details a further study on P-based DDA, examining the impact of two different variations—proactive and reactive—on PX and physical effort.
- **Chapter 8** summarises the key findings from the statistical tests of each experiment, provides a general discussion that connects the findings and situates the results on DDA in exergames within the broader context of DDA in conventional video games, and concludes the research by addressing the research questions, discussing contributions, highlighting limitations, and outlining potential directions for future work.

Chapter 2

Background

This chapter provides the background for this PhD thesis, which examines the effects of different dynamic difficulty adjustment (DDA) functions in exergames on player experience (PX) and physical effort. It begins with a review of the concept of exergames and physical activity.

The chapter then reviews the concept of game challenge and its influence on players, discussing how existing works have addressed challenge levels. Two common approaches to managing challenge levels, manual difficulty adjustment and DDA, are examined, with a particular focus on DDA.

Next, the chapter reviews how DDA in video games, particularly in exergames, influences player experience. Finally, the chapter concludes with a summary of related works and identifies the research gaps that this thesis aims to address.

2.1 Exergame

Physical activity has been incorporated into commercial video games for several decades [40]. Early examples include the Exertainment Life Cycle[1], which utilised exercise equipment, the Nintendo Power Pad[2], featuring a floor mat controller, and Dance Dance Revolution[3]. In more recent years, advancements in game technology, such as Wii Sports[4], Virtual Reality video games like Beat Saber[5], Nintendo Switch Sports[6], and Nintendo Ring Fit[7]—all designed for specific gaming consoles—have continued this trend. Given the benefits of video games, such as entertainment, motivation, and engagement [41], they have emerged as useful tools for promoting physical activity. These games aim to encourage energy expenditure and support physical activity in a fun and interactive way.

Before exploring how exergames are discussed in the related literature, this thesis provides a brief background on what physical activity is, its benefits, and how games can help promote engagement in physical activity.

2.1.1 Physical Activity

Caspersen *et al.* [42] defines physical activity (PA) as any bodily movement from skeletal muscles that results in energy expenditure. This includes a wide range of activities, such as sports, dance, leisure activities, and household tasks. Exercise, which is often used interchangeably with PA, is a specific subset of physical activities. Unlike PA, exercise is designed with the explicit purpose of improving or maintaining physical fitness. It is typically planned, structured, and repetitive [42], [43].

Engaging in physical activities leads to greater energy expenditure compared to sedentary behaviours such as television viewing, computer use, and other inactive activities. Furthermore, participation in PA has been associated with improved mental health, including enhanced self-esteem and self-efficacy [44]. Physical activity also promotes physical fitness. For instance, Moholdt *et al.* [45] conducted a cohort study to examine the relationship between changes in PA, body mass index, and mortality among individuals with coronary heart disease. Their findings indicate that participants with higher levels of PA had significantly lower mortality risks compared to those with sedentary lifestyles. Similarly, Diaz *et al.* [46] conducted an evidence-based review, providing substantial evidence that appropriate PA can help prevent hypertension. Overall, engaging in physical activity at appropriate levels offers benefits, including improved physical fitness and mental health.

[1]"Life Fitness Exertainment System," Nintendo Fandom, [Online]. Available: click here to the reference source. [Accessed: 15-Mar-2025].

[2]"Power Pad," Wikipedia, [Online]. Available: click here to the reference source. [Accessed: 15-Mar-2025].

[3]"Dance Dance Revolution," Wikipedia, [Online]. Available: click here to the reference source. [Accessed: 15-Mar-2025].

[4]"Wii Sports," Wikipedia, [Online]. Available: click here to the reference source. [Accessed: 15-Mar-2025].

[5]"Beat Saber," Beat Saber Official Website, [Online]. Available: click here to the reference source. [Accessed: 15-Mar-2025].

[6]"Nintendo Switch Sports," Nintendo Official Website, [Online]. Available: click here to the reference source. [Accessed: 15-Mar-2025].

[7]"Ring Fit Adventure," Nintendo Official Website, [Online]. Available: click here to the reference source. [Accessed: 15-Mar-2025].

To quantify the amount of physical activity, three key factors are assessed: duration, intensity, and frequency [44]. Duration refers to the length of time a person engages in a specific activity. Intensity measures the rate of energy expenditure during the activity and heart rate (HR) can serve as an objective measure for assessing exercise intensity, as it is directly linked to variations in physical exertion levels [47].

Heart rate measurements can be obtained using modern devices, such as smartwatches and chest straps equipped with electrocardiogram sensors. Many of these devices are now widely accessible and compatible with diverse physical activities, making HR monitoring practical and efficient. Because of these advantages, HR data is commonly integrated into exergames (e.g. [18]) to evaluate performance in physical activity.

To classify exercise intensity, a person's maximum heart rate (MHR)—defined as the highest number of beats per minute a person can safely achieve during physical activity—is used. Table 2.1 provides an overview of exercise intensity categories based on heart rate, serving as a criterion for evaluation.

A range of percentages of a maximum heart rate	Category
90% – 100%	Maximum
80% – 90%	Hard (Anaerobic Zone)
70% – 80%	Moderate (Aerobic Zone)
60% – 70%	Light (Fat-Burning Zone)
50% – 60%	Very light (Resting Zone)

Table 2.1: Adapted from [48], this range of percentages of a maximum heart rate indicates the levels of exercise intensity.

To estimate MHR in non-clinical contexts (e.g. everyday exercise), a person's age is commonly used in the age-predicted maximal heart rate formula. One of the most widely used formulas [30], [49] for decades is:

$$\text{MHR} = 220 - \text{age}$$

However, this formula tends to overestimate MHR, especially for older adults. To address this limitation, an alternative formula has been recommended by Tanaka et al. [30], which is:

$$\text{MHR} = 208 - 0.7 \times \text{age}$$

Despite these limitations, age-related estimated maximal heart rate formulas are still widely accepted in common practice (e.g. [29], [32], [34], [49]). Also, a related study in exergames by Martin-Niedecken *et al.* [49] found that the formula-based MHRs, used in their DDA functions, closely aligned with individually pre-assessed heart rates.

Lastly, frequency refers to how often a person engages in physical activity within a specific period. The recommended volume of physical activity varies based on factors such as the

type and purpose of the activity, age, gender, medical conditions, and physical state. For instance, the World Health Organization (WHO)[1] recommends that healthy adults (aged 18–64) engage in moderate-intensity aerobic exercises for 150–300 minutes per week. In contrast, for children and adolescents (aged 5–17), the WHO suggests performing moderate-to-vigorous exercises for approximately 60 minutes per day throughout the week.

To engage people in achieving a sufficient dose of PA, motivation in psychology—an essential driving force studied and applied to sports science—needs to be considered. The definition of motivation, as explained by Sewell *et al.* [44], is a combination of the direction of effort and the intensity of effort. Regarding the direction of effort, it is described that when people are motivated by something, they will put in effort to search for and approach it. Regarding the intensity of effort, it is explained that when people are motivated by something, they will engage with it intensely.

Motivation is typically divided into:

1. Intrinsic motivation—arising from internal stimuli, such as the desire to achieve personal satisfaction or fulfill internal needs, without external influence.
2. Extrinsic motivation—driven by external factors, such as monetary rewards or recognition.

The relationship between motivation and PA has been explored in various studies (e.g. [50]–[52]), which show that motivation significantly affects PA by promoting adherence in PA. However, some individuals face challenges in finding motivation for exercise due to barriers such as the perception of repetitive and tedious tasks [53].

Using games to address these challenges is a common technique to promote enjoyment and motivation in PA [54]. Studies (e.g. [55], [56]) show that games can increase motivation for exercise compared to traditional exercise by providing engaging experiences, such as enjoyment.

Overall, this section briefly reviews what PA is and its physical benefits. However, PA can be perceived as tedious by some individuals. Thus, adopting video games to promote entertainment might help people engage more in PA. Such games are often referred to as exergames. However, there are various terms used to describe these games, such as fitness games, and multiple definitions exist for the term "exergames". Therefore, the next section reviews the concept of exergames in related works to clarify the scope of this term within the context of this research.

[1]World Health Organization, "Physical activity," World Health Organization, 2022. [Online]. Available: click here to the reference source. [Accessed: Jan. 8, 2025].

2.1.2 The Term Exergames

Various terms have been used to describe video games that require player movement to interact with the game, including exergames, active video games, movement-based games, fitness games, and serious games for health, such as rehabilitation games. Among these, the most common term is "exergames" (also known as exertion games). Exergames are digital games in which physical activity or exercise is a core component of gameplay. Unlike traditional video games, which primarily focus on entertainment while minimising physical movements, exergames integrate physical exertion as a central element [1], [57]. The following points present characteristics of exergames from various researchers.

- **Physical activity involvement:** exergames necessitate physical movement as the primary means to interact with and progress in the game (Marshall *et al.* [1], Hwang *et al.* [58], and Ketcheson *et al.* [59]).
- **Game outcome:** exergames cause players to exert physical effort and expend energy, unlike traditional games that more focus on entertainment and aim to minimise such exertion (Park *et al.* [54] and Mueller *et al.* [57]).
- **Forms of physical activity and input devices:** exergames can include a wide range of physical movements, such as strength, balance, flexibility, and dance, often using motion capture systems or devices to detect player activity (Lee *et al.* [60] and Durmanova [61]).
- **Social and competitive aspects:** according to Mueller *et al.* [62], exergames may involve social interaction and can be categorised based on competition types:

Another commonly used term is active video games, which frequently appears in health-related studies and emphasises physical activity during gameplay. According to Biddiss *et al.* [63], active video games differ from traditional games (passive video games) that rely on conventional hand-held controllers, as they require physical movement to interact with the game, keeping players physically engaged throughout gameplay. Similarly, Gao *et al.* [64] defines active video games as a form of exercise that encourages players to be physically active.

Furthermore, Biddiss *et al.* [63], LeBlanc *et al.* [65], and Oh *et al.* [66] describe active video games as screen-based games that demand more physical activity than sedentary or passive video games. Overall, the term active video games focuses on players *being active* through physical movements and actions to play the game, which can lead to energy expenditure and physical health benefits during gameplay.

The term "movement-based video game" is typically used when focusing on interactions that require players to input physical movement. According to Pasch *et al.* [67], movement-based video games allow users to interact through active body movements as their primary mode of interaction. Mueller *et al.* [68] highlights that in movement-based games, players input their movements, with digital games where gross-motor bodily input influences the game's outcome. Additionally, Hämäläinen *et al.* [69] introduces the concept of gravity-based movement in video games, referring to such games as movement-based. Overall, this term

is primarily used when *focusing on the mode of interaction with the game through player movement input.*

Fitness video games refer to video games that require player movement for interaction, with an emphasis on fitness context and workout experience [24], [70]. Lastly, serious games for health, such as physiotherapy games, use the entertainment benefit of video games to engage people in beneficial activities. For example, rehabilitation video games (e.g. [71]) encourage players to perform structured physiotherapy movements through gameplay, aiming to improve players' health or physical condition while having fun.

Overall, terms such as exergame, fitness video game, and active video game share a common concept: these games require players to physically move and interact with the game. To achieve this, the games often rely on specialised equipment to translate players' physical actions into gameplay.

In this research, the term **"exergames"** (or exertion games) is used consistently. Based on the review, exergames are defined as video games that integrate physical activity into interactive gaming experiences, typically requiring additional hardware to detect players' movements or gestures, thereby encouraging physical activity through gameplay.

Previous research demonstrates that playing exergames can lead to physical benefits, such as promoting physical exertion. Studies by Marshall *et al.* [1], Gao *et al.* [56], and Peng *et al.* [72] reveal that exergames can elicit light, moderate, or vigorous intensity levels, depending on the game mechanics and types of exercises involved.

The main game element that causes energy expenditure during gameplay is "physical challenge". Since players must rely on their physical limitations to tackle challenges related to speed and accuracy [9], game designers can leverage physical challenge to make gameplay more intense to increase energy expenditure. This contrasts with physical challenges in conventional video games, such as rotating shapes in Tetris, where players use only finger movements, resulting in little to no physical exertion.

Examples of physical challenges in off-the-shelf exergames include Ring Fit Adventure[1] and Wii Fit[2], where players use their physical abilities and endurance to run in place, explore the game world, and face obstacles. Besides, these games provide additional physical challenges that players must overcome by performing actions such as jumping, squatting, or knee lifts, which further increase energy expenditure.

Overall, exergames commonly adopt physical challenges to induce exertion. Beyond energy expenditure, challenges can also enhance player engagement. Malone [73] identify three factors that make games enjoyable: fantasy, curiosity, and, importantly, challenge. Challenge creates a sense of uncertainty, making players feel uncertain about winning or losing. It also fosters a sense of accomplishment when overcoming obstacles, which boosts players' self-esteem.

The next section further explores the concept of challenges applied in games.

[1] Nintendo, "Ring Fit Adventure," Nintendo, 2023. [Online]. Available: click here to the reference source. [Accessed: 09-Jan-2025].

[2] "Wii Sports," Wii Sports Wiki. [Online]. Available: click here to the reference source. [Accessed: 09-Jan-2025].

2.2 Game Challenge

A widely mentioned concept in video game design is "easy to learn, hard to master" [74]–[76]. This means creating games that are simple for players to start learning or playing, often through easy-to-understand rules or straightforward gameplay (initial use). However, after players are attracted to the game, what makes them continue playing and striving to master it (extended use)? One approach is to integrate challenges into the game, adding layers of stimulation and engaging experience.

Challenge is commonly used as a fundamental element in creating an engaging, motivating, and enjoyable gaming experience [9], [75], [77], [78]. Denisova *et al.* [9] describe challenge in video games as stimulating tasks or problems that can sometimes be perceived as difficult (Dziedzic *et al.* [79] refer to difficulty as a combination of the objective characteristics of tasks and the subjective experience of the person interacting with them), making it harder for players to overcome them. Vahlo *et al.* [77] further clarify that while challenge and difficulty are related concepts, they are not identical, as challenges are often tied to the game's goals, requiring players to interact with and overcome them to achieve the desired outcomes.

Similarly, Schell [80] describe challenges in games as arising from the presence of goals and the struggles players face to achieve those goals. Macklin *et al.* [81] conceptualise game challenges as obstacles that players encounter, which can take the form of either physical or mental barriers. Additionally, although the term challenge is sometimes used interchangeably with competition, Furze [78] clarify that challenge refers to an individual's engagement with in-game obstacles, whereas competition involves social interactions with other players. Therefore, building on these concepts, this research defines challenge as a stimulating game element that prevents players from easily achieving goals. Players must overcome these challenges to reach their goals, aiming to enhance the overall gaming experience.

Denisova *et al.* [9] categorised challenges in video games into three main types:

Cognitive challenge: a challenge requires the player to actively use their mind to anticipate the outcomes of their choices within the game and to understand unclear parts of the game narrative or story.

Physical challenge: players use their physical limitations or abilities to interact with challenges through the speed and precision of their actions.

Emotional challenge: this type of challenge involves evoking and resolving players' emotions as they encounter emotionally charged content or strong in-game characters. Players must navigate tension in the narrative, connect with characters, and address uncertainties.

These three types of challenges can shape players' perception of challenges (perceived challenge [9]) in four scenarios: cognitive challenge, emotional challenge, performative challenge, and decision-making challenge [15]. In contrast to the challenge classification proposed by Denisova *et al.* [15], Furze [78] categorise video game challenges in a manner similar to in-game quests. They identify two types of challenges: emergent challenges, which allow players

to decide how to approach and solve tasks or even create their own challenges; and progression challenges, which require players to follow a linear, predefined set of actions to complete the game, typically offering only one correct way to proceed.

The benefits of challenges in games include enhancing enjoyment and making the experience more engaging. Besides, as noted in Section 2.1.2, physical challenges are commonly incorporated in exergames to provide both a sense of challenge and energy expenditure. However, such challenges often make it inevitable for players to encounter setbacks or failures while they are attempting to overcome them [82]. In addition, Frommel *et al.* [83] noted that higher levels of difficulty in the game are often related to an increased likelihood of failure.

The next section reviews setbacks and failures in video games.

2.2.1 Setbacks and Failures

In everyday life, people generally avoid failure. However, in the context of video games—where failure, loss, or even death of avatars occurs in a safe environment without directly impacting players in real life—some players are drawn to challenging games [10]. These games often involve frequent failure, which is typically viewed as a negative or unpleasant experience in real life, yet players engage with them to fulfil needs such as achieving a sense of competence after overcoming challenges [16]. This phenomenon is described in the concept of the "paradox of failure", introduced by Juul [84]. It highlights the contradiction that, while people usually avoid failure in real life, they actively seek out games designed to cause it [83]. This section reviews how failure and setbacks have been studied in the existing literature.

The term "setback" is generally defined as "something that happens that delays or prevents a process from developing"[1]. Within the context of video games, the concept of setbacks can be understood in various ways and is often used interchangeably with failure. Juul [85] discuss punishment as a form of setback, where players are required to invest additional time or resources to address the punishment. This, in turn, delays players' progress toward completing game goals. Similarly, Frommel *et al.* [83] describe setbacks as temporary failures that occur frequently within games but do not have a major or lasting impact on the overall game experience. Moreover, Cuerdo *et al.* [37] regard setbacks as "mini-failures" that hinder players' progress within the game. These mini-failures persist until players either successfully complete the game or encounter a critical failure state, such as a game over.

Juul [86] present a contrasting view, suggesting that all failures in a game context can be considered as setbacks, positioning failure as a subset of setbacks. According to their argument, failures are typically accompanied by punishments—such as energy depletion, loss of lives, or termination of the game—that delay the player's progress toward achieving the game's goals. These punishments serve as obstacles that hinder advancement within the game. This perspective partially aligns with the findings of Aytemiz *et al.* [87], who observe that while certain failures result in a "Game Over" screen, requiring players to restart or replay, some players interpret these occurrences as setbacks rather than definitive failures.

[1]Cambridge University Press, "setback," Cambridge Dictionary, 2025. [Online]. Available: click here to the reference source. [Accessed: Jan. 9, 2025].

This research argues against the perspective of Juul [86], as setbacks are regarded as a subset of failure, aligning more closely with the views of Cuerdo *et al.* [37], Frommel *et al.* [83], and Juul [85]. Setbacks occur when players face obstacles or challenges and cannot overcome them but still have the opportunity to improve their skills or revise strategies to progress toward their goal. In contrast, failure is characterised by the perception that the goal is entirely unattainable, requiring significant effort or resources to recover and continue toward the objective.

Aytemiz *et al.* [87] highlight that some players interpret "Game Over" as merely a setback. This research proposes that for failure to be acknowledged by players, the inability to accomplish a task or challenge must be perceived as a significant disruption to their goal while playing. For example, encountering a "Game Over" screen and restarting might not be considered as failure if it does not align with the player's individual goal [82]. Players may define their primary goals of playing differently from intended goals set by game designers. If reaching the "Game Over" screen does not undermine their personal goals, it may not be perceived as a failure. (The role of goal-setting in the perception of failure is explored further in the following sections.)

Therefore, in this research, setbacks are defined as consequences arising when players are unable to manage tasks, obstacles, or challenges, resulting in delayed progress toward their goals. Unlike failures, setbacks provide players with opportunities to refine their skills or strategies and overcome them with comparatively less effort or fewer resources. While setbacks share similarities with failure as part of the iterative learning and improvement process in gaming, they do not result in an absolute inability to achieve the main goal.

The term "failure" is more commonly mentioned in HCI in video games than "setback", as shown in many previous studies (e.g. [62], [83], [87]). Generally, "failure" refers to "the fact of someone or something not succeeding" or "a lack of success in achieving something" [1].

In video games, failure is conceptualised in various ways. According to Juul [85], failure is defined as the inability to successfully complete tasks within the game. Similarly, Juul [86] describes failure as being unsuccessful at a game task, resulting in punishment as a consequence. Aytemiz *et al.* [87] defines failure with a similar concept of inability but focuses on the inability to progress towards the game's overall goal, rather than merely failing specific tasks presented in the game.

However, players' perceptions of failure can differ from what game developers intend. Players may not always align their goals with the goals defined by the developers. For instance, while the intended main goal of a game might be to win a single game, players might set their own goal, such as winning multiple games to increase their rank. In this case, failing to rank up is perceived as a failure, whereas losing a single game might not be, as it does not conform to their self-defined goal [82], [83]. A study by Frommel *et al.* [83] highlights that players assess their performance as success or failure based on whether tasks or challenges align with their personal goals.

[1] Cambridge University Press, "failure," Cambridge Dictionary, 2025. [Online]. Available: click here to the reference source. [Accessed: Jan. 9, 2025].

Therefore, in this research, failure is defined in alignment with the review and the research aim as follows: Failure in video games refers to a player's inability to achieve a perceived goal during gameplay, provided that the goal is designed to be achievable within the game's mechanics or rules. Additionally, while attempting to reach their goal, players may encounter setbacks that hinder their progress but do not necessarily result in outright failure.

Frommel *et al.* [83] classified failure in video games into two types. The first is perpetual failure that is critical failures that players repeatedly encounter. These failures can lead to feelings of hopelessness, frustration, or being stuck, as players perceive no progress toward their goal. The second is temporary failure, which describes minor setbacks that are part of the game. These are typically trivial, and players encountering such failures often maintain their belief in success and keep trying.

The concept of temporary failures leading to a critical failure process is further elaborated by Cuerdo *et al.* [37], who describe failure in video games as a cyclical process composed of challenges, the mini-failure loop, and the critical failure state. During gameplay, players enter a mini-failure loop, where they encounter challenges to overcome. If they fail, minor setbacks occur, temporarily hindering their progress toward the goal. This cycle persists until a critical failure state is reached, often resulting in game termination.

Also, Aytemiz *et al.* [87] introduced a classification of failures in video games from another perspective, considering both the game designer's and the player's views. They distinguish failures into two primary types: in-loop failures and out-of-loop failures.

1. **In-loop failures (planned failures):** these are failures intentionally designed to align with the game's objectives and are expectable to meet them by players. In-loop failures typically occur when players struggle to overcome challenges due to poor planning or ineffective execution. Examples include failing to complete an action on time or not using an optimal strategy to deal with a challenge. Such failures are a natural part of the gameplay experience and are integrated into the game's design intent to enhance engagement and enjoyment.
2. **Out-of-loop failures (unplanned failures):** these failures arise unintentionally and detract from the overall gameplay experience, deviating from the designers' intended vision. Players do not expect to encounter these failures, which can result from confusing controls, unclear objectives, or other unforeseen issues. Out-of-loop failures often lead to frustration and diminish the game's quality.

Aytemiz *et al.* [87] recommend that game designers minimise out-of-loop failures to prevent negative experiences. However, in certain cases, players might perceive out-of-loop failures as enjoyable, prompting designers to reconsider their designs. Furthermore, in-loop failures can sometimes evolve into out-of-loop failures, potentially resulting in negative experiences.

For instance, a player repeatedly attempting to overcome a planned challenge without success and without any form of assistance or guidance might become frustrated. Initially, these repeated attempts could be considered in-loop failures, but they may transition to out-of-loop failures if the game fails to account for such scenarios and lacks appropriate mitigation strategies.

This case highlights the need for a real-time approach (e.g. DDA functions) to address overly challenging game scenarios where players struggle and seem unable to overcome the challenge after multiple attempts. Implementing such mechanisms might help prevent negative experiences or potential game abandonment.

Overall, this section shows that while setbacks and failures are used in games to enhance engaging game experience, they can also negatively impact players. The next section reviews previous studies to explore how failure and setbacks in video games affect players.

2.2.1.1 Understanding the Impact of Failures and Setbacks in Video Games on Players

Failures and setbacks in video games are not always negative experiences. They can contribute to player enjoyment and satisfaction. Many players view failure as an integral part of the journey toward achieving their game goals. Waldenmeier *et al.* [88] highlight that challenges in games often involve constraints such as time limits, limited resources, or complex rules, which may cause stress. However, overcoming these challenges can enhance players' enjoyment and sense of accomplishment.

Failure can enhance the overall positive experience of playing video games. Anderson *et al.* [82] observed that players are not merely driven by the desire to win but aim for a "well-played game", which involves finding a balance between challenges that are not too easy (no or less failure) or too difficult (repeated failure). Similarly, Furze [78] and Juul [86] argue that although failure contrasts with success and can lead to negative experiences, it enhances game enjoyment, as overcoming failure makes victory more rewarding. In contrast, continuous success without failure can result in dissatisfaction, as the lack of challenge reduces the sense of accomplishment.

The idea that failure can enhance enjoyment is further explored in several studies. Petralito *et al.* [10] found that high levels of challenge, even when accompanied by failure, can induce anxiety and fear. However, these negative emotions often turn into positive outcomes, such as a sense of achievement and enjoyment, when players eventually overcome the challenges. Similarly, Van den Hoogen *et al.* [12] demonstrated that players often embrace failure as an approach of improving their play and overcoming obstacles. While player death itself is not enjoyable, it leads to a sense of challenge and enjoyment, with players frequently smiling after dying a few times at the beginning (however, if players continue to fail repeatedly, it may eventually lead to frustration and decreased enjoyment). Furthermore, Foch *et al.* [11] revealed that the more intense the negative emotions players experience while attempting to overcome a challenge, the greater the positive emotions they feel upon succeeding.

While failure can enhance the gaming experience, repeated failures or excessively punishing consequences can lead to frustration and decreased enjoyment. Van den Hoogen *et al.* [12] and Frommel *et al.* [83] found that while initial failures may evoke positive emotions, frequent failures often result in frustration, reduced enjoyment, and even game abandonment. This frustration often stems from challenges or obstacles that hinder progress toward game goals [89]. Moreover, losing valuable in-game items as a consequence of failure can further intensify negative emotions [90].

The reviews highlight that players can experience both positive and negative outcomes when facing failure. However, individual player characteristics can influence these experiences. The impact of failure on PX can vary depending on personal traits. Anderson *et al.* [82] and Frommel *et al.* [83] found that players with a high challenge orientation or a mastery-oriented mindset tend to enjoy both success and failure, viewing failure as an opportunity for growth. These players perceive challenges as a chance to develop resilience and persistence. In contrast, individuals with a low challenge orientation, a helpless mindset, or a state-oriented approach tend to prefer enjoyment derived from success over failure. They are more likely to feel stuck, perceive failure negatively, and experience reduced performance following failure. Such players may even engage in rule-breaking behaviours, such as cheating, to avoid failure [88].

In the context of exergames, where physical exertion is a key component, failure may impact both their playing experience and their perception of exertion or fatigue. According to Cuerdo *et al.* [37], unlike traditional video games where no exertion is involved, players may become fatigued from playing while trying to deal with failure. However, in traditional video games, players can relax and retry to overcome failure, making it temporary. In contrast, physical games involve physical exertion, where physical fatigue during gameplay can lead to exhaustion. This exhaustion may discourage players from persisting through failure. So, exergames need players to use not only cognitive or emotional effort but also physical effort to play, which may add complexity to how failure impacts players in this context.

Despite growing interest in exergames, there is limited literature specifically examining the effects of failure in this unique context. The closest relevant study can be by Haglind [91], which explores failure in sports. Their findings suggest that failure in physical activities, particularly among athletes, leads to similar impacts to failure in video games in certain respects. Failure—defined as injury or unmet expectations—can trigger negative emotions such as stress, fear, and frustration. However, overcoming failure was also found to promote personal development, resilience, and strength, with participants becoming more careful in subsequent tasks. Notably, enjoyment was not addressed in their study.

Overall, players perceive failure or setbacks differently, and these experiences do not always have a negative impact. Experiencing failure can make a game more challenging, and overcoming these challenges or achieving a goal after setbacks can enhance enjoyment and foster a sense of accomplishment. Moreover, failure in video games can promote self-learning and improvement, making the game content more enriching. However, when failures occur repeatedly, they can negatively affect players, decreasing motivation and enjoyment, and potentially leading to cheating behaviours.

This section reviews setbacks and failures in video games, highlighting their potential to offer both benefits and drawbacks to players. The following chapter explores how challenges presented in games impact players.

2.3 The Impact of Game Challenges on Players

Regarding the above sections, to engage players in exergames, challenge is commonly adopted in commercial games and research studies (e.g. [23]) and regarded as a core of gameplay [92]. Challenges have the potential to enhance enjoyment, which is linked to motivation [93], and in the context of exergames, they can also lead to increased physical effort as players respond to physical challenge. Given these preliminary benefits, this section further explores how challenges impact players.

Different levels of in-game challenges can influence players' **perceived challenge** [15]. Moreover, an increased perceived challenge can heighten players' tension, which may enhance enjoyment, unlike games that lack tension [94]. However, while a sense of challenge can serve as a useful motivator [9] and enrich gameplay through tension and drama [92], challenges perceived as excessively high compared to the player's skill level can lead to overwhelming **pressure and tension** [15] and repeated failures which also lead to negative PX [12]. Moreover, this may also negatively impact players' **motivational effort** to play, as overly difficult challenges can diminish their overall motivation to continue.

Flow [13], [95] is another experience closely related to challenge [78] and is considered an optimal experience that many players seek in games. It is a psychological state of complete absorption in an activity which is seen as beneficial to game engagement and enjoyment [60], [96]. According to Jackson *et al.* [14], the following components are necessary to enter a flow state:

1. **Challenge-skill balance:** it highlights the importance of ensuring that the challenge aligns with the level of skill of an individual, fostering the belief that the task is achievable within their abilities.
2. Action-awareness merging: to promote this sense, a person should be given a task that can be performed effortlessly and spontaneously, with minimal thought about how to act. If the activity involves equipment or multiplayer interaction, it should provide a sense that the equipment is a part of their body, or that the player and team are united as one.
3. Clear goals: to promote focus on tasks and prevent distractions, a person should be provided with a clear goal in advance or given proper time to know exactly what to do, thereby promoting a state of flow.
4. Unambiguous feedback: providing a person with feedback on their performance can help keep them on track towards their goal. They can use this feedback to improve themselves or adjust their strategy to achieve the goal.
5. Concentration on the task at hand: a state in which a person is fully focused on their task, free from distractions or concerns about external stimuli.
6. Sense of control: sense of control is when players believe in their ability to successfully manage tasks or achieve their goals.
7. Loss of self-consciousness: during this stage, individuals do not worry or have negative thoughts about their performance, what others think of them, or whether they win or

lose. They are completely focused on their activity.

8. Transformation of time: it is a stage where a person is fully concentrated on their work, losing track of time. They may feel that time passes faster or slower than it actually does due to their intense focus.

9. Autotelic experience: this component is regarded as a key element of flow. It is the stage in which people engage in an activity to satisfy themselves without caring about external rewards [96]. They become absorbed in the activity, finding it intrinsically rewarding and enjoyable. Consequently, they often seek to repeat the activity for further fulfilling themselves.

In video games, players are motivated by the desire to win, but the game should not be too easy but instead offer an optimal level of challenge that is "neither too easy nor too hard" [84]. Similarly, the theory of flow highlights the importance of balancing challenge and skill, regarding this balance as a crucial factor for entering the flow state [14]. The alignment between the level of challenge and the player's skill can impact the PX in different ways.

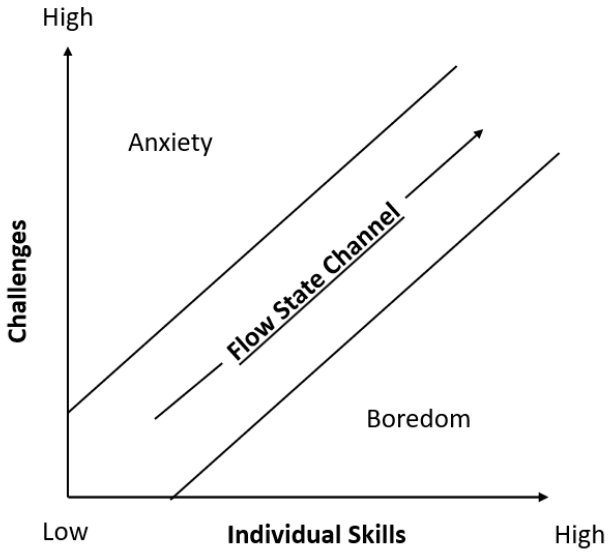

Figure 2.1: Flow State Model: emphasising the balance between challenge and skill adapted from [13], [14]

As shown in Figure 2.1, if the challenge is too easy compared to the player's skills, players may become bored and lose motivation. On the other hand, challenges that are too difficult or unachievable relative to the player's skills can lead to anxiety (Falstein [97] argue that in the context of video games, anxiety should be replaced with frustration) and a potential loss of motivation.

Existing research on exergames (e.g. [18], [23], [26], [33]) commonly addresses boredom and frustration (anxiety) through the challenge–skill balance, often by using mechanisms such as difficulty adjustment. This is because an insufficient challenge may lead to boredom and restrict the level of physical activity, while excessive demands can lower players' perceived

competence and increase their exhaustion. Both boredom and frustration can reduce player engagement and undermine the primary goal of exergames in promoting physical activity.

However, it is important to acknowledge that simply balancing challenge and skill does not entirely eliminate boredom and frustration, nor does it guarantee long-term player engagement. In video games, these negative emotions can also stem from a variety of other factors, such as a lack of novelty, poor game production, an unclear narrative or game goal, and a perceived lack of fairness in game mechanics. Despite these complexities, the challenge-skill balance is a foundational component of exergame design. It often serves as the key to attracting players and providing the initial positive experiences necessary for sustained engagement over time.

This claim is further supported by psychophysiological evidence. A study by Rodrigues *et al.* [98] found that players in an easy condition exhibited positive valence but lacked arousal, suggesting a lack of excitement. In contrast, medium difficulty led to increased arousal and positive valence, aligning with the idea that moderate challenge enhances flow and engagement. However, when the game became too difficult, players reported negative valence and lower arousal than in the medium condition, possibly indicating that overwhelming difficulty reduced their excitement. These findings reinforce the importance of aligning challenge with player skill to sustain engagement within the flow state.

In the flow model, finding the optimal balance between challenge and skill does not imply that there will be no further improvement or progression. This model still allows for player skill improvement alongside the increasing difficulty in the game. The key is to create a "fuzzy safe zone", a space where the activity is not overwhelmingly stimulating but still offers a taste of challenge with the promise of more to come. This may keep players engaged and hopeful for future growth within the game [95].

Applying the flow model to video games appears promising for promoting player engagement; however, it also has limitations. In the original flow model, both the challenge and the skill levels constantly increase to maintain balance. However, this smooth increase might not always work well in a game context, as Juul [86] argues that it can lead to a banal problem, where the game lacks dynamic progression. Falstein [97] propose a refined flow model, as shown in Figure 2.2, and argue that while gradually increasing difficulty relative to the player's skill level over time is superior to having no difficulty changes (which could prevent boredom), this pattern of difficulty adjustment can be further improved.

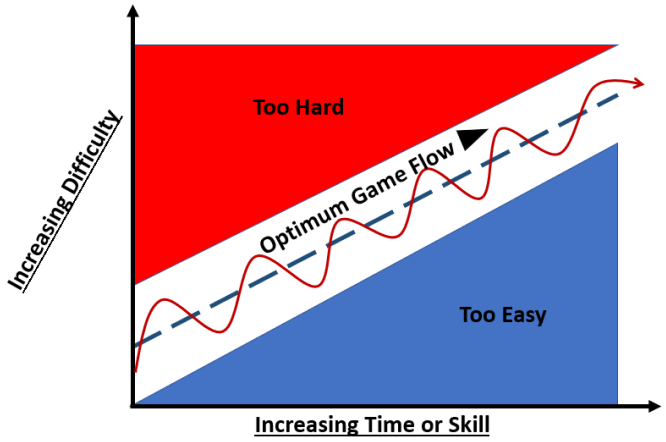

Figure 2.2: Smooth flow model from [86]

They suggest incorporating intervals where the difficulty might slightly increase or decrease, rather than maintaining a constant upward trajectory. This allows players moments to relax, prepare, or reassess their strategies before facing a tougher challenge, potentially promoting excitement and enhancing the game's dynamic.

Despite the benefits of flow, it is not always ideal for all video games in general due to potential limitations [20]. For instance, players may feel too much in control due to game difficulty adjustments, leading them to neglect other aspects of the game. However, in the context of exergames, managing the balance between game challenges and player skill or fitness is crucial for supporting continued engagement in the physical activity. Sinclair *et al.* [19] emphasise the integration of challenge–skill balance (Flow) into exergame design through what they call the Dual Flow Model (Figure 2.3). This model aims to achieve both attractiveness and effectiveness, ensuring that exergames engage players while also delivering physical benefits.

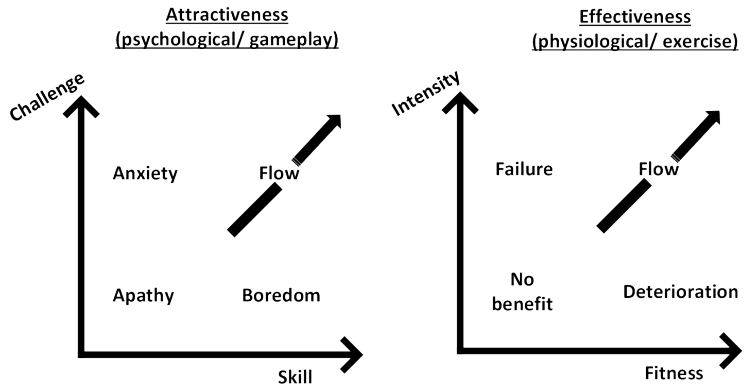

Figure 2.3: Dual flow model adapted from [19]

Attractiveness (psychological flow) is a dimension of the exergame design that aligns with the original flow model, which is about balancing perceived challenge with the player's perceived skill. This focus is on making exergames engaging enough for players to start playing through this balance, and to mitigate boredom or frustration during game playing to promote long-term engagement of players, which is a prerequisite for longevity. This can be achieved by

using players' data, such as performance data, for adjusting challenge levels [23], [24], [38].

The aim of exergames is not only to provide engaging experience, but it should also provide enough level of exertion to deliver physical benefit and prevent overexertion. Therefore, Sinclair *et al.* [19] proposed an additional axis, Effectiveness (physiological flow), which is the balance between exercise intensity and the player's individual fitness. This promotes the effectiveness of the exergame in promoting physical activity and prevents failure and overexertion. To achieve this, related works (e.g. [26], [29]) commonly use players' physiological data that can identify exertion levels, such as heart rate, for making a decision to adjust the game's physical demands in line with the player's current physical state.

Intrinsic motivation is another aspect of PX that may be influenced by challenges in video games. According to Sweetser *et al.* [96], one reason players continue engaging with games is the **competence satisfaction** gained from overcoming challenges and achieving goals. This satisfaction aligns with self-determination theory (SDT) [16], [99], which highlights the importance of fulfilling psychological needs for competence—the need for challenges that allow individuals to test their skills, experience a sense of mastery, and gain a sense of accomplishment [78]—to foster intrinsic motivation [100].

However, poorly designed challenges may fail to meet players' needs, leading to **frustration** and negatively impacting motivation. Thus, achieving a balance between challenge and skill is important for creating an engaging gaming experience that encourages players to keep coming back playing [78], [97].

When competence is satisfied, it can also positively influence **enjoyment** for many players [16], [100], [101]. Enjoyment is another player experience that has been shown to be linked with challenge [9], [102]. Lee *et al.* [60] and Sweetser *et al.* [96] consider player enjoyment to be the most crucial goal of computer games, as it motivates players to continue playing and is closely linked to both playtime duration and the potential for game addiction. If a game fails to provide enjoyment, players are unlikely to engage with it.

Within the context of video games, enjoyment can be described as a player's subjective experience of satisfaction and positive affect arising from interacting with a game [100]. Research suggests that the enjoyment of games can be influenced by some factors such as suspense (a feeling of excitement and uncertainty) [103] and a sense of competence during gameplay, which can also enhance intrinsic motivation [16], [100], [104].

However, an imbalance between challenge and player skill can negatively impact this experience. When tasks are excessively difficult or too easy, players may struggle to maintain focus and ultimately fail to enjoy the game [14]. Similarly, the Yerkes-Dodson law, as discussed in Sorenson *et al.* [105], suggests that enjoyment occurs at an optimal level of challenge rather than at extremes. If a task is excessively challenging or too easy, it may lead to too high or too low arousal, reducing overall enjoyment.

In exergames, physical challenges influence both **physical effort**—often measured using heart rate—and **perceived exertion**, which refers to an individual's subjective perception of effort during physical activity [106]. This perception reflects the psychophysiological response to the game. As the game's demands increase, players naturally exert more effort, which can result in higher perceived exertion and diminished positive feelings [107].

On the other hand, well-balanced challenges can support moderate effort, leading to a more enjoyable experience [108]. Besides, Lee *et al.* [60] highlight that very high-intensity physical activity is associated with reduced exercise adherence, lower pleasure, decreased enjoyment, and may even result in fatigue or the abandonment of the activity.

Overall, this section reviews how challenges impact players. The review shows that the inclusion of challenges is a useful strategy for promoting player engagement. However, when challenges are not well-balanced, they can disrupt the player experience. To address this, video game design has developed two primary approaches: manual difficulty adjustment and adaptive difficulty adjustment, both of which are reviewed in the following section.

2.4 Coping with Game Challenges

Challenge not only impacts player experience but also shapes how players assess the quality of a game. Games that are either too easy or excessively difficult are often evaluated as "bad" whereas "good" games are perceived when the game achieves the right balance of challenge [80]. This highlights the importance of balancing challenge in video games.

To address this, video games typically use two common approaches to adjust difficulty levels to match players' abilities: manual adjustment and dynamic difficulty adjustment, both of which are discussed in this section.

2.4.1 Manual Difficulty Adjustment

For decades, manual difficulty adjustment (also known as static difficulty adjustment) has been used in video games, where developers define fixed difficulty levels. Players select one of these options based on their skill level or individual preferences before entering the game mode. Bostan *et al.* [74] and Andrade *et al.* [109] refer static difficulty adjustment as a pre-defined setting, such as "Easy", "Medium", or "Hard", chosen by players prior to gameplay. This type of difficulty remains constant throughout the game and fails to adapt to a player's developing skill or changing needs as they progress.

Previous studies [21], [22], [74] found that this approach promotes a sense of control over the game's challenge by allowing players to select a preferred level. However, it has been argued that static difficulty is ineffective in maintaining consistent player engagement because fixed difficulty levels may fail to provide an appropriate level of challenge for individual players.

For example, novices or players with no prior gaming experience may find the easiest mode too difficult, while highly skilled players might perceive the hardest mode as too easy [110]. Furthermore, manual adjustments can interrupt the game flow, as players must stop playing to change settings [22], [28], [111].

Regarding exergames, which involve physical exertion, playing at a fixed difficulty level can be problematic. If the selected difficulty is too demanding, it may lead to continuous fatigue throughout the play session. Conversely, if the selected level requires too little exertion, it may result in boredom or a lack of exercise benefits [19].

As difficulty levels remain consistent throughout playtime and are not adaptable based on current in-game data from the player or the player's current physical state, another approach—dynamic difficulty adjustment—can be used to address this issue, as reviewed in the subsequent section.

2.4.2 Dynamic Difficulty Adjustment

Dynamic difficulty adjustment (DDA) is a promising feature integrated into video games and has been used in commercial games for decades. A notable example includes the rubber-banding technique in Mario Kart (1996)[1], where the game dynamically adjusts game difficulty based on player performance. This technique is particularly common in racing games, where the game monitors player progress and modifies opponent behaviour to maintain a sense of challenge and engagement [112].

DDA adjusts difficulty levels or game content in real-time based on player skill [113] or in-game data. Techniques range from simple algorithms to advanced methods like heuristics, decision trees, and machine learning due to the nature of games [114]. By tailoring challenges to individual player abilities, DDA overcomes the limitations of static difficulty settings, preventing interruptions in game flow [115]. This personalised approach enhances player experience by maintaining an optimal balance of challenge, promoting a sense of competence that increases enjoyment and motivation [103]. Additionally, DDA not only adapts difficulty to match player abilities but also aims to advance player skill, fostering mastery and sustained engagement [116].

The definition of DDA has been presented with slight variations across previous studies. Firstly, DDA relies on **player data** to adjust difficulty levels. According to Danousis *et al.* [117] and Lopes *et al.* [118], DDA integrates in-game functions that adapt to a player's skills, performance, and emotions during a game session. These functions use player-related data, such as in-game performance or physiological responses, to adjust the game's difficulty. Importantly, these adjustments should align with the core goals of the game design to ensure meaningful outcomes, thereby enhancing the overall game experience.

However, these definitions do not mention the concept of **automatic or real-time adjustment**. As highlighted by Ajani *et al.* [27], Fisher *et al.* [110], and Li *et al.* [119], DDA functions dynamically modify a game's features, parameters, scenarios, and behaviours in real time based on the player's performance or physiological responses. This real-time adjustment prevents players from experiencing boredom when the game is too easy or frustration and loss of confidence when it becomes overly challenging. Nevertheless, some studies (e.g. [120]) have also considered DDA that does not necessarily work in real time. Instead, these approaches adjust game elements before the game starts, based on player behaviour or feedback from previous game rounds.

In order to adjust difficulty, DDA functions typically incorporate either **rules or learning patterns/statistical (probabilistic) models** [121]. As described by Bostan *et al.* [74], Smeddinck [122], and Magerko [123], DDA commonly includes predefined rules or parameter

[1]Fandom, "Mario Kart 64," Mario Kart Wiki, 2025. [Online]. Available: click here to the reference source. [Accessed: Mar. 16, 2025].

ranges, user models, and predictions about the player's ability or actions to ensure the game remains appropriately challenging.

It seems that these definitions of DDA align with the concept of flow, which focuses on maintaining a balance between challenge and skill. Therefore, in this research, DDA refers to a function in video games that aims to induce an optimal challenge level for individual players by adjusting the difficulty level in real time based on player data. These adjustments often lead to changes in in-game elements that influence overall game difficulty.

As previously mentioned, rubber-banding is a well-known sample of DDA technique commonly used in racing games to enhance competitiveness and player engagement [25]. This technique involves real-time adjustment of the opponent's behaviour based on the player's position: the opponent slows down to allow the player to catch up when ahead and speeds up to close the gap when behind. In practice, DDA developers divide the distance between the opponent and the player into zones, with each zone assigned different speed multipliers for the opponent [25].

For example, at the start of the race, both the player and the opponent begin at the same point, resulting in zero difference and a multiplier of 1. However, as the opponent moves far ahead or falls behind, the multiplier is adjusted for each zone to either decrease or increase the opponent's speed, ensuring they catch up or wait within an appropriate time-frame.

According to Mi *et al.* [25], rubber-banding can be implemented using two primary methods. The first method explicitly adjusts the opponent's speed, enabling the opponent to either catch up to or wait for the player effectively. However, this approach can sometimes cause a perception of unfairness due to unrealistic speed changes (e.g. sudden accelerations or implausible vehicle speeds).

The second method involves adjustments to the opponent's skill level, such as improving reaction times (e.g. braking earlier to avoid collisions), allowing the opponent to perform better without noticeable speed change. This concealed approach is less likely to be perceived by players as unrealistic or unfair, as it avoids abrupt and obvious changes in speed.

In exergames where physical activity is involved, DDA has the potential to enhance the overall game experience.

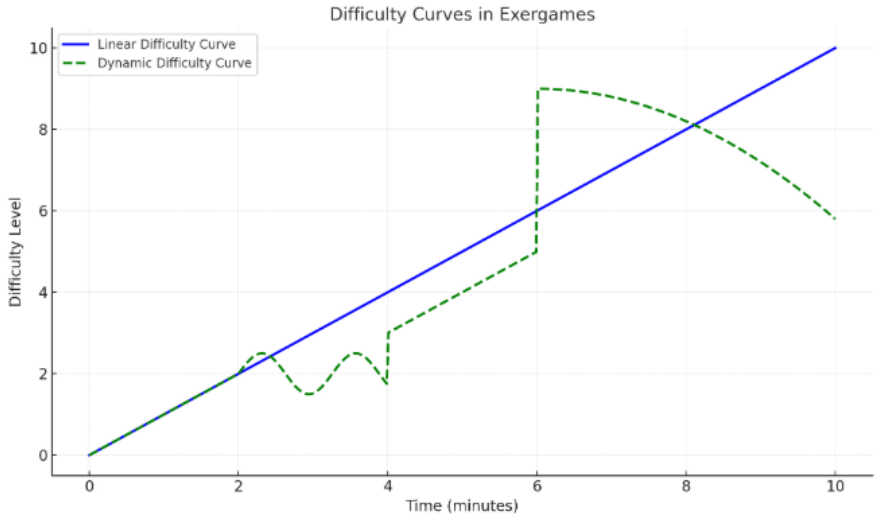

Figure 2.4: A mock scenario illustrating both a linear difficulty curve, which steadily increases challenge, and a dynamic difficulty curve, which adjusts to the player's performance or physical effort.

As illustrated in Figure 2.4, a linear difficulty curve (a blue line)—representing a mock scenario without difficulty adjustment—shows a steady increase in physical challenge over time. This constant progression may lead to heightened fatigue as players exert more effort to keep up with the rising challenge, potentially diminishing the overall positive game experience. In contrast, a dynamic difficulty curve (a green dashed line) introduced through DDA allows the game to adapt to the player's performance or physical effort.

For instance, when players encounter failures—either due to their inability to meet the challenge or from fatigue—the game can temporarily lower the difficulty, providing a period of recovery. Conversely, when players perform well without failures over a specific time frame, the game increases the challenge, potentially promoting a more engaging game experience.

Although there is limited literature on the impact of different difficulty curves in exergames on PX, a study by Sarkar *et al.* [124] on general video games found that different patterns of difficulty curves influenced some aspects of PX. For example, IMI: perceived competence was affected (however, IMI: interest/enjoyment and IMI: effort/importance showed no significant differences).

Therefore, the following section further reviews previous studies that examine the impact of DDA in video games on player experience and physical effort.

2.5 DDA for Video Games in Previous Studies

A review by Seyderhelm *et al.* [125] shows that DDA has been implemented in various types of video games, ranging from casual games like Tetris, Pong, first-person shooters, and quiz games to more complex genres, such as multiplayer role-playing games. Their review shows that DDA commonly uses performance or physiological data for difficulty adjustment and typically modifies game parameters such as time constraints, task complexity, procedural content generation, and speed to increase, decrease, or maintain difficulty levels.

However, this raises the question of how game designers determine if a game is difficult or how they assess difficulty levels. Dziedzic *et al.* [79] explain that game difficulty can be measured based on several factors: (1) the finite set of possible scenarios within a game (e.g. the number of possible moves left in a chess game) and current state player is in to decide probability to achieve goal, (2) the number and complexity of tasks or any game elements that may hinder players from completing them (e.g. the number of spawning enemies or required collected items), and (3) player performance (e.g. success or error rate, number of defeated enemies, or collected stars). Additionally, (4) perceived challenge, such as players' emotional responses, is also considered in assessing difficulty levels.

Seyderhelm *et al.* [125] show that the theories underlying DDA are often linked to Flow Theory, which focuses on balancing optimal challenge and skill, and SDT theory, particularly in promoting a sense of competence to enhance positive player experiences (as discussed in Section 2.3). For example, Sorenson *et al.* [105] applied a genetic algorithm to generate game challenge patterns following as described by the Yerkes-Dodson law (inverted-U relationship shown in Figure 2.5), where a person's optimal performance peaks at moderate arousal levels.

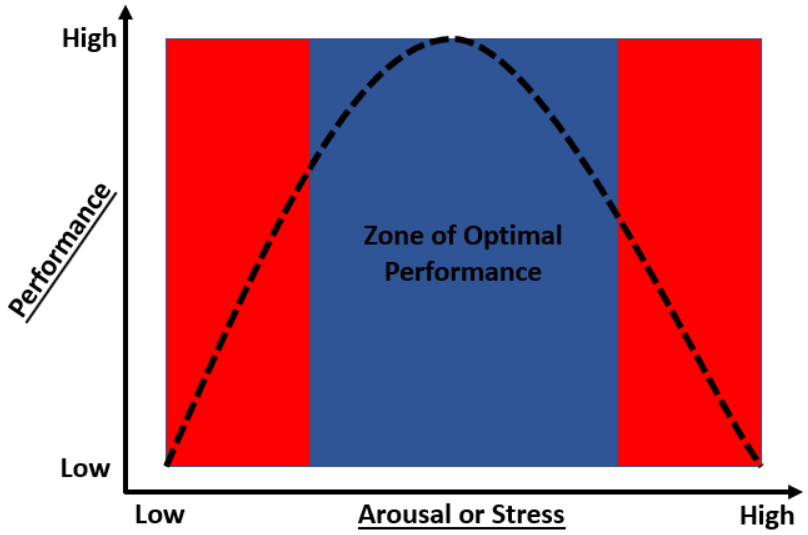

Figure 2.5: Inverted-U relationship adapted from [126]

Their training model alternated between high and low challenge levels throughout gameplay to maintain an optimal challenge level that enhances player enjoyment and performance. In their sample game (Mario), high challenge was characterised by numerous obstacles and the need for quick reactions (e.g. jumping to avoid sudden obstacles), whereas low challenge involved fewer obstacles and wider platforms, requiring less rapid response. However, they did not directly observe its effects on player experience.

Several studies have shown that flow-based DDA can help promote a challenge-skill balance. For example, in the casual game Tetris, Ang [127] found that applying performance-based DDA (where the drop rate of objects increases based on performance) improved the challenge-skill balance compared to no DDA (where the drop rate remains constant). However, participants in the DDA condition reported a lower sense of control than those in the no DDA condition. It should be noted that the DDA used in this study was not a fully dynamic function, as it only increased difficulty when players succeeded but did not decrease it when they were about to lose.

DDA based on challenge-skill balance can also enhance perceived competence. For instance, Moschovitis *et al.* [128] found that participants in DDA conditions reported higher perceived competence than those in no DDA conditions.

Moreover, DDA has the potential to enhance the overall flow experience in casual games. Climent *et al.* [129] demonstrated this in a casual spaceship shooter game, where their reinforcement learning-based DDA, which adjusted difficulty based on player performance, resulted in a higher flow compared to the no DDA condition. Additionally, their DDA function improved the win rate. Similarly, Sharek *et al.* [130] found that DDA can promote higher performance without degrading the gameplay experience. By maintaining a stimulating and challenging experience without overwhelming the player, DDA supports the flow experience, making gameplay more engaging than when no DDA is applied.

Further supporting this, Longhi *et al.* [131] demonstrated that a reinforcement learning-based DDA function, which adapts to player skill levels, increases the flow experience compared to non-adaptive versions. Likewise, Lora-Ariza *et al.* [132] found that performance-based DDA led to a stronger flow experience than non-adaptive game versions. Their study also suggests that DDA can be particularly beneficial for beginners, as it helps them achieve flow more easily.

However, some evidence suggests that flow may not always be influenced by DDA, even when DDA aims to balance challenge and skill. For example, Robb *et al.* [133] found no difference in flow between performance-based DDA, no DDA, and incremental difficulty adjustment in a casual game where players controlled an avatar by tilting a game console to avoid dropping objects. Although these studies used different games, DDA techniques, and flow measurement questionnaires, a review of Flow Theory suggests that achieving a flow state requires multiple factors, such as autotelic. It is possible that simply balancing challenge and skill may not be enough to fully support the flow experience.

DDA functions can also affect enjoyment. A review by Mortazavi *et al.* [134] shows that DDA in video games, which uses psycho-physiological data to balance game challenge and player skills, has the potential to enhance positive player experiences such as enjoyment and motivation. Moschovitis *et al.* [128] implemented a biofeedback-based DDA function that

adjusted game difficulty based on players' heart rates. When players successfully lowered their heart rates, the game became easier; otherwise, it became more challenging. This approach resulted in higher IMI: interest/enjoyment scores compared to the no DDA condition.

However, overly promoting success through DDA does not always lead to greater enjoyment and preference. Moreover, it can decrease the sense of achievement, as shown in a study by Vang [135]. This emphasises that DDA should be well-balanced, providing both being challenging but being achievable. Also, it is important to consider that enjoyment does not always increase when DDA is applied. A study by Robb *et al.* [133] found no significant difference in enjoyment between DDA and no DDA conditions. Similarly, a study by Cutting *et al.* [136] found no difference in IMI: interest/ enjoyment between a casual game with a balancing function (Tree search algorithms with performance-based data) and one without, even though the balancing condition led to a higher win rate in both easy and hard modes. These findings suggest that enjoyment is a more complex factor, influenced by various elements such as game type, individual preferences, and the needs of the player (as discussed in Section 2.3), rather than just optimal challenge and win rate. This complexity may explain the conflicting results in enjoyment observed across studies.

As previously reviews, DDA can influence PX such as flow, perceived competence, and enjoyment. However, the way difficulty is adjusted (e.g. reactively or proactively) can also shape the player experience. Different DDA actions may impact some aspects of PX differently. Regarding these actions, Hunicke *et al.* [137] provide useful information into when DDA typically begins adjusting difficulty. Firstly, reactive action refers to in-play adjustments, where DDA modifies difficulty while players are interacting with challenges. Secondly, proactive action, also known as off-stage adjustment, involves modifying upcoming challenges before they are presented to players. Examples include adjusting the spawning order or altering the properties of enemies before they appear.

Both approaches have their advantages and disadvantages. Reactive action is simple and directly addresses difficulty adjustment, but it may disrupt immersion since changes occur while players are currently engaged. In contrast, proactive action avoids such disruptions by making adjustments beforehand. However, it may lead to unpredictable or inaccurate difficulty adjustment, as the pre-set adjustments might not align with how players actually engage with the challenge. This misalignment may need for additional reactive adjustments.

Overall, while DDA in traditional video games has shown mixed results regarding its impact on some player experiences (e.g. enjoyment and overall flow), it has the potential to enhance positive player experiences, such as achieving an optimal challenge and increasing perceived competence. It should be noted that DDA has also been criticised for some limitations. For example, abrupt or unrealistic difficulty adjustments can cause a sense of disbelief, while predictability may lead to player exploitation, negatively affect skill development, and decrease immersion [36], [138].

However, in the context of exergames, DDA may trade off this limitation in exchange for other benefits. Unlike traditional video games, exergames require both gameplay skill and physical effort. Implementing DDA in this context could help regulate exertion levels—preventing excessive exertion levels that may harm players while ensuring that effort remains high enough to provide physical benefits.

In these conventional games, DDA is often designed to deal with emotional challenges (e.g. [128]) or cognitive challenges (e.g. [127]). However, in the context of exergames—where physical exercise is involved—DDA might focus on a different type of challenge, requiring a different approach for adaptation and might impact players differently.

In exergame, challenges are mainly physical challenges, requiring players to use both their skills and fitness levels to succeed. These challenges typically involve quick reactions to stimuli (reaction speed), persistence in performing physical activities with a required number of times (frequency), and endurance to sustain a target exercise intensity (intensity). As highlighted in the following literature, DDA functions frequently adjust these parameters during gameplay to personalise the experience and regulate players' energy expenditure.

For example, Muñoz *et al.* [31] used a DDA function that adjusts the speed of a Pong ball based on players' average heart rates, requiring them to adjust their reaction speed to deal with the ball and stay within the target heart rate zone. Similarly, Karime *et al.* [139] designed a game where players jump over obstacles, with the DDA adjusting avatar speed and obstacle frequency to maintain suitable exertion levels. Likewise, Liu *et al.* [32] used a DDA function that monitors heart rate, adjusting treadmill speed and incline to keep players within target zones (intensity). Huber *et al.* [140] implemented a game where players perform various exercise patterns for a specified number of repetitions adjusted by DDA.

In general, DDA in exergames aims to ensure that challenges match players' abilities and maintain beneficial exertion levels (unlike in common video games, which do not prioritise physical benefit). However, its impact on PX remains under-explored. If DDA negatively affects PX, it might lead to disengagement and game abandonment. The next section reviews studies investigating effects of DDA in exergames on PX and physical effort compared to no DDA conditions.

2.6 Impact of Dynamic Difficulty Adjustment In Exergames on Player Experience and Physical Effort Compared to no DDA

The above section 2.5 shows that DDA, when working with players' heart rates during gameplay, can potentially increase players' physical effort to the targeted exertion levels. However, how does DDA in exergames impact player experience? Several studies have investigated DDA across various types of physical activity, ranging from light to vigorous exercise intensity presented in exergames. While some findings suggest that DDA can enhance player experiences, other studies with similar physical activity types, PX measurements, and DDA functions have found no significant differences when DDA was applied.

In low-intensity exergames, only a limited number of studies have investigated the impact of DDA functions on players, and their findings are mixed, even when similar types of exergames and DDA mechanisms were used. For example, Goršič *et al.* [38] ($N = 64$) and Ajani *et al.* [27] ($N = 10$) investigated DDA in a Pong video game where players used either joysticks or customised handheld devices to direct a virtual ball in competition against other players or the system. In both studies, DDA adjusted the ball's speed and paddle size based on

player and opponent scores. The results showed that DDA conditions significantly enhanced players' interest/enjoyment and effort/importance compared to no-DDA conditions. However, the effect on perceived competence was inconclusive: while Goršič *et al.* [38] reported no significant difference, Ajani *et al.* [27] found an improvement when DDA was applied.

A similar inconsistency appears in pressure/tension. Goršič *et al.* [38] observed an increase when DDA was used, whereas Ajani *et al.* [27] found no such effect. However, it is important to note that Ajani *et al.* [27] used a smaller sample size compared to Goršič *et al.* [38]. Despite these differences, Ajani *et al.* [27] also found that DDA significantly improved flow.

Another study by Darzi *et al.* [28] ($N = 50$) investigated a similar Pong game but compared two DDA techniques: one based solely on performance data (as in Ajani *et al.* [27] and Goršič *et al.* [38]) and another that combined performance, preference, and physiological data (e.g. respiration rate and brain signals) within a regression-based classifier algorithm to adjust ball and paddle size. The findings indicated that neither DDA function had a significant effect on interest/enjoyment, perceived competence, effort/importance, or flow compared to a manual adjustment condition. However, DDA significantly increased pressure/tension, consistent with the results of Goršič *et al.* [38]. The researchers suggested that this increase may have resulted from challenges being well aligned with player preferences, which in turn heightened the sense of pressure during gameplay.

Similar to low-intensity exergames, the impact of DDA functions on PX in high-intensity exergames remains inconclusive. Martin-Niedecken *et al.* [24] ($N = 54$) investigated DDA in a full-body exergame called Plunder Planet, designed for children and adolescents. This holistic immersive game projected visuals on the wall, while players interacted with physical buttons and used body gestures captured by Kinect. Players controlled a virtual spaceship through body movements, navigating obstacles by either avoiding or attacking them. In this study, DDA adjusted difficulty by monitoring players' heart rate and performance scores to alter the frequency of obstacles and the layout of the game environment. The findings indicated that playing under DDA conditions enhanced flow and enjoyment compared to a no-DDA condition. However, it is important to note that the adaptive function in Martin-Niedecken *et al.* [24] was not fully automated, as researchers manually adjusted game parameters in real time.

In a subsequent study, Martin-Niedecken *et al.* [23] ($N = 40$) investigated an automated DDA function in a comparable exergame designed for adults with similar difficulty parameters. The results showed no significant differences in flow or enjoyment compared to a no-DDA condition. Their game, ExerCube, is a holistic immersive setup in which players play inside a room with images projected on the walls and sensors tracking their gestures. Players control an avatar on a hoverboard, navigating through coloured gates by performing specific gestures and punching incoming attacking objects. The DDA adjusted challenges—specifically the race speed and the time window for the gates—based on players' average heart rate (BPM), to maintain it within the target zone, as well as on their performance scores.

Similarly, studies on cycling exergames and leg-movement exergames (both forms of high-intensity physical activity) found no impact of DDA on PX. Ketcheson *et al.* [18] ($N = 18$) and Wünsche *et al.* [26] ($N = 6$) reported no significant improvements in interest/enjoyment, perceived competence, pressure/tension, effort/importance, flow, or challenge–skill balance. In both works, heart rate–based DDA was implemented in cycling exergames with biking

machines to encourage players to continue pedalling and to keep their heart rates within target zones. The DDA functions monitored heart rate in BPM, adjusted game challenges, and rewarded players for maintaining their heart rate in the zone. Likewise, Schwarz *et al.* [33] ($N = 94$) used performance-based data (acceleration of leg movement) to estimate participants' exertion levels during the day and used DDA to adjust game tasks in order to help them reach the target level of physical activity, but no significant differences were observed compared to a no-DDA condition.

Not only are the results on player experiences mixed, but the impact of DDA on physical effort is also inconsistent, even among studies using similar types of exergames and DDA functions. For instance, Ketcheson *et al.* [18] (cycling) reported that DDA led to higher average heart rates during playtime and increased perceived exertion. In contrast, Wünsche *et al.* [26] (cycling) and Martin-Niedecken *et al.* [24] (full-body) found no differences in average heart rate between DDA and no-DDA conditions.

Thus, in high-intensity exergames, it also remains unclear whether DDA impacts PX and physical effort and, if it does, how it influences them. Interestingly, the studies on both low- and high-intensity exergames are grounded in the challenge-skill balance concept in flow and dual flow [13], [19]. When players' skills match the game's difficulty, they may experience a greater sense of challenge-skill balance and achievement, potentially enhancing competence [16]. However, studies (e.g. [23], [28], [38]) that examined these factors found no improvement when DDA was applied. Besides, the number of studies exploring these aspects is limited, leaving open questions about whether challenge-skill-based DDA aligns with flow theory and SDT.

A summary of the reviewed empirical studies is presented in Section 2.10. Overall, DDA adopted in exergames typically uses performance-based and physiological data, similar to DDA in conventional video games. However, in exergames, physiological data primarily focuses on describing exertion levels rather than players' emotions or preferences. Even though DDA has been applied across various types of games, from casual, light-intensity games like Pong to more complex, high-intensity ones like ExerCube [23], the reviewed DDA functions consistently adjust difficulty parameters related to exertion and energy expenditure. However, it remains uncertain whether DDA in exergames impacts or promotes player experiences and physical effort.

2.7 Categorisation of DDA for Exergames Based on the Review

As reviewed, DDA in exergames can be classified into two types based on the different player data used: exercise intensity-based DDA and performance-based DDA.

2.7.1 Exercise intensity (EI)-based DDA

EI-based DDA in this research refers to a function, based on the dual flow model [19], that balances the game's physical challenge to regulate exertion levels in line with individual

fitness levels. This ensures that players remain within the target exercise intensity zones, maintaining the game's effectiveness in promoting physical activity.

To achieve this, DDA uses in-game physiological data, such as heart rate, which reflects exercise intensity. During gameplay, this data is measured, evaluated against predefined criteria, and used to adjust game difficulty parameters. As a result, players must physically respond to these changes, altering their physical efforts and overall exertion levels in the exergame.

Research commonly uses two exercise patterns in designing DDA functions: one that maintains continuous exercise intensity, referred to as continuous exercise intensity-based DDA (e.g. [18], [31], [32]), and another that alternates between low and high-intensity exercises, called interval exercise intensity-based DDA (e.g. [34]).

2.7.2 Performance (P)-based DDA

Darzi *et al.* [28], Fisher *et al.* [110], Danousis *et al.* [117], and Robb *et al.* [133] explained that performance-based DDA is a function that adapts game difficulty in real-time by using player performance data, such as success rate, score, and accuracy, which game designers consider as indicators of player performance. This approach aims to balance challenge and skill (aligning with flow theory [13]), preventing boredom or frustration.

Regarding the review of Hunicke *et al.* [137]'s study (see Section 2.5), DDA functions in two ways: reactive action and proactive action. It is important to note that the terms reactive and proactive in this context differ from those used in Demediuk *et al.* [141]'s study on Monte Carlo Tree Search DDA in fighting games between human players and AI. In that study, AI actions are categorised into two approaches: (1) Reactive Outcome-Sensitive Action Selection, where the AI takes a defensive stance rather than actively knocking players out, and (2) Proactive Outcome-Sensitive Action Selection, where the AI adopts a more offensive approach while maintaining game balance.

In general video games, reactive actions have been used in various studies. For instance, Hunicke [36] developed a probabilistic P-based DDA function that considers player health scores and damage taken during combat to predict the probability of player death. If a player's probability of death exceeded 40% (while other studies, such as [129], [135], consider a 50% win rate as suitable for a challenging but achievable experience), the DDA function adjusted the game difficulty to maintain a challenge while reducing frustration. Their results indicated a decrease in player deaths compared to a no DDA condition.

A similar reactive approach has been adopted in exergames, though often relying on direct success/failure counts rather than probability-based calculations. For instance, Martin-Niedecken *et al.* [23], [24] implemented DDA functions that adjusted difficulty based on the number of mistakes players made when attempting to overcome in-game challenges. If a player failed to avoid obstacles multiple times, the game triggered an adaptive function to lower the difficulty. Conversely, when players performed successfully without encountering failure, the adaptive function increased the challenge level to maintain engagement.

Even though the mentioned studies [23], [24], [36] did not directly investigate the impact of

this approach on player experience, reactive actions may cause sudden changes in challenge, potentially leading to noticeable and unrealistic situations [36]. Besides, as reactive DDA requires players to experience a set number of setbacks before adjustments take effect, some individuals may encounter repeated failures, which could lead to frustration. For instance, Hunicke [36] found that although the death rate decreased, newbie players still perceived the need to repeat tasks. However, with limited supporting studies, it is not possible to determine the exact impact on player experience.

In contrast, this approach may enhance enjoyment for some players by introducing challenging situations with setbacks that must be overcome before DDA takes action. For example, Hunicke [36] observed a trend suggesting that, for players familiar with the game, the DDA condition led to a slight increase in enjoyment. However, the study lacks statistical tests or detailed statistical results to support this claim.

There are limited studies that adopt proactive actions as a stand-alone approach; most incorporate both reactive and proactive elements. For example, Erali *et al.* [126] developed a DDA function where difficulty initially starts at a medium level and then adjusts up or down based on the player's performance during combat (reactive), which serves as the primary approach. Additionally, previous performance was used to adjust the difficulty of subsequent encounters, such as appropriate enemy spawns, though this was a minor aspect of the game system. In the context of exergames, to the best of current knowledge as shown in the review, no studies have yet employed this approach. This lack of research leaves uncertainty about how such an approach might impact player experience and how it could be applied to DDA in the exergame context.

In this research, P-based DDA that adjusts game difficulty in real time while players are actively interacting with challenges, based on their current performance, is called reactive P-based DDA. Meanwhile, P-based DDA that adjusts game difficulty before players encounter a challenge, predicting potential setbacks or failures by evaluating their performance beforehand, is called proactive P-based DDA.

2.8 Research Gaps

Due to the limited number of studies examining the impact of DDA on player experience and physical effort in exergames, and the conflicting findings presented in the literature, significant gaps remain. While DDA in video games has been studied widely, its impacts on PX and physical effort in exergames remain under-explored.

In the context of exergames, there are two primary goals of DDA presented in the reviewed studies: promoting the effectiveness of exergames (usually by targeting exercise intensity) and enhancing their attractiveness (e.g. improving player experience). While effectiveness-focused DDA commonly uses exercise intensity-based data to regulate exertion, its impact on PX remains unexplored. Moreover, the literature reveals two main exercise patterns—continuous exercise intensity and interval exercise intensity—but their impact on perceived exertion and other aspects of PX is still under-researched. These different exercise patterns may create different player perceptions of exertion and game experience as they generate different difficulty curves.

Regarding DDA for attractiveness, which typically works with performance data, the existing research presents unclear findings on its impact on PX. Furthermore, the relationship between performance-based DDA and physical effort or perceived exertion has not been adequately explored. Moreover, limited research has examined how reactive and proactive DDA actions—both of which adjust game difficulty based on player performance but differ in the timing of their adjustments—impact PX and physical effort. Reactive DDA may heighten challenge and lead to improved player performance, as players receive feedback when they fail to overcome a challenge. However, it may also induce frustration and decreased engagement, especially when players encounter repeated setbacks or failures before the DDA takes action (as reviewed in Section 2.2.1 about failures and setbacks).

In contrast, proactive DDA may provide a smoother difficulty adjustment, reducing the likelihood of failure and setbacks. However, by lacking immediate feedback on performance (e.g. the absence or minimal presence of punishment or consequences), it may also diminish the sense of challenge, potentially leading to lower performance improvement and reduced enjoyment.

These gaps highlight the need for further investigation. This research aims to address these gaps by exploring how different DDA functions impact both player experience and physical effort, with a focus on understanding how they influence the overall effectiveness and attractiveness of exergames in order to answer the research questions.

2.9 Chapter Summary

Figure 2.6: Hierarchical overview of literature review

As illustrated in Figure 2.6, this chapter provides a review of the existing literature relevant to the study of DDA in exergames. The review begins by examining the concept of exergames, exploring how they integrate physical activity with gameplay, and outlining the guidelines provided by existing studies on how to design exergames.

A key reason people engage in video games is the challenge they present. The role of challenge in video games is not only in enriching game content but also in enhancing player motivation and enjoyment, particularly when players successfully overcome obstacles or setbacks. However, as discussed in the review, challenge can also have negative consequences if it becomes too difficult or too easy relative to the player's skill level, leading to repeated failures or a lack of stimulating tasks. Flow theory suggests that such mismatches between difficulty and player skill can result in frustration or boredom, potentially leading to a decline in flow, competence, enjoyment, and motivation.

To address the impact of challenge on PX, two main approaches are commonly used: manual difficulty adjustment and DDA. Both approaches have their advantages and drawbacks. Manual difficulty adjustment commonly involves pre-setting difficulty levels at the start of a game or during specific stages. While this method is simple, it might fail to cater to the needs of individual players, as it does not adjust in real time. This limitation may require players to exit the game to change difficulty settings, disrupting the gaming experience and interrupting the game flow.

In contrast, DDA offers a more flexible solution by enabling real-time adjustments based on player performance and data. DDA can dynamically modify game difficulty during gameplay, considering factors such as player skill and physiological data. This real-time adaptation allows for a smoother, more tailored experience for each player, maintaining the right balance of challenge and enjoyment throughout the game. However, DDA also has its limitations, such as unrealistic element adjustments.

The literature on DDA in exergames suggests that DDA potentially leads to positive effects on physical effort and player experience. Several studies highlight how DDA enhances aspects such as flow and intrinsic motivation. However, other studies show contrasting results, where DDA does not significantly impact these factors, which conflicts with flow theory and SDT. These mixed findings highlight the need for further exploration into the effects of DDA in exergames on both player experience and physical effort. The limited number of studies and the varying results presented cause a gap in the current literature, providing an opportunity for further research. This study aims to address these conflicting findings and offer a clearer understanding of how DDA in exergames influences both player experience and physical effort.

2.10 Summary of Related Works on DDA for Exergames

No.	Study	Year	Research Design	Duration of Play	N	Game	PA	DDA approach			Difficulty	Average Heart Rate		Perceived Exertion	
								Other	EI-based	P-based		Measures	Results	Measures	Results
1	Ajani *et al.* [27]	2023	within-subject design with 2 conditions: DDA and random adjustment	-	10 (F4:6M)	Pong game : arm rehabilitation game	arm rehabi litation	player performance and ball speed	-	-	ball speed and paddle size	-	-	-	-
2	Darzi *et al.* [28]	2021	between -subjects with 5 conditions : manual, random, P-based DDA , preference -performance DDA, performance -preference -physiological DDA	18 minutes (2 minutes 9 intervals)	50 (13F:37M), 10 assigned to each condition	Pong game	arm exercise	Performance data, physiological data ,preference data	-	-	a speed of ball and a size of paddle	-	-	-	-
3	Wünsche *et al.* [26]	2021	within-subjects with 2 conditions: with and without balancing	-	6 (1F:5M)	Game with an exercise bike	cycling race	-	heart rate (BPM)	-	In-game speed increases as a reward when the player's heart rate reaches the target zone	built-in sensors	nd. (small sample size)	-	-
4	Schwarz *et al.* [33]	2021	between-subjects with 2 conditions : no DDA and DDA	-	94 (35%F:59%M)	narrative -driven exergame	lower-body movement	-	identify exertion level using accele ration data of leg movements	-	adjust narrative content to require players to increase or decrease physical activity	-	-	-	-

Table 2.2: A summary of related works examining DDA in exergames compared to no DDA (Part 1/1)

No.	Study	Interest/Enjoyment		Perceived Competence		Pressure/Tension		Effort/Importance		Flow		Challenge-skill balance		Perceived Challenge	
		Measure	Results	Measure	Results	Measure	Results	Measure	Results	Measure	Results	Measure	Results	Measure	Results
1	Ajani *et al.* [27]	IMI	DDA > random	IMI	DDA > random	IMI	nd.	IMI	DDA > random	FEM[142]	DDA > random	-	-	-	-
2	Darzi *et al.* [28]	IMI	nd	IMI	nd	IMI	performance-preference-physiological DDA > random	IMI	nd	FEM [142]	nd	-	-	-	-
3	Wünsche *et al.* [26]	IMI	nd. (small sample size)	IMI	nd. (small sample size)	IMI	nd. (small sample size)	IMI	nd. (small sample size)	-	-	-	-	-	-
4	Schwarz *et al.* [33]	-	-	custo mised scale	nd. (but few participants actively playtested the game)	Kid-GEQ	nd. (but few participants actively playtested the game)	-	-	Kid-GEQ	nd. (but few participants actively playtested the game)	Kid-GEQ	nd. (but few participants actively playtested the game).	-	-

Table 2.2 (continued Part 1/2)

No.	Study	Year	Research Design	Duration of Play	N	Game	PA	DDA approach			Difficulty	Average Heart Rate		Perceived Exertion	
								Other	EI-based	P-based		Measures	Results	Measures	Results
5	Martin-Niedecken *et al.* [23]	2019	within-subjects with 3 conditions: traditional exercise, game without DDA, game with DDA	10 minutes	40 (19F:21M)	ExerCube	full body exercise	Players' heart rate for physical challenges is checked every 0.5 minutes if it's less than the lower bound, and every 1 minute if it's higher than the upper bound. Performance data for cognitive challenges is checked every 20 seconds.	-	-	game speed and overcome obstacles	-	-	-	-
6	Martin-Niedecken *et al.* [24]	2017	within-subjects with conditions: no DDA (where difficulty level increases over time) and DDA	4 minutes	54 (24F:30M)	Plunder Planet	full body exercise	the player's heart rate and performance (not fully DDA because adjustments were made by investigators)	-	-	the frequency of obstacles	Polar H7 sensor	nd.	-	-
7	Goršič *et al.* [38]	2017	within-subjects with 3 conditions: no adaptation, manual, DDA	8 minutes	64 (20F:44M)	competitive Pong game with hand controllers	arm rehabilitation	-	-	points earned for adjustment	the ball speed and the size of the paddles	-	-	-	-
8	Ketcheson *et al.* [18]	2016	within-subjects with 3 conditions: non-customised game, customised game with pedalling, customise game with pedalling and DDA	7 minutes: playing 5 minutes: resting	18 (5F,13M)	Half-Life 2 and The Elder Scrolls V : Skyrim	pedal	-	heart rate (BPM)	-	receive rewards when heart rate reaches the target zone	Garmin Premium heart rate monitor	DDA > pedalling game without DDA	BRPE	DDA > pedalling game without DDA

Table 2.2 (continued Part 2/1)

No.	Study	Interest/Enjoyment		Perceived Competence		Pressure/Tension		Effort/Importance		Flow		Challenge-skill balance		Perceived Challenge	
		Measure	Results	Measure	Results	Measure	Results	Measure	Results	Measure	Results	Measure	Results	Measure	Results
5	Martin-Niedecken *et al.* [23]	single-item measures	nd.	-	-	-	-	-	-	SFSS	nd.	-	-	single-item measures	between game with and without DDA, optimal challenge and insufficient challenge did not differ
6	Martin-Niedecken *et al.* [24]	customised scale	DDA > no DDA	-	-	-	-	-	-	GameFlow	DDA > no DDA	-	-	customised scale	perceived higher challenge in no DDA and perceived higher optimal challenge in DDA
7	Goršič *et al.* [38]	IMI	DDA > no adapt.	IMI	nd.	IMI	DDA > no adapt.	IMI	DDA > no adapt.	-	-	-	-	-	-
8	Ketcheson *et al.* [18]	IMI	nd.	IMI	nd.	IMI	nd. between the pedalling game and the pedalling game with DDA	IMI	nd. between the pedalling game and the pedalling game with DDA	-	-	-	-	-	-

Table 2.2 (continued Part 2/2)

Chapter 3

Research Methodology

This chapter presents the research methodology, outlining the overall research design and rationale. This research focuses on two primary DDA functions identified in prior research (shown in Chapter 2)—exercise intensity-based (EI-based) and performance-based (P-based)—and comprises three experiments to address the research questions:

- Experiment 1 compares EI-based DDA to a no-DDA condition.
- Experiment 2 compares P-based DDA to a no-DDA condition.
- Experiment 3 explores two variations of P-based DDA, comparing adjustments made before versus after player setbacks to address gaps identified in the literature review and Experiment 2.

3.1 Research Design

Given that all experiments involved the comparisons between experimental conditions and after reviewing Cairns *et al.* [143] and related works (see Section 2.10), a within-subject design was adopted to reduce inter-participant variability, with the same participants taking part in all conditions. This design was considered suitable for this research, given the potential difficulty of recruiting a large participant pool due to the nature of the research, which involved light-to-vigorous physical activity.

To control for carry-over effects between conditions, counterbalancing was used, and participants were given break periods between conditions to allow their heart rates to return to resting levels and to minimise fatigue. Resting heart rates were recorded before each play session to ensure no significant differences existed at the start of each condition, as heart rate data collected during gameplay was used for analysis.

Details on experimental variables are provided in each experimental chapter.

3.2 Participants

Each experiment was open to all participants. The eligibility criteria for participation were as follows:

- **Age**: 18 years or older.
- **Physical Activity**: Ability to perform running in place and arm-hand stretching without limitations.
- **Physical Activity Readiness**: Answered "No" to all questions on the Physical Activity Readiness Questionnaire (see Appendix E). This questionnaire served as a preliminary screening tool to ensure that participants considered themselves healthy enough to engage in research involving physical exertion. It has been used in previous studies (e.g. [144], [145]).
- **Medical Device Compatibility**: No limitations in using a heart rate sensor (Galaxy Watch 4) and no implanted medical devices that could be interfered with by the device.

Recruitment for each experiment was conducted through various methods: posters distributed around the university and at bus stops, electronic letters from the Department of Computer Science and the School of Arts and Creative Technologies, social media platforms (e.g. Discord) of the department and the university, and word of mouth.

Initially, the sample size for this research was estimated through a power analysis (paired t-test, two-tailed) using TTestPower in Python. The analysis aimed for 80% power with an alpha level of .05, based on effect sizes from related works [18], [23], [28], [38] and the experiments in this research before proceeding to the next. The results suggested a sample size of approximately 100–200 participants for some variables (e.g. perceived exertion, interest/enjoyment, pressure/tension, effort/importance, and flow) and around 10–40 for others (e.g. competence and challenge-skill balance).

However, participant recruitment was challenging due to the long study duration (approximately one to two hours) and the involvement of light-to-vigorous exercise intensity, which may have limited participant interest. Recruiting a larger sample could have been difficult and might have extended the PhD timeline. Therefore, based on the related works with similar designs, discussions with supervisors, and adopting within-subject design, 30–40 participants per experiment were selected and considered sufficient to detect statistical differences across conditions.

3.3 The Exergame

This PhD research examined the effects of exergames with DDA functions on PX and physical effort; therefore, an exergame was required. For this purpose, ExerWitch, an indoor running exergame developed for this research, was used. In the game, a witch avatar is pursued by a menacing dragon, and players must help the avatar escape and reach a destination to seek help. To progress, players physically run to move the avatar forward and overcome obstacles by performing specific hand actions. The game maintains engagement through the challenge of escaping the dragon while promoting physical activity through continuous running and arm movements.

This exergame was developed using the Unity game engine, with all assets obtained from free-asset repositories. It was built to run on Android smartphones and requires additional devices for gameplay. Specifically, a device is used to monitor players' heart rates during play, allowing the game to identify overall physical effort and detect current target zones. Another device captures foot acceleration to control the avatar's running speed. Both functions are supported by Galaxy Watch 4 devices, worn on the left wrist and the right ankle. An Android smartphone with a custom application was also used to detect player gestures during play.

Overall, this game was developed to support the research investigation. The physical activity involved ranges from light to vigorous exertion levels and is closely related to the cardiovascular system, which supports the design of the DDA functions in this study. This design enables a wide range of difficulty adjustments and heart rate is used to support the exercise intensity-based DDA. Further details and justification for the game design are provided in Chapter 4.

3.4 Experimental Procedure

As shown in Figure 3.1 (next page), the procedure for all experiments in this research began with a briefing and pre-experiment documentation, followed by device preparation and attachment, game familiarisation, and a warm-up session. Participants then took a break, sitting to lower their heart rates to resting levels. The heart rate sensor (watch) was removed for cleaning due to sweating.

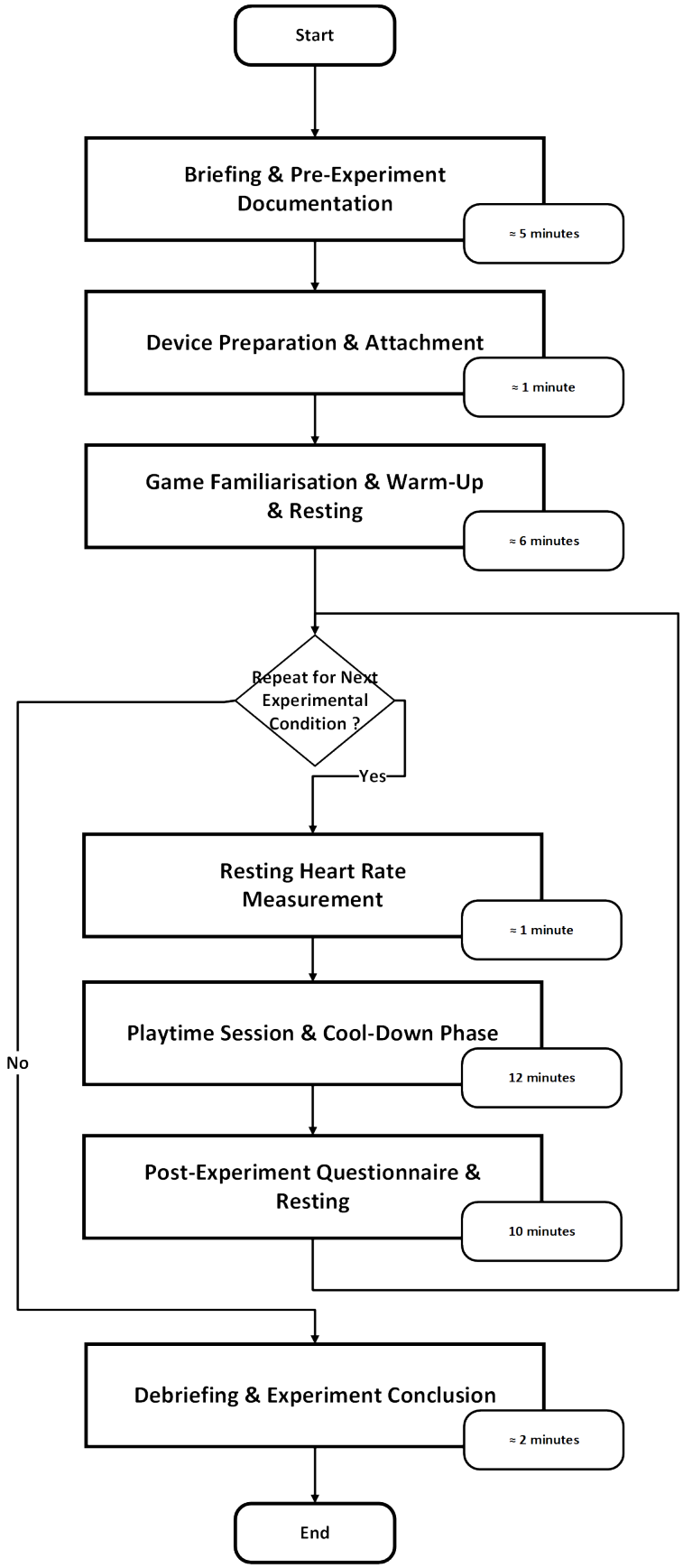

Figure 3.1: The overall experimental procedure flowchart with estimated time for each step.

After participants were ready for the gameplay session, their resting heart rates were recorded using a Galaxy Watch 4 strapped to the left wrist. The reason for measuring resting heart rates is that the study followed a within-subject design with multiple sessions. To ensure that the overall average heart rate (physical effort) during each session was not strongly influenced by physical activity from a previous session, the resting heart rate at the start of each session was measured. This allowed investigation of whether there were differences in resting heart rates between sessions. Therefore, resting heart rates were measured before every gameplay session rather than only once at the beginning of the experiment.

Participants' resting heart rates were measured three consecutive times to obtain an average resting heart rate and to mitigate potential sensor accuracy errors. Prior to this, they were informed about the procedure and instructed to take deep breaths and relax. During the measurement, the investigator stood at a distance to avoid disturbance. After the measurements, participants proceeded to the playtime sessions.

Before starting the game, participants were reminded that they would play for 10 minutes, after which they would complete post-experiment questionnaires to assess their experience. They were also informed that they could stop at any time if they felt unwell, prioritising their health and safety to ensure ethical considerations.

The 10-minute duration was considered sufficient to induce adequate physical activity levels without excessive exertion while allowing participants to engage meaningfully with the gameplay. Similar studies (e.g. [18], [23], [28], [38]) have reported significant differences in heart rate and player experiences within this duration (approximately 7 - 18 minutes). Also, a pilot study (Section 4.4.6) confirmed the appropriateness of this duration, as no participants reported severe exhaustion or pain during gameplay.

After 10 minutes of gameplay, the session concluded with a cool-down phase, during which participants took a slow walk and relaxed before proceeding to the next phase.

After each playtime session, participants completed post-experiment questionnaires to assess their player experiences. They also took a break to allow their heart rates to return to resting levels. If another playtime session followed (for a different experimental condition), their resting heart rate was measured again before beginning the next playtime session. This process repeated until all experimental conditions were completed.

Finally, the experiment concluded with a debriefing. Further details are provided in each experimental chapter. Overall, each experiment lasted at least 1 hour, depending on the number of experimental conditions included.

Figure 3.2 shows an overview of the experimental room, which was designed to ensure a safe and suitable environment for physical activity. The space was kept clear, while proper ventilation was maintained through open windows and fans. Sufficient lighting was also ensured to minimise potential risks associated with the experimental setup.

Figure 3.2: An overview of the experimental room setup, showing a participant playing the game in a clear space with proper ventilation and sufficient lighting.

3.5 Data Collection and Analyses

A quantitative approach was used to statistically analyse the differences between conditions. Player experiences were measured using established scales (further detailed in each experimental chapter), administered immediately after the play sessions. Heart rates during gameplay were also recorded using a heart rate sensor of Galaxy Watch 4 to assess physical effort.

3.5.1 Collection of Player Experiences

3.5.1.1 Self-Determination Theory

The Intrinsic Motivation Inventory (IMI) [146], based on Self-Determination Theory (SDT) [16], is a multidimensional measurement tool designed to assess participants' subjective experiences related to a specific activity. The IMI is widely used in related works to evaluate intrinsic motivation (as summarised in Section 2.10). It includes seven subscales: Interest/Enjoyment, Perceived Competence, Effort/Importance, Pressure/Tension, Perceived Choice, Value/Usefulness, and Relatedness.

Given the research scope, this research focuses on Interest/Enjoyment, Effort/Importance, Pressure/Tension, and particularly Perceived Competence, as these factors are likely influenced by DDA functions, according the review. Sample items from IMI include: Interest/Enjoyment — "I enjoyed playing this game very much", Effort/Importance — "I put a lot of effort into playing this game", Pressure/Tension — "I did not feel nervous at all while playing this game", and Perceived Competence — "I think I am pretty good at this activity". The complete IMI used in this research is provided in Appendix K.

To further investigate player frustration and satisfaction after experiencing DDA functions, this research used the Basic Needs in Games Scale (BANGS) by Ballou *et al.* [147], a within-game-context scale based on SDT. The BANGS comprises six factors, measuring Autonomy Satisfaction and Frustration, Competence Satisfaction and Frustration, and Relatedness Satisfaction and Frustration.

This research specifically focused on Competence Satisfaction and Frustration, as these factors are potentially influenced by DDA functions. The BANGS was used in Experiment 3, with further details provided in that chapter. A sample item for Competence Satisfaction is "I felt I was getting better at playing this exergame", while a sample item for Competence Frustration is "I often felt that I lacked the skills necessary for this exergame". The full BANGS questionnaire used in this research is included in Appendix L.

Questionnaires based on SDT, such as the Player Experience of Needs Satisfaction (PENS) [148] and the Ubisoft Perceived Experience Questionnaire (UPEQ) [149], were also considered for this research. However, after reviewing these instruments, it was found that they lack certain factors of interest, such as Interest/Enjoyment, Pressure/Tension, and Frustration. To ensure consistency with related studies (e.g. [18], [26]–[28], [38]) and better alignment with the research objectives, these questionnaires were not selected.

The Physical Activity Enjoyment Scale (PACES) [150] was also reviewed as a tool measuring of participants' enjoyment of physical activity. This scale has been used in previous studies [151]–[153]. While the Interest/Enjoyment subscale of IMI also assesses enjoyment, PACES differs in that it uses bipolar adjective pairs (e.g. "I enjoy it" vs. "I hate it") and is more specific to physical activity.

However, PACES was not included in this research for several reasons. First, it is not directly grounded in SDT, which serves as the theoretical foundation of this research. Moreover, using both PACES and IMI to assess enjoyment would have increased the total number of questionnaire items, potentially prolonging the experiment and adding to participants' cognitive load. So, only the IMI was used to measure enjoyment in this research.

3.5.1.2 Flow

The Flow State Scale (FSS), developed by Jackson *et al.* [154], is a widely used tool to measure the experience of flow. It consists of 36 items distributed across nine dimensions, capturing different aspects of flow based on Csikszentmihalyi *et al.* [13]. These dimensions include challenge-skill balance, action-awareness, clear goals, unambiguous feedback, concentration on the task at hand, sense of control, loss of self-consciousness, transformation of time, and autotelic experience. Participants rate their agreement with each statement on a Likert scale to reflect the intensity of their flow experience. The FSS is used in video game research (e.g. [155]) to evaluate how activities promote flow. A sample item of FSS is "I was challenged, but I believed my skills would allow me to meet the challenge". A full version of FSS used in this research is shown in Appendix I.

Another commonly used tool for measuring flow is the Flow Short Scale (SFSS), developed by Engeser *et al.* [156] and validated in subsequent studies [157]. The SFSS is a short version of the original FSS, designed to assess the flow experience more concisely, making it more

practical for large-scale surveys. This is particularly useful in this research, which examines various player experiences, where a more extensive scale like the FSS might be too lengthy. The SFSS focuses on six core dimensions: challenge-skill balance, clear goals, immediate feedback, concentration and focus, loss of self-consciousness, and sense of control. The scale consists of 10 items, and to save experimental time, it was used in Experiment 2. A sample item in this scale is "I was challenged, but I believed my skills would allow me to meet the challenge". A full version of SFSS used in this research is shown in Appendix J. Examples of related works that have used this scale are [88], [151].

In addition to these scales, other tools, such as the Game Experience Questionnaire (GEQ) [158], are also used to measure flow in video game research. However, after reviewing this questionnaire, it was found to be unsuitable for the design of this research, as it does not measure the challenge-skill balance factor, which is a primary variable of interest. Therefore, the FSS and SFSS were selected, as they are more suitable for the nature of this research, measuring overall flow while specifically addressing the subscale of challenge-skill balance.

3.5.1.3 Perceived Challenge

The Challenge Originating from Recent Gameplay Interaction Scale (CORGIS), developed by Denisova *et al.* [15], is a tool designed to assess players' perceived challenges in digital games. It has been used in previous studies (e.g. [83]) and evaluates challenges across four dimensions: Cognitive Challenge, Performative Challenge, Emotional Challenge, and Decision-Making Challenge.

In this research, performative challenge, based on CORGIS, refers to the physical execution of in-game actions, requiring quick reflexes and reaction time to respond to in-game events adjusted by DDA functions. This dimension: Performative Challenge of CORGIS was used to quantify how players perceive performative challenges across different experimental conditions. A sample item is "I had to react quickly when playing the game" The full version of CORGIS: Performative Challenge used in this research is provided in Appendix G.

3.5.1.4 Perceived Exertion

To quantify participants' perceived exertion levels, Borg's Rating of Perceived Exertion (BRPE), developed by Borg *et al.* [106], was used. This subjective assessment tool is widely applied in exergame research (e.g. [18], [140], [159]–[161]) and recommended by the American College of Sports Medicine [162]. The BRPE scale is a single item ranging from 6 (No exertion at all) to 20 (Maximum exertion).

A sample of the BRPE scale used in this research is provided in Appendix H.

3.5.2 Collection of Heart Rate

Heart rates during gameplay, used as indicators of physical effort, were recorded in beats per minute (BPM) using a Galaxy Watch 4 worn on the left wrist of all participants. This method aligns with prior studies in related work (see Section 2.10) that commonly use heart rate data in BPM to assess physical exertion.

Heart rate variability (HRV) was initially reviewed but was not selected for this research, as the primary aim of using heart rate is to quantify physical exertion. Heart rate in BPM serves as a direct, well-established metric for assessing physical effort and energy expenditure during exercise.

In contrast, HRV primarily reflects autonomic nervous system activity, such as stress and frustration which is commonly examined in affective DDA studies in video games (e.g. [35], [98]), rather than raw physical exertion levels. Since measuring psychological states from heart rate falls outside the scope of this research, HRV was not chosen.

In this research, BPM measurement follows the common practice of continuous and real-time heart rate monitoring in related works (e.g. [23], [24]). Photoplethysmography (PPG) (a sample of PPG sensor shown in Figure 3.3) is used instead of deriving BPM from RR intervals (a sample of plotted RR interval in a graph shown in Figure 3.4), which are typically obtained from electrocardiogram (ECG) sensors (a sample of ECG sensor shown in Figure 3.5). Unlike ECG, which requires high-precision and often intrusive devices, PPG provides a more practical and accessible method for measuring heart rate.

Figure 3.3: Sample of a smartwatch with PPG sensor emitting green light, ready to measure heart rate from Healthcare Digital [1].

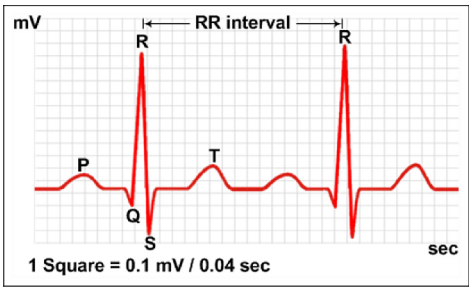

Figure 3.4: A plotted ECG graph showing RR intervals and heart electrical activity from ResearchGate [2].

[1] M. McGill, "Physics and light: Apple's competitive advantage in healthcare," Healthcare Digital, Feb. 28, 2018. [Online]. Available: click here to the reference source. [Accessed: Mar. 8, 2025]

[2] R. P. K. P. Sarma, "Illustration of QRS complexes and RR interval of ECG signals," ResearchGate, [Online]. Available: click here to the reference source. [Accessed: Mar. 8, 2025]

Figure 3.5: A sample ECG sensor: Polar H10 from Amazon UK [1].

To collect these data, a Galaxy Watch 4 running custom software developed in Android Studio was used. Heart rate was recorded in beats per minute, with the device capturing approximately one reading per second.

3.5.3 Analyses

To test the hypotheses, data analysis was performed using IBM SPSS 28.0.1.1. The data underwent pre-processing, including checks for normality and outliers, to ensure assumptions were met for statistical tests.

For analysing average heart rate, a data processing pipeline was applied to remove artefacts. The procedure involved: (1) removing null or non-numeric values, (2) excluding readings below 60 BPM, which were treated as sensor errors given the physical nature of exergames [30], and (3) excluding readings above 220 BPM, as these values were deemed physiologically implausible [30]. The cleaned data were then used to compute the average heart rate for analysis.

3.5.3.1 Three-Condition Comparisons

- **Average heart rate:** assumed to follow a normal distribution, differences in average heart rates across conditions were analysed using a repeated-measures ANOVA (F) with sphericity consideration. η_p^2 was calculated for effect size. Post-hoc analysis of significant results involved pairwise comparisons, using Bonferroni corrections to control for Type I errors.

  To interpret η_p^2, .01 represents a small effect, .06 represents a medium effect, and .14 represents a large effect.

- **PX:** a Friedman test was conducted to explore differences across conditions. Kendall's W was used to quantify the magnitude of significant effects. Post-hoc analysis for significant results was further examined using Wilcoxon signed-rank tests, with Bonferroni corrections for pairwise comparisons.

[1] Polar Electro, "Polar H10 Heart Rate Sensor with Bluetooth connectivity," Amazon UK [Online]. Available: click here to the reference source. [Accessed: Mar. 8, 2025]

3.5.3.2 Two-Condition Comparisons

- **Average heart rate:** a paired t-test was used to assess differences in average heart rates between two conditions. Cohen's d was calculated to determine the effect size. To interpret Cohen's d, .2 represents a small effect, .5 represents a medium effect, and .8 represents a large effect.
- **PX:** a Wilcoxon signed-rank test was used for comparisons between two conditions. Effect size (r) was reported to describe the strength of differences. To calculate **r**, the formula $r = \frac{Z}{\sqrt{N}}$ is used. To interpret **r**, .1 represents a small effect, .3 represents a medium effect, and .5 represents a large effect.

3.5.4 Statistical Significance

The alpha level was set to .05, consistent with related studies in HCI (e.g. [55]). Detailed analyses for each experiment are presented in subsequent sections.

3.6 Ethical Considerations

All experiments were reviewed and approved by the departmental ethics committee (see Appendix A). Participation was entirely voluntary, and all participants were provided with an information sheet (see Appendix B) and gave their consent before taking part. They were fully briefed about the studies and had the opportunity to ask questions related to the research.

Participants had the absolute right to stop the study at any time without facing any negative consequences on the day of the experiment. Also, they were eligible to request the withdrawal of their data within 14 days after the study concluded.

Further details regarding ethical considerations and data management are provided in the subsequent sections.

3.6.1 Do No harm

Although the experiments involved light-to-vigorous physical activity as part of the gameplay, participants had the absolute right to stop playing at any time. They were assured that their health was the top priority and that stopping would have no negative consequences. Throughout the study, participants' heart rates and physical appearance were continuously monitored by the investigators.

If participants' heart rates reached anaerobic or vigorous exercise intensity zones (indicated in the game display based on age-related estimated maximum heart rate), the investigators reminded them that they could stop if they felt unwell. In case of an emergency, emergency services (999) would be contacted without delay. A first-aid kit was also prepared on-site.

To ensure a safe and comfortable environment, the experimental room was set up with adequate ventilation (windows were opened and electric fans were used) and sufficient lighting. The space was cleared of any objects that participants might hit or trip over during gameplay. Drinking water and snacks were provided in case participants needed refreshment. All shared equipment was disinfected with rubbing alcohol before each participant's session to prevent the spread of germs. A safety and venue preparation checklist was followed prior to starting any experiment. Details of this checklist are provided in Appendix F.

The management of participants' data and privacy was considered and is explained in the following sections.

3.6.2 Anonymity and Confidentiality

A participant used only a given anonymous participant ID when they took part in the study or answered any forms, questionnaires, or scales. The ID was used for linking other data instead of using individual data.

Emails were kept separately from other data and were used only for communications with participants and to send rewards for completing the study. They were not used for linking any other data.

Photos of participants were taken for inclusion in potential publications or the thesis. The investigator only took photos of participants from behind to ensure that faces were not visible. However, if any faces were present, they were blurred. These photos were kept separate from other data and were not used for linking to any other data. They were stored in encrypted folders on a university laptop.

Finally, no identifiable data were used in the final research output or data publication.

3.7 Data Management

The data collected during these studies were used exclusively for research purposes and were managed in compliance with the university's policies, the UK General Data Protection Regulation (GDPR), and the Data Protection Act 2018. These measures ensured privacy, security, and ethical compliance as described in this section.

3.7.1 Data Storage and Data Retention

- **Soft copy data:** demographic data and player experience measures were anonymised and stored in the university's Qualtrics services. Processed data, including heart rates and in-game player data, were then stored on a password-protected personal laptop provided by the department. Emails, collected only for participant communication, were also stored on the laptop. Additionally, photos of participants, intended for research publications and the investigator's thesis, were stored on the laptop and had their faces blurred within three days of the experiment's completion to ensure anonymity.

- **Hard copy data:** observational notes, containing no identifiable information, were stored in locked drawers at the investigator's departmental office. These notes were linked to other data using anonymised participant IDs.

All data mentioned, except for email addresses, have been retained for 10 years in compliance with the university's research data policy. Email addresses were deleted three months after the study's completion to allow sufficient time for voucher compensation to be sent.

3.7.2 Management Responsibility

The investigator is responsible for all data management, except for data stored in Qualtrics, which is managed by the service provider. Access to the anonymised data is strictly limited to the investigator and their supervisors. However, this data may also be shared with authorised personnel for research purposes.

Chapter 4

Exergame Design and Development

The previous chapter outlined the methodology of this research, based on the literature review. However, this research requires an exergame that supports different types of DDA functions to investigate their effects on PX and physical effort. To facilitate this investigation, a suitable exergame capable of integrating custom DDA functions was explored.

To address the research questions and align with the research scope, the following criteria were established to ensure that the selected game supports the research's objectives:

1. The game should induce at least aerobic physical activity. Previous studies adopted a range of intensities from light to vigorous physical activity; however, low-intensity activity limits the exertion level range that DDA can adjust. Aerobic physical activity allows for a broader exertion range, leading to more noticeable DDA adjustments.

   Besides, aerobic exercise is closely linked to cardiovascular system, aligning with the research's focus on heart rate as an indicator of physical effort. Moreover, EI-based DDA adjusts the game's difficulty based on heart rate changes during gameplay.

2. The game must be single-player to align with the research scope.

3. Physical challenge should be the main challenge in the game, as the DDA functions in this research are designed to address this type of challenge and align with the research scope.

4. The game could continue and end (reach the goal) within the 10-minute play session time specified in the research methodology.

5. Given that the single experimental session and all tasks must be completed within 1 to 2 hours, the gameplay should be straightforward to minimise tutorial time and ensure players can easily understand what they should do within the game.

The next section describes the game selection steps.

4.1 Exploration of Existing Exergames

An initial exploration focused on commercial exergames. Wii Fit[1] (Figure 4.1) and Ring Fit Adventure[2] (Figure 4.2) were listed as potential candidates for this research, as they meet the criteria. For example, these games offer a variety of physical challenges, such as squatting, running, stretching, and flexibility exercises, potentially inducing physical activity in the aerobic zone and above.

Figure 4.1: A player runs in place to move their avatar through a hanging pendulum in the Wii Fit game [1].

Figure 4.2: A player runs in place to navigate their avatar, exploring the virtual world and overcoming game challenges in Ring Fit Adventure [2].

However, these games present limitations in customisation due to restricted access to their SDKs and source codes. The proprietary nature of the games, along with licensing restrictions, prevents the integration of customised DDA functions that are developed in the main experiments.

The exploration then moved on to potential open-source exergames or conventional video games that could be adapted into exergames, with a search conducted on GitHub[3]. Unfortunately, the number and quality of available video games were limited and did not meet the criteria. Even with access to source code, significant technical and design challenges emerged in adapting existing games for this research purpose.

Since commercial exergames and open-source video games could not be applied to this research, developing a custom exergame was necessary. This approach allows full control over game mechanics, DDA implementation, and data collection processes, ensuring alignment with the research's goal and the criteria. Before proceeding with game design and development, it is important to explore previous studies to understand (1) the types of physical activities adopted, as well as (2) the game themes and challenges used to engage players. A summary of related works describing these aspects is presented in Table 4.1.

[1]Nintendo, Wii Fit Plus, [Online]. Available: click here to the reference source. [Accessed: Mar. 17, 2025].
[2]Nintendo, Ring Fit Adventure, [Online]. Available: click here to the reference source. [Accessed: Mar. 17, 2025].
[3]GitHub, "Explore GitHub - Discover Open Source Projects," GitHub, [Online]. Available: click here to the reference source. [Accessed: 2022].

No.	Study or Game	Year	Physical Activity	Challenge
1	Martin *et al.* [163]: FITOON	2024	Running	A physical challenge where players run on a treadmill, with a smartwatch capturing acceleration data to convert into in-game speed. The objective is to move the avatar and reach the finish line in the shortest time possible.
2	VRun Yoo *et al.* [164]	2016	Running	A physical challenge requiring players to run in place, with the smartphone's accelerometer converting movement into in-game speed. Players must navigate obstacles by either stopping and waiting or running quickly to attack, aiming to reach the finish line.
3	Ahn *et al.* [165]	2009	Running and Hand Stretching	Running on a treadmill to row a virtual boat and compete with opponents, while using hand movements such as punching, shaking, and flapping to overcome obstacles.
4	Bayrak *et al.* [39]	2017	Biking with a machine and VR	Players need to bike to avoid obstacles and gather rewards, aiming to cover a greater distance than their opponents to win the race. They also implemented an adaptive function that adjusts each player's speed based on heart rate and machine cadence to ensure fair competition.
5	Sinclair *et al.* [29]	2009	Biking with an exercise bike	Players pedal a bike to move the avatar up and down, avoiding obstacles. The game uses DDA (Fuzzy Logic) to maintain the player's heart rate within a target zone and balance the game's challenge by considering both heart rate and success rate for decision-making.
6	Ajani *et al.* [27],Darzi *et al.* [28],Goršič *et al.* [38]:Pong game	2023-2017	Arm and hand movements	A physical and cognitive challenge where players adapt to varying ball and paddle sizes (based on DDA) to compete against opponents.

Table 4.1: A summary of the exploration of existing exergame studies on physical activity and gameplay

No.	Study or Game	Year	Physical Activity	Challenge
7	Finkelstein *et al.* [166]: Astrojumper	2021	Full-Body	Physical challenge: Rapidly move body to dodge virtual planets and collect bonuses. The game also uses P-based DDA to adjust difficulty based on player setbacks.
8	Khundam *et al.* [167]	2021	Arm swing and squat	Players engage physically by swinging their arms or squatting to control the avatar's movements.
9	Martin-Niedecken *et al.* [49],Martin-Niedecken *et al.* [70],Martin-Niedecken *et al.* [23],Schättin *et al.* [151]:ExerCube and its mini games	2021	Full body	The game presents physical challenges, requiring players to react quickly and overcome in-game obstacles. It also incorporates DDA functions based on heart rate and performance metrics, such as failure rate.
10	Martin-Niedecken *et al.* [168],Martin-Niedecken *et al.* [24]: Plunder Planet	2017-2016	Full body	A physical challenge involves steering a virtual spaceship while dealing with opponents and obstacles.
11	Yoo *et al.* [169]: Snowballz	2017	Full body	A physical challenge involves squatting to pick up snowballs, engaging in combat with enemies, and physically dodging attacks. The game incorporates performance-based DDA, adjusting difficulty based on the player's success and error rate in hitting enemies and the number of snowballs collected.

Table 4.1: A summary of the exploration of existing exergame studies on physical activity and gameplay (Continued)

Previous studies have shown that physical activity varies in type and exertion level, ranging from light-intensity activities (e.g. Pong) to vigorous exercises (e.g. running, biking, and full-body exercise). These studies highlight that physical challenge is often the primary challenge in exergames. Physical challenges require players to push their physical limits, respond quickly, or use dexterity, leading to energy expenditure that is the main objective of exergames, which aim to promote health by reducing sedentary behaviour.

To meet the criteria mentioned earlier, the following physical activities were considered: running (a widely used theme in exergames [5]), biking, and full-body movements. These activities have the potential to induce aerobic zones within a 10-minute session, can be applied to a single-player game theme, and do not involve many interaction patterns that players need to learn and adapt to. However, running was selected as the representative aerobic activity for this research for the following reasons:

1. Does not require exercise machines like biking [29], [39].
2. Requires minimal space and the least special devices, unlike ExerCube [23], [49], [70], [151] or Plunder Planet [24], [168].
3. Avoids excessive intensity, as players control their own effort rather than being constrained by an exercise machine.
4. Can be performed alone, making it suitable for individual gameplay, unlike [39].
5. Potentially sensitive to increased heart rates during playtime due to the experimental design of the 10-minute session, unlike Pong game [27], [28], [38]

To ensure that running is suitable for this research, an additional review was conducted to gather more information about it. Running is a form of physical activity similar to walking but involves a phase where both feet are momentarily off the ground [170]. It is classified as a cardiovascular workout, also known as aerobic exercise, and is beneficial for cardiovascular health [171]. Running, like other cardio workouts such as cycling and dancing, raises heart rates and increases breathing. In addition to its physical benefits, running has a positive impact on mental health, potentially reducing stress and anxiety [172].

Continuous training is a common method used in running to improve cardiovascular endurance. This type of exercise is characterised by a steady, unchanging intensity throughout its duration [173]. However, prolonged engagement in continuous training can lead to boredom or plateaus [172]. To address these limitations, interval workouts offer an alternative approach.

Interval training can improve motivation and may reduce the risk of injury from prolonged repetitive tasks [172]. Furthermore, Bartlett *et al.* [173] suggests that high-intensity interval running is perceived as more enjoyable than moderate-intensity continuous exercise. As described by Dack [172], the fundamental principle of interval training involves alternating between periods of high-intensity running (maximal effort at a consistent pace over a specified distance) and recovery periods of lower-intensity activity, such as jogging, walking, or slow running. Repeating these intervals throughout the exercise session offers several potential benefits, such as increased calorie expenditure.

Given these characteristics, running was chosen as the focal activity for this research, as it serves as a representative example of cardiovascular workouts with a wide range of exercise intensity. This selection supports the potential generalisability of the findings to other forms of aerobic exercise.

As an exergame is developed in this research, the following section presents the conceptual considerations behind the design of the exergame.

4.2 Exergame Design Consideration

One consideration of game design is GameFlow model by Sweetser *et al.* [96], a framework designed to measure player enjoyment in video games. It consists of a set of criteria derived from the literature on user experience in games and is organised into eight elements, which correspond to Sweetser *et al.* [174] concept of flow, which this GameFlow model aiming to lead to overall game enjoyment.

- **Concentration:** games should provide engaging and meaningful stimuli that quickly capture players' attention and sustain it without causing distractions while they interact with these stimuli. Additionally, games should present a high workload to ensure full engagement, but this workload must remain within the players' perceptual, cognitive, and memory limits.
- **Challenge:** games should align difficulty levels with individual player skills, ensuring that these levels progress at an appropriate pace as players enhance their abilities.
- **Player Skills:** games and their components should be easy for players to pick up and learn at the start. Learning about the game should be engaging, perhaps through tutorials or initial levels designed to feel like part of the gameplay. As players advance their skills to match the game's challenges, the game should introduce progressively higher levels of difficulty to encourage further improvement while rewarding players for their efforts and achievements.
- **Control:** games should allow players the freedom to choose their own actions and strategies, rather than strictly following preset paths defined by developers, to foster a sense of control.
- **Clear goals:** goals should be clearly defined and communicated to players at the appropriate time.
- **Feedback:** games should provide feedback on players' actions, their status or score, and their progression toward achieving the goal.
- **Immersion:** games should provide experiences that allow players to become less aware of their surroundings, lose track of time, and become emotionally and engaged in the gameplay.
- **Social interaction:** games should foster competition or cooperation, encourage interaction among players, and support a gaming community.

Although this model has faced criticism for its application in certain contexts—particularly because it originates from strategy games—applying its criteria to casual, easy-to-play games may not always be suitable. However, the model has been widely adopted in video game research, with many studies adapting it to suit specific scenarios [175], [176].

There is another consideration that is more specific to exergames proposed by Mueller *et al.* [57].

- **The responding body:** this facet highlights the importance of understanding how physical activity in games impacts players' bodies both in the short term (during gameplay) and long term (after gameplay, such as weight loss or muscle gain). For example, physical responses like increased heart rate and sweating can be analysed and used to design gameplay. This relationship can also be leveraged to adjust physical challenge levels based on individual players' exertion responses, such as using heart rate data to dynamically modify the game.
- **The moving body:** this facet highlights the importance of understanding how players move while performing physical activities during gameplay. Examining players' movements can enhance the effectiveness of exercise and minimise physical risks. This involves analysing the positioning of each body part required for specific movements, as well as their spatial orientation during performance. Moreover, the intensity and smoothness of these movements should be considered to prevent excessive or insufficient exertion levels and to promote natural and realistic motion.
- **The sensing body:** this facet highlights the importance of understanding how players' bodies interact with their surroundings within the game system. These surroundings can include physical objects, such as exercise equipment or game devices, as well as the virtual world in the game and the physical environment, like the room where the game is played. Game designers should consider what types of surroundings should be included in the game system—such as running indoors or outdoors—and evaluate the pros, cons, and risks associated with each, in order to foster both an engaging experience and effective exercise.
- **The relating body:** this facet emphasises the importance of designing exergames that allow players to relate to each other, whether as enemies, cooperators, or even an audience. Social interaction in games can enhance performance and increase tolerance to pain during gameplay.

Both game design considerations offer useful information into game design. While each consideration approaches the concept from different perspectives, one common aspect emphasised in both is how to handle game challenges. The next section explores the considerations involved in designing game challenges.

4.3 Challenge Design Consideration

Regarding the work by Brandse *et al.* [75], the challenge design consideration is given:

- Challenges should be designed to follow the core of the game. Challenges that deviate from the core gameplay, such as mini-games unrelated to the main gameplay, can frustrate players, break immersion, and disrupt the flow of the game.
- Technical problems, such as bugs, must not prevent the player from overcoming challenges.
- Overcoming challenges should depend on players' actions, not their luck or outside factors such as the randomisation of the game system.
- The game system itself should provide the necessary information to players to deal with challenges in the game, rather than requiring them to find information outside the game.
- Using AI for challenge balancing may lead to negative experiences, such as feelings of being cheated, unfairness, and frustration. Moreover, it can create unrealistic perceptions, as the game may adjust elements in an unnatural way. For example, Rubber-Banding AI, which aims to make the game more challenging, can negatively impact player experience. In Mario Kart: Double Dash!!, when a player's kart is far ahead, the NPC karts may suddenly speed up to catch the player's kart in an unrealistic manner, leading to frustration. This highlights the importance of carefully designing DDA and considering how it is presented to players.

Although Brandse *et al.* [75] highlighted some negative effects of balancing the challenge-skill on certain aspects of the playing experience, this concept remains widely discussed in many studies as a key factor in promoting positive experiences, such as achieving a flow state and enjoyment. For instance, Macklin *et al.* [81] emphasise the importance of balancing challenge to keep players engaged and avoid frustration or boredom. Similarly, Sweetser *et al.* [96] also highlight the importance of adequately balancing challenge in video games. This involves matching the game's difficulty levels to individual player skills, ensuring that the game neither progresses too quickly nor too slowly. Their GameFlow model emphasises key considerations for challenge design: (1) challenges should align with the players' abilities, (2) different players should encounter difficulty levels suited to their individual skills, (3) as players advance and improve their play skills, the challenge level should increase, and (4) new challenges should be introduced at a suitable pace to maintain engagement without overwhelming or boring the player.

Furthermore, Bostan *et al.* [74] complements Brandse *et al.* [75]'s recommendations with four additional points: challenges should align with the storyline (similar to [75]), DDA should not diminish the sense of achievement (similar to [75]), DDA should be perceived as realistic (similar to [75]), and (5) difficulty curves should align with the three skill acquisition phases (adapted from [177] and [178]).

The three skill acquisition phases are: cognitive (players frequently rely on instructions or examples to understand gameplay), associative (players shift from a slow, deliberate use of

skills to more fluid and error-free proficiency), and autonomous (players reach a point where skills are used effortlessly and quickly without deliberate thought). This means categorising players based on their experience and skill levels into three stages and adjusting the difficulty accordingly.

With these reviews, challenges play an important part in the game, and their design should be carefully considered as it can impact player experience and their attitude towards the game.

These two sections provide a brief review of design considerations for video games and game challenges. While not all considerations can be fully applied in practice due to the unique contexts of different games, they give general guidelines to reflect on during the design process. The next section details the design and development of the exergame used in this research.

4.4 Designing and Developing The Exergame

Regarding the game system, previous studies (e.g. [4], [163], [164], [167], [169]) in exergames have commonly developed exergames in two primary environments: virtual reality (VR) and systems using camera detectors or inertial devices. While VR environments offer immersive experiences, some studies (e.g. [4], [179], [180]) have highlighted potential limitations, such as motion sickness and nausea. Given the focus of this research on running, which involves full-body movement and can induce light-to-vigorous intensity levels, minimising potential harm to participants during experiments was a priority. Therefore, this research utilised camera and inertial sensors as the mediums for participants to interact with the game.

Game Overview

For this research, a custom-designed indoor running exergame, ***"ExerWitch"***, was developed. In this game, players help an avatar, a witch, in breaking free from a vault and escaping a wicked dragon by running persistently. The objective is to reach another castle to seek help with minimum time used.

The game is designed to support different DDA functions, allowing the dragon's speed to adapt based on player data: exercise intensity (heart rates) or performance. No extra exercise equipment is required to play, making it suitable for home use.

Game interactions involve running to move the avatar and escape from the chasing dragon, stretching the arms at junctions to turn left or right, and punching to cast spells that destroy approaching angry log monsters. Further details are provided in the following sections.

The applicable game design considerations proposed by Mueller *et al.* [57] and Sweetser *et al.* [174], as shown in the review, were applied to guide the game's design and development. However, since this research focuses on a single-player experience rather than a multiplayer or Massively Multiplayer Online Role-Playing game, considerations related to social interaction and others were not considered.

To illustrate the design of the game, the elemental tetrad framework by Schell [80] was utilised, categorising the game's design into story, aesthetics, mechanics, and technology shown in the following sections.

4.4.1 Story

The game's story is simple and draws inspiration from endless runner games, such as Temple Run (see Figure 4.3), a popular runner mobile game with over 500 million downloads on Google Play [1]. Players control a character navigating a maze-like environment, avoiding obstacles, collecting coins, and escaping from chasing monkeys. The game features swipe-based controls (left, right, jump, and slide) and procedurally generated paths to keep gameplay unpredictable. The game primarily incorporates physical challenges, requiring players to react quickly to in-game obstacles. Also, it integrates cognitive challenges, prompting players to strategise for survival.

With the popularity of this type of game, its engaging story, and its easy-to-learn gameplay, players of ExerWitch are likely either already familiar with the genre or able to understand it quickly, aligning with the criteria mentioned earlier.

Figure 4.3: Temple Run game by Imangi Studios from Google Play [1]

The gameplay concept of endless runner games was adapted, where players control a self-running avatar being chased by monsters or opponents, serving as a driving force to keep them playing and avoiding capture or loss. However, instead of the game automatically moving the avatar, this was modified for ExerWitch to require players to physically run to control movement, aligning with the exergame concept that emphasises physical exertion. This design enhances engagement by creating a sense of being chased, motivating players to run while also providing physical benefits.

The game's theme is a dark magic world with an engaging storyline. This setting was chosen to evoke a sense of fantasy while also creating tension, as players must escape from the dark world to reach the finish line. Moreover, incorporating a magic theme encourages more physical interaction, as players perform hand movements to cast spells while playing.

[1] Temple Run, Imangi Studios [Online]. Available: click here to the reference source. Accessed: [Feb. 19, 2025].

Players take on the role of a kind witch (Figure 4.4), who peacefully rules her realm until she is betrayed by a wicked and menacing dragon (Figure 4.5). The dragon imprisons her in a castle, strips away her powers, and casts a spell that cloaks the world in darkness. Determined to escape, the witch breaks free from her vault and reaches the castle's front door (Figure 4.6), but to be spotted by the dragon. Now, players must help her gather enough power to evade the pursuing dragon, defend herself against its servants (angry logs) attacking her (Figure 4.7) for more engaging experience, and reach another castle to seek help.

Figure 4.4: Players assume the role of a witch attempting to escape from a dragon.

Figure 4.5: A menacing dragon chases the avatar, roaring louder as it gets closer, and attacks to prevent the avatar from reaching the finish line.

Figure 4.6: Before the game begins, the avatar stands at the castle's gate, ready to flee from the dragon.

Figure 4.7: As an angry log approaches, the player must cast a spell to summon a giant pumpkin and destroy the log.

4.4.2 Aesthetics

Figure 4.8: A figure shows the overall game atmosphere

Figure 4.8 illustrates the game atmosphere, which is intentionally designed to align with the game story, featuring a dim setting to help players stay focused on the gameplay. A layer of fog envelops the forest, limiting the player's visibility of obstacles or running tracks ahead. To avoid a sense of isolation, various animals (e.g. flying creatures) are introduced. As the player runs, they can observe the environment and see animals performing actions such as jumping, walking, or flying. To make the environment feel dynamic rather than static, different types of trees and flowers are randomly regenerated at specific intervals.

The game design emphasises providing feedback through both visual and auditory elements, ensuring players are informed about the outcomes of their actions. Figure 4.9 depicts the game interface.

Figure 4.9: The game scene interface

To reflect players' physical effort, the game displays:

- Heart rate (A1) in beats per minute (BPM), and the exercise intensity zone (A2) are determined based on the age-related maximal heart rate formula.
- The game also displays a progress bar from the avatar's current position to the finish line in A3.
- The game displays the running speed and time used in Box A4.

The game also uses visual and sound cues to enhance player awareness:

- Warning notifications alert players to approaching angry logs (Figure 4.10) or upcoming junctions (Figure 4.11), prompting timely responses.
- When the avatar is hit by the dragon, the screen turns red, and animated heart objects rise (Figure 4.12), emphasising the impact of the event.
- If the player stops running during the game, an alert sound and a message will prompt them to keep running.

Figure 4.10: When an angry log approaches, the game displays a punch icon and plays the monster's sound to alert the player to start punching and cast a spell to destroy it. If the player has already performed the punch, the icon changes from grey to orange.

Figure 4.11: When a junction is ahead, the game displays a stretching arm icon with an arrow indicating the left or right hand to use. Once the player performs the action, the icon changes from grey to orange.

Figure 4.12: When the avatar is attacked by the dragon, the screen flashes red, a hit sound plays, and a heart icon appears above the avatar to notify the player of the damage taken.

To create a more immersive experience, the game integrates audio feedback:

- Background music, aligned with the game's theme, motivates players to keep running.
- The sound of the avatar's footsteps reinforces the connection between the players' physical actions and the avatar's movements.
- As the dragon approaches, its roaring sound effects intensify, signalling players to run faster.
- Distinct sound effects play for various events, such as angry logs approaching, casting spells, and receiving notifications, ensuring players stay informed and engaged.

At the end of the game session (or after 10 minutes), a relaxation scene appears, featuring a peaceful atmosphere with rabbits jumping around a forest. Text prompts encourage players to take a slow walk as a cool-down before proceeding to the next experimental phase, as shown in Figure 4.13.

Figure 4.13: The game shows a relaxation scene with a peaceful atmosphere, encouraging players to take a slow walk to move their avatar through the forest as a cool-down session.

4.4.3 Mechanics

In this game, players run in place to move their avatar toward the destination point in the shortest time possible. The avatar's speed corresponds to the players' running speed—faster running results in quicker movement. The main challenge is from a menacing dragon that chases and attempts to catch the avatar. When the dragon gets close enough (the red zone shown in Figure 4.14), it attacks, decreasing the avatar's energy level and stunning it, which increases the time taken to reach the destination. Players must exert physical effort to outrun the dragon. This design ensures an engaging experience that promotes physical activity while playing.

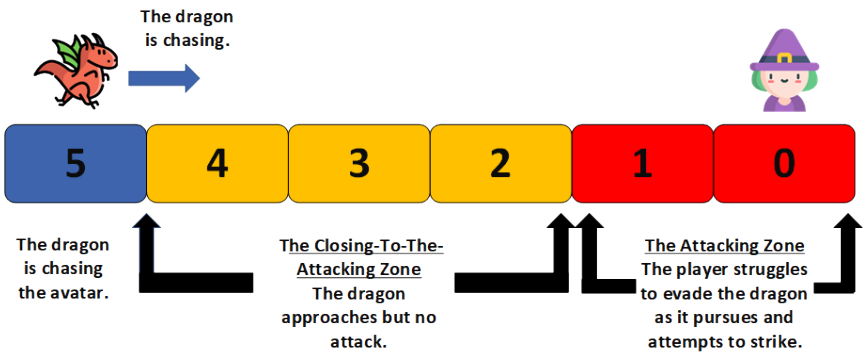

Figure 4.14: The zones in ExerWitch illustrate how the dragon interacts with the avatar upon entering each zone [1].

Figure 4.14 shows how the dragon interacts with the avatar upon entering each zone. If the absolute distance difference between the dragon and the avatar is five or more, the dragon continues chasing the avatar (blue zone). When the distance difference is between two and four, the dragon is still chasing but is marked as approaching the attacking zone (yellow zone). Finally, if the avatar fails to increase the distance and the dragon reaches the attacking zone (red zone), it begins attacking.

The distance difference is not only used to determine when the dragon attacks but is also used in the DDA functions, explained in each experimental chapter.

To keep players engaged, the game introduces additional tasks. Junctions appear, requiring players to stretch their arms left or right to turn the avatar. If players fail to do this in time, the avatar hits a wall and becomes stunned, giving the dragon a chance to catch up and attack. Moreover, angry logs appear on the running path, obstructing the avatar. Players must perform a punch to cast a spell and summon a giant pumpkin to smash the logs. Failure to do so results in the avatar being hit and stunned for a while. The justification for incorporating stretching out the arms and punching is that they do not interfere with running and players can perform them simultaneously.

[1]The images of the dragon and the witch are from FREEPIK of the dragon and FREEPIK of the witch.

The game concludes when players either reach the finish line or the experimental playtime session ends. Table 4.2 shows an overview of the game mechanics, while Table 4.3 shows player interactions with the game.

Aspect	Description
Game goal	Help the avatar reach the finish line with minimum time used by physically running.
Main game challenge	The dragon chases the avatar, aiming to attack and prevent it from reaching the goal.
Setback and its consequence	Being attacked by the dragon results in the avatar being stunned, an increase in game time, and a decrease in energy level.
Failure	Inability to reach the finish line.

Table 4.2: the overview of game mechanics

Game Interaction	Description
Running in place throughout the game session (Figure 4.15)	To complete the game, players are required to run to move their avatars. This activity can promote cardiovascular health and calorie burning during the game.
Stretching arms out once to turn the avatar's side (Figure 4.16)	When a player approaches the junction ahead, a notification is triggered to warn them to start performing stretching arms out. This action potentially provides physical benefits by encouraging the player to stretch their body, promoting flexibility.
Punching twice to cast a spell that destroys an angry log (Figure 4.17)	When an angry log monster approaches, the player must perform a high punch to fend it off. This action also potentially helps promote flexibility.

Table 4.3: the overview of player interactions with the game

Figure 4.15: The player runs to move the avatar and escape from the dragon.

Figure 4.16: A right-turn junction is ahead, so the player stretches out their right arm to turn the avatar to the right.

Figure 4.17: An angry log is approaching, so the player punches to cast a spell and destroy it.

4.4.3.1 Designing Game Challenges and Difficulty Levels

Existing studies, as shown in Table 4.1, indicate that exergames commonly incorporate physical challenges as their primary game challenge. One possible reason is that physical challenges require players to use their physical limitations to overcome obstacles, potentially leading to increased physical exertion.

This game incorporates the dragon's chase as its main challenge, a common challenge in commercial video games (e.g. Temple Run and Subway Surfers[1]) where players control an avatar to run. Integrating this challenge into an exergame has the potential to enhance exertion and energy expenditure, as players respond to the dragon's approach by adjusting their running speed to evade it.

This challenge was considered from the design principles outlined in Section 4.3. For example, this challenge aligns with the game's core mechanics and storyline as a running exergame. Also, it ensures that overcoming obstacles depends on the player's physical effort rather than the random of the game.

Figure 4.18: The chasing dragon's speed ranges from 6 (lowest speed) to 20 (highest speed).

As shown in Figure 4.18, the dragon's speed (referred to as a difficulty parameter) ranges from 6 (the lowest speed, providing low-intensity gameplay) to 20 (the highest speed, creating high-intensity gameplay). These values were determined during game development and fine-tuned in a pilot study. The upcoming DDA functions will adjust this difficulty parameter to regulate game difficulty.

The game's difficulty curve, illustrated in Figure 4.19, starts with the dragon at its slowest speed, giving players time to acclimate and warm up. To prevent monotony and ensure players experience all difficulty levels as intended by the research's methodology, the game gradually increases the dragon's speed, reaching its maximum within 10 minutes.

[1]Kiloo and SYBO Games, Subway Surfers. Google Play Store. Available: click here to the reference source. [Accessed: Feb. 23, 2025]

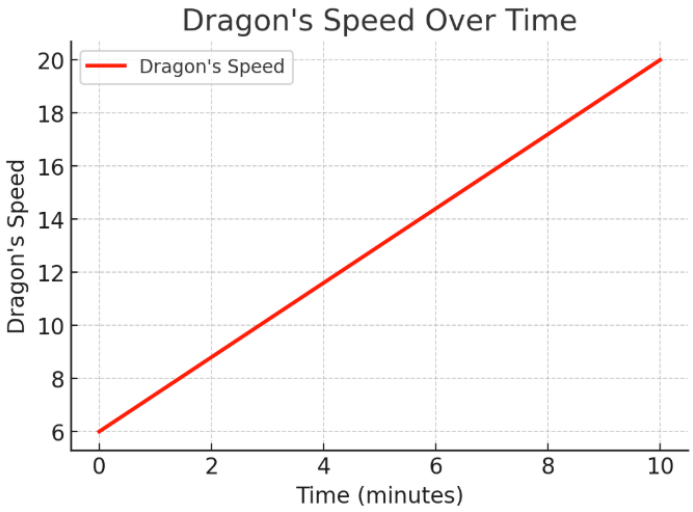

Figure 4.19: The game's difficulty curve shows a steadily increasing line, indicating that the dragon's speed increases over time.

4.4.4 Technology

To play this game, the following devices are required: one Android smartphone as the game device, another Android smartphone as a posture detector (for detecting actions like turning left, turning right, or punching), a heart rate sensor, and an accelerometer. These devices communicate with each other via Bluetooth as shown in Figure 4.20.

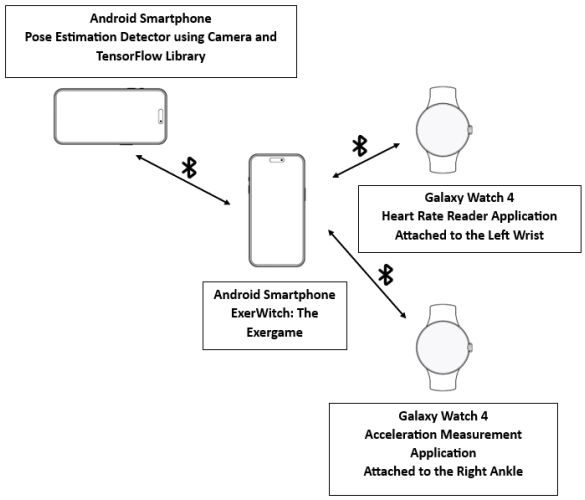

Figure 4.20: The required devices for playing this game and their communication via Bluetooth [1].

[1]The images of smartphones, smartwatches, and Bluetooth symbols are from FREEPIK for smartphones, FREEPIK for smartwatches, and FREEPIK for Bluetooth.

Android smartphones were chosen over other operating systems (e.g. Windows) or devices (e.g. personal computers) because they come equipped with essential sensors like Bluetooth (used for both the game application and posture detection) and cameras (used for posture detection). They also support screen casting to larger displays, such as TVs, similar to personal computers using a USB cable and the Vysor application [1]. Moreover, Android offers low-level libraries that simplify Bluetooth communication and camera access, making it suitable for this application.

The accelerometer measures acceleration data along the x, y, and z axes in meters per second squared, which is used to quantify the running magnitude and control the avatar's speed. The Galaxy Watch 4 was selected over other devices (e.g. programmable boards) because it includes both an accelerometer and Bluetooth functionality, and it operates on Android. This Android-based system provides libraries for easy access to the device's sensors and simplifies application development. Moreover, developing an application for this smartwatch is more time-efficient, helping to save time during developments.

The heart rate sensor is used to provide players with feedback on their physical effort displayed on the screen, as well as for data analysis. The Galaxy Watch 4, which was previously used in a study [181], was selected over other devices, such as the Polar sensor with a chest strap [24], as wearing a watch is less intrusive than attaching a sensor directly to the chest. Moreover, the chest strap presents challenges for investigators in affixing the device to players and raises concerns regarding personal privacy. Moreover, using this watch aligns with the accelerometer measurement application and the game, reducing development time.

4.4.5 Game Development

The ExerWitch game was developed using Unity Engine (Windows) version 2021.3.8f1, incorporating customised lower-level Android activity classes to deal with Bluetooth access. The acceleration measurement application (WearOS, compileSdk 32), the heart rate reader application (WearOS, compileSdk 32), and the pose estimation application (compileSdk 34) were implemented using Java in Android Studio (Windows) version Flamingo 2022.2.1 Patch 2. The pose estimation application utilises TensorFlow to detect player joints from camera images, enabling the identification of hand-arm positions during stretching or punching.

[1] Vysor, "Vysor - Download," Available: click here to the reference source. [Accessed: Mar. 18, 2025].

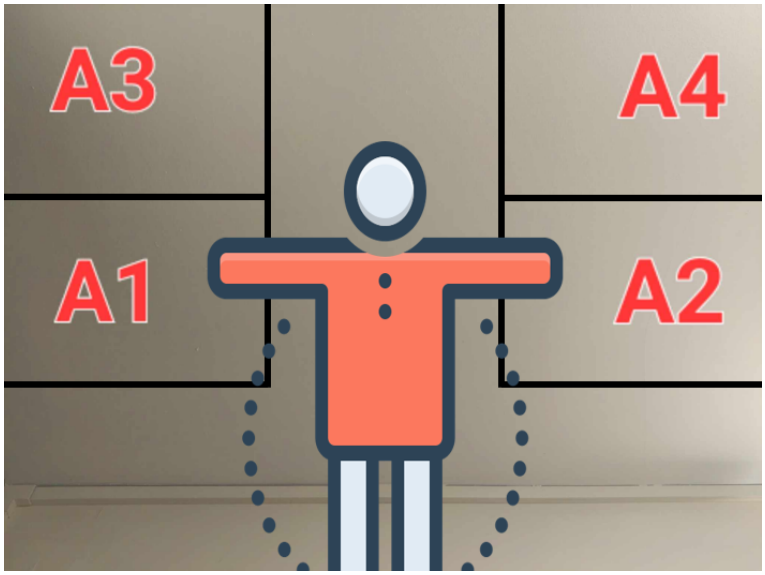

Figure 4.21: The screen of the pose estimation detector indicates which areas will be interpreted as stretching or punching when the hand or arm covers those regions [1].

As illustrated in Figure 4.21, if a player's hand or arm is in position A1 or A2, it indicates left or right stretching, allowing the avatar to turn accordingly. Similarly, if the hand is in positions A3 or A4, it indicates left or right punching, enabling the casting of spells to defeat the angry log monsters.

The source code and the external game assets used in this game are available in Appendix M.

4.4.6 Pilot Study

The objective of this pilot study is to playtest the developed exergame in order to identify application defects and gather player feedback on their attitudes towards the game. Moreover, it aims to evaluate whether the proposed experimental design requires any adjustments to its design for the main experimental studies. The study was reviewed and approved by the Physical Sciences Ethics Committee, Department of Computer Science, University of York, UK as shown in Appendix A.

This study adopted playtesting, observation, and informal interviews to identify potential issues in the game application and to gather insights into players' attitudes and experiences with the game and the experimental design. Each session was conducted individually with a single participant. After each participant completed their session, potential issues related to the research were resolved before the next participant's test.

Five voluntary participants (mean age: 30.20 $\pm$ 4.97 years; 3 male, 2 female) were recruited without compensation. All participants were students from the department, invited through departmental group chat channels and word of mouth.

[1] The human posture image is from FREEPIK.

The study revealed that all participants understood the game concept and were able to complete the game, indicating satisfactory playability. Furthermore, they completed the game without reporting severe discomfort or muscle pain during the play session, suggesting that a 10-minute playtime duration is feasible for future studies assessing PX and physical effort, along with sufficient relaxation between sessions. Also, game parameters—such as the speed of avatar movement corresponding to players' running speed, the speed of the dragon, and the content generation rate—were fine-tuned throughout this study. All potential application issues were resolved, and no perceivable delays were noted in device communication via Bluetooth, indicating that the game is ready for subsequent experiments.

4.4.7 Development Challenge and Future Improvement

This game development phase highlights challenges that may lead to future improvements. There is redundancy in using two smartphones—one for the main game application and another for the pose detection application. The main game application smartphone also has a camera that could be integrated with the pose detector application (using TensorFlow libraries). However, since the ExerWitch game is built on the Unity engine rather than being a native Android application, this leads to complications. The Unity engine, while capable of supporting Android, presents challenges in accessing the mobile camera at a low level, running the camera alongside the game, and utilising TensorFlow within Unity. This results in errors during the build process.

Although this issue requires further exploration, it was not addressed in this stage of research due to time constraints and because it was not deemed a major issue, as the game remains playable. Nonetheless, it should be reconsidered in the future, especially if the game is to be made available for real players. Addressing this issue could reduce costs and streamline the installation and usage processes in practical applications.

Besides, if the game is to be used in the real world, the cost of using the Galaxy Watch 4 may be excessive, especially considering that only a few features of the watch are necessary for gameplay: heart rate and acceleration data measurement. The choice of this watch in this research was due to its reliability in measuring heart rate, which is crucial for the study, as well as its less intrusiveness and ease of application development for controlling the device. However, in the context of simply playing the game, the need for such advanced features may not be as significant. Future improvements could involve using lower-cost devices, such as microcontroller boards, which would be more acceptable for practical use.

4.5 Chapter Summary

This chapter presents the justification behind the selection of designing and developing the exergame used for the following experiments. Initially, commercial exergames were explored, however, limitations in licensing and customisation made this option unfeasible. Available video games or exergames on an online source code repository were also examined, but there was a lack of suitable games. Consequently, this research aimed to develop a custom exergame. Before the design and development phases, existing exergames, as well as design concepts for exergames and challenges, were reviewed. The ExerWitch game was implemented as an indoor running-in-place exergame, where players run their avatars to reach the finish line while being motivated to keep running by a dragon chasing them throughout the play session. This game is integrated with DDA functions in each main experiment to address the research questions.

The literature review shows that DDA in exergames commonly relies on exercise intensity-based data and performance-based data. The next chapter begins by examining the impact of EI-based DDA in the exergame on PX and physical effort.

Chapter 5

Experiment 1: Effects of Exercise Intensity-Based DDA on Player Experience and Physical Effort in Exergames

5.1 Introduction

The previous chapter introduced the developed running exergame, designed to induce light-to-vigorous exercise intensity based on running activity. This exergame serves as a tool for integrating DDA functions to examine their impact on PX and physical effort. Each DDA function addresses physical challenges—where a dragon chases the player's avatar, requiring the player to adjust their running speed to evade attacks and avoid punishment—by dynamically adjusting a game difficulty parameter (the dragon's speed) to modify exertion levels and game experience.

Based on the dual-flow model by Sinclair *et al.* [19], which posits that exergames should balance attractiveness (challenge-skill balance) and effectiveness (exercise intensity-fitness balance), this experiment examines how EI-based DDA impacts both dimensions.

A subsequent study by Sinclair *et al.* [29] explored EI-based DDA using average heart rate (AHR) to maintain players' exertion levels within a target exercise intensity zone. However, this study did not examine how DDA affects PX, leaving a gap in understanding its impact. Besides, although a few studies [18], [24], [26] have investigated the effects of EI-based DDA on PX, limitations remain.

Also, the impact of DDA on physical effort compared to no DDA is rarely explored, and findings [18], [26] are mixed, raising the question of how EI-based DDA impacts players' physical effort.

These gaps motivate this experiment to investigate the effects of EI-based DDA on PX and physical effort. The following section presents the hypotheses for this experiment.

5.2 Hypotheses

Based on the review of related works, the following hypotheses were formulated to address the research gaps and questions:

H_1 : Players' average heart rates differ when playing exergames with and without EI-based DDA.

H_2 : Players' perceived exertion differs when playing exergames with and without EI-based DDA.

Prior studies (e.g. [31], [32], [34]) indicate that EI-based DDA potentially regulates exertion levels of players (by dynamically adjusting game difficulty based on AHR) because players adjust their physical effort in response to changes in the game difficulty. In contrast, no-DDA conditions lack this feedback loop, potentially resulting in a different game experience where players' physical effort is not controlled by DDA. So, AHR may differ between these two conditions.

However, the limited number of studies comparing EI-based DDA to no-DDA conditions, along with inconsistent findings, leaves this effect unclear. Ketcheson *et al.* [18] reported higher AHR in the EI-based DDA condition, whereas Wünsche *et al.* [26] found no significant differences. Given this uncertainty, a non-directional hypothesis is proposed, expecting differences in AHR between EI-based DDA and no-DDA conditions (H_1).

Perceived exertion reflects an individual's subjective perception of physical effort during activity and is closely linked to exertion levels presented in the game. As exertion levels change, players tend to adjust their physical effort in response, potentially leading to differences in perceived exertion influenced by changes in exertion levels and AHR.

Ketcheson *et al.* [18] found that perceived exertion increased alongside AHR in the EI-based DDA condition. However, due to the limited number of studies examining the effects of EI-based DDA on perceived exertion and the mixed findings regarding AHR, perceived exertion is expected to differ between the EI-based DDA and no-DDA conditions (H_2). Given the uncertainty on the impact of EI-based DDA on AHR, the direction of this difference remains unclear.

H_3 : Players' intrinsic motivation: enjoyment/ interest ($H_{3.A}$), perceived competence ($H_{3.B}$), effort/ importance ($H_{3.C}$), and pressure/ tension ($H_{3.D}$) differs when playing exergames with and without EI-based DDA.

H_4 : Players' flow experience: flow ($H_{4.A}$) and its challenge-skill balance ($H_{4.B}$) differs when playing exergames with and without EI-based DDA.

Building on the dual-flow model [19] and flow theory [13], individuals are more likely to enter a flow state when their skill or physical fitness aligns with the game's difficulty level or physical demands. Previous studies on EI-based DDA [18], [26], [31], [32], [34] have adopted these principles by adjusting exertion levels to keep players within targeted exercise intensity

zones. These zones are determined based on individual fitness levels, calculated using age-related maximal heart rate formulas, ensuring that players exercise within a suitable physical range for safe and effective physical activity.

By adjusting physical demands to align with individual fitness levels, differences in challenge-skill balance and flow are expected between EI-based DDA and no-DDA conditions.

Regarding the SDT [16], when players' needs are satisfied, it potentially leads to intrinsic motivation. In this experiment, perceived competence plays an important role, as EI-based DDA dynamically adjusts physical demands based on heart rate. By maintaining a balance where physical demand is neither too low nor excessive, EI-based DDA could induce an experience in which players feel capable of managing in-game physical challenges. As a result, perceived competence is expected to differ between EI-based DDA and no-DDA conditions.

Moreover, Jackson *et al.* [14], Ryan *et al.* [16], Mekler *et al.* [100], and Qin [101] argues that challenge-skill balance and competence can lead to enjoyment, as players can fully engage in an activity when task demands align with their abilities and increase sense of achievment. Additionally, research [101], [182] argues that individuals tend to seek new challenges when they successfully complete tasks, implying that dynamically adjusted physical demands may encourage greater motivational effort. Therefore, differences in interest/enjoyment, pressure/tension, and motivational effort are expected between EI-based DDA and no-DDA conditions.

Martin-Niedecken *et al.* [24] reported that players' interest/ enjoyment and flow improved when DDA was applied compared to a no-DDA condition. However, this study had a limitation as the DDA was not fully automated. Investigators manually adjusted difficulty based on player performance and heart rate data. In contrast, Ketcheson *et al.* [18] and Wünsche *et al.* [26] found no significant differences in intrinsic motivation: interest/ enjoyment, pressure/ tension, and effort/ importance between DDA and no-DDA conditions. A limitation of Wünsche *et al.* [26] was its small sample size.

Due to the limited number of studies on the impact of EI-based DDA on flow and intrinsic motivation, along with limitations in related works, the direction of this effect remains unclear. This research expects differences in intrinsic motivation and flow state between EI-based DDA and no-DDA conditions (H_3 and H_4).

5.3 No DDA and DDA Experimental Conditions

This section details each experimental conditions in Experiment 1: no DDA, continuous EI-based DDA, and interval EI-based DDA.

Based on the literature review (e.g. [172]), two types of exercise patterns commonly found in exergames and running-based physical activities are continuous and interval. In the continuous pattern, previous studies (e.g. [18], [26]) have aimed to maintain players' exertion levels within a specific target exercise intensity zone based on maximal heart rate. In contrast, the interval pattern (e.g. high-intensity interval training, or HIIT in an exergame by Martin-Niedecken *et al.* [55]) also seeks to regulate players' heart rates but involves alternating between high-intensity sessions and low-intensity recovery periods throughout the physical activity session.

To estimate maximal heart rate and calculate exercise intensity zones used in the EI-based DDA functions, this experiment follows a widely used approach in existing research, adopting the age-related formula: $208 - 0.7 \times \text{age}$ [30]. The exercise intensity zones, as detailed in Table 2.1, are classified as percentages of maximal heart rate.

A range of percentages of a maximum heart rate	Category
90% – 100%	Maximum
80% – 90%	Hard (Anaerobic Zone)
70% – 80%	Moderate (Aerobic Zone)
60% – 70%	Light (Fat-Burning Zone)
50% – 60%	Very light (Resting Zone)

Table 2.1: A restated table showing each exercise intensity zone based on maximum heart rate.

These intensity zones are used in each DDA function to maintain players' heart rates within the specified ranges. Figure 5.1 illustrates the general concept of a feedback loop (adapted from Lopes *et al.* [183]), demonstrating how EI-based DDA functions influence player behaviour and physiological response (AHR) in the ExerWitch game.

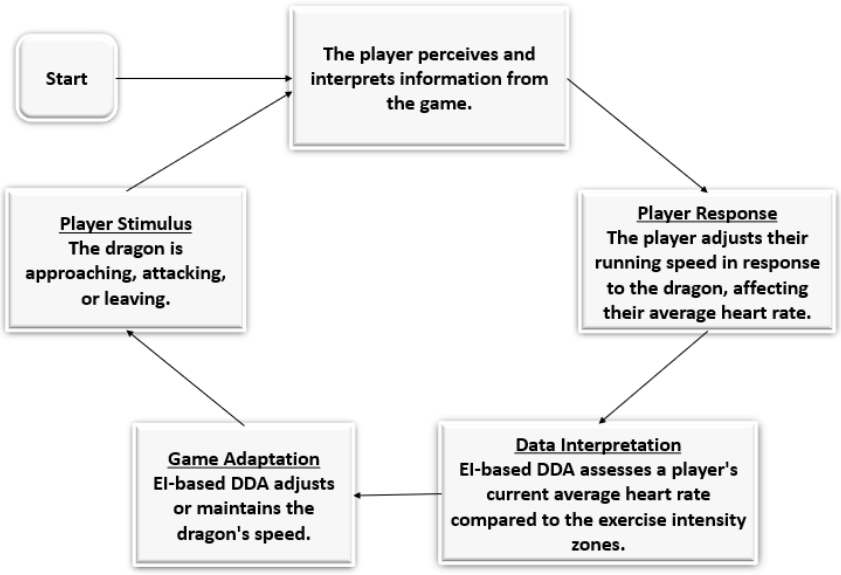

Figure 5.1: A feedback loop showing how exercise intensity-based DDA functions impact player behaviour and physiological response in the ExerWitch game.

EI-based DDA functions aim to make players' AHR reach the target exercise intensity zones by assessing their current AHR, then adjusting the dragon's speed and using its approach to stimulate the player, encouraging them to adjust their physical effort, leading to changes in AHR.

The following section begins by outlining the control condition in which no DDA is applied. Subsequent sections then detail each exercise intensity-based DDA function.

5.3.1 No DDA (nDDA)

In this nDDA condition, the dragon's speed gradually increases over time until the session ends. The increase follows a linear progression as shown in Figure 4.19, with the speed incrementing by 1.5 points (given the speed range of 6 to 20) every minute until the game session ends at 10 minutes. This progression occurs without considering player data or applying any DDA functions.

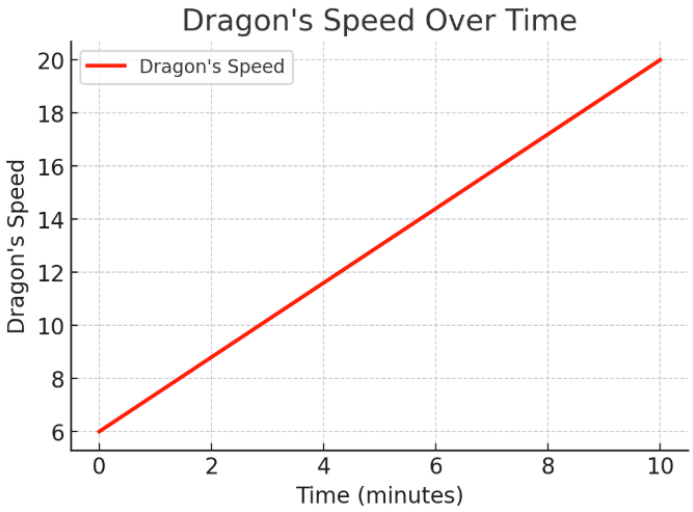

Figure 4.19: A restated figure showing the game's difficulty curve shows a steadily increasing line, indicating that the dragon's speed increases over time.

The justification behind increasing difficulty over time instead of selecting a fixed difficulty level is that individual players vary in skill and fitness levels [19]. Setting the same difficulty level for all players (e.g. medium) may not provide a balanced experience—for example, novices may fail, while experts may disengage due to boredom. Also, allowing players to select their preferred difficulty level does not align with the objectives of this research, as this study does not focus on player preference. Therefore, this approach ensures that all players experience the same sequence of challenges and all difficulty levels.

This nDDA condition was set to begin at the lowest difficulty, aligning with Finkelstein *et al.* [166]. The rationale for starting the nDDA condition at the lowest difficulty is to allow players to gradually adapt and prepare themselves, serving as a warm-up. This approach follows a fundamental principle of exercise, preventing players from suddenly being forced to run at medium or high intensity right from the start of the game.

5.3.2 Continuous EI-based DDA (DDA1)

Consistent with related studies [18], [24], [26], [29], DDA1 adjusts the difficulty parameter based on player data: average heart rate, which reflects players' exertion levels during running. As running is a form of aerobic exercise linked to the cardiovascular system, heart rate serves as an indicator of physical effort.

Unlike nDDA, which does not use player data for adjustment, DDA1 dynamically modifies difficulty to keep players' heart rates within the aerobic zone (see Table 2.1). This zone is considered beneficial for health and helps players sustain continuous running without excessive exertion.

The overall concept of DDA1 (similar to the related works) is as follows: in each checking round, if a player's heart rate (BPM) exceeds the upper bound of the predefined aerobic zone by more than 5 BPM [1] (to prevent excessive sensitivity or measurement errors of the watch), the dragon's speed is set to the lowest level, and it moves backward, allowing an easier phase for the player to lower their heart rate. If the average heart rate falls below the aerobic zone by more than 5 BPM, the dragon's speed increases by 1 point, encouraging players to run faster to escape and causing more energy expenditure. If the heart rate remains within the target zone, the dragon's speed stays the same. The following paragraph details the mechanics of DDA1 in greater depth.

[1] J. Fedewa, "How Accurate Is the Galaxy Watch's Heart Rate Monitor?," How-To Geek, Oct. 3, 2023. [Online]. Available: click here to the reference source. [Accessed: Feb. 27, 2025].

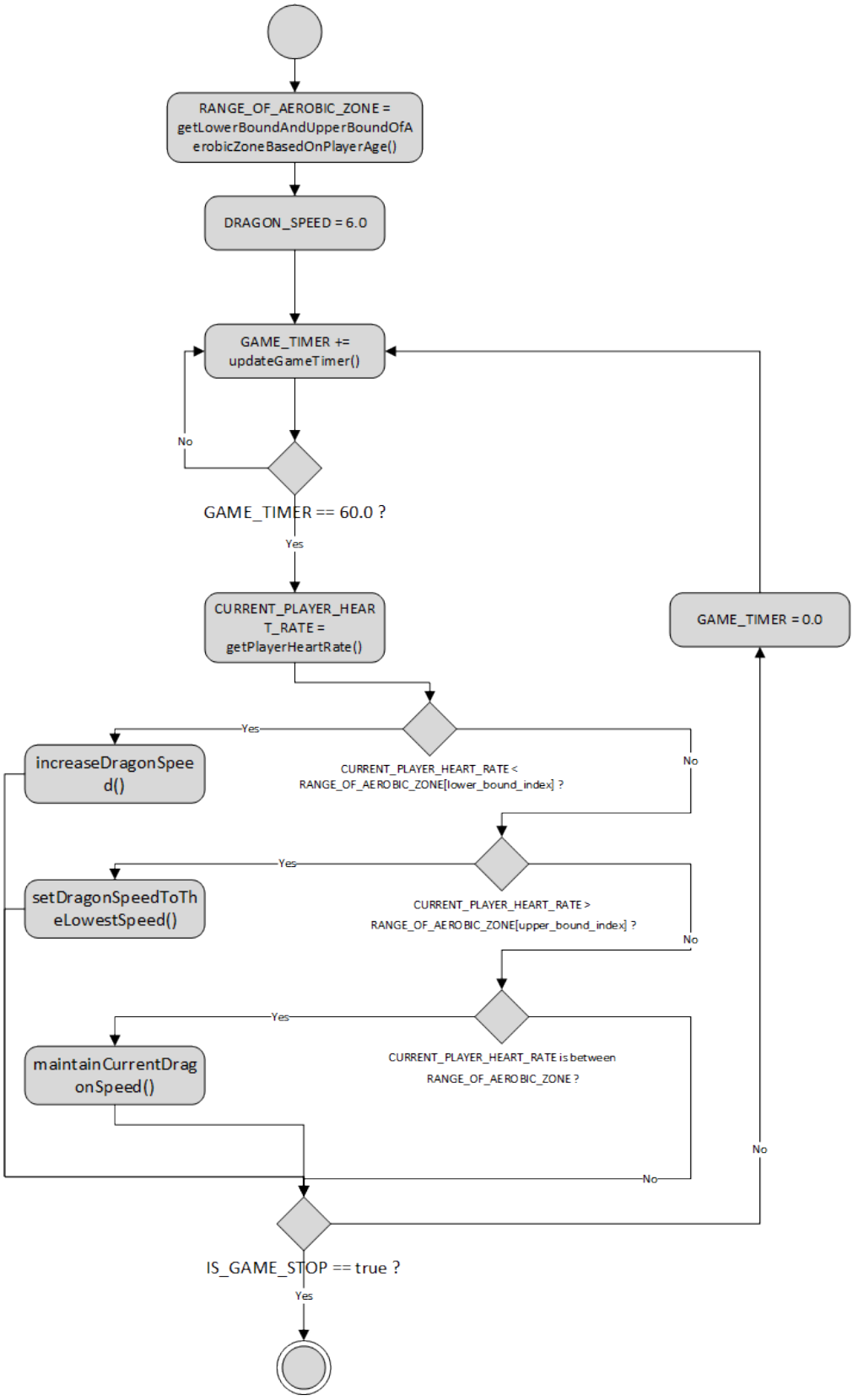

Figure 5.2: DDA1's flow chart showing how continuous exercise intensity-based DDA functions.

Figure 5.2 illustrates how DDA1 functions. Initially, similar to nDDA, the dragon's speed starts at the lowest level, allowing players to adjust themselves to the game. A game timer (in seconds) then increments, and every time it reaches 60 seconds—an interval aligned with similar DDA approaches in previous studies (e.g. Goršič *et al.* [38]:1 minute and Martin-Niedecken *et al.* [23]: 20 seconds) and fine-tuned during development to suit a 10-minute session without being overly sensitive or too delayed for difficulty adjustment—the player's average heart rate is retrieved and assessed based on the following conditions:

Increase dragon speed: If the heart rate falls below the lower bound of the aerobic zone, indicating that the game might be too easy, the dragon's speed increases by 1 point (with a maximum value of 20, as detailed in Chapter 4). This adjustment encourages players to run faster, increasing their exertion level.

Lower dragon speed and withdraw the dragon: Else if the heart rate exceeds the upper bound of the aerobic zone, suggesting that the game might be too demanding, the dragon's speed resets to its initial value (6, the slowest speed) and moves backward. This adjustment allows players to recover by providing an easier phase without the dragon chasing them, helping to lower their heart rates.

Maintain dragon speed: Else if the heart rate remains within the aerobic zone, indicating that the exertion level is at the intended target, the current dragon speed remains unchanged.

After evaluating these conditions, the game timer resets and increments again for the next evaluation cycle, continuing this process throughout the gameplay session.

5.3.3 Interval EI-based DDA (DDA2)

Adopting a similar concept from previous studies [34], [55], DDA2 applies an interval exercise pattern. Like DDA1, DDA2 uses players' heart rates (BPM) during gameplay to regulate exertion levels within the exercise intensity zones. However, unlike DDA1, which maintains exertion within a single exercise intensity zone, DDA2 alternates between easy (lower intensity) and hard (higher intensity) phases, continuously swapping between these phases until the game session ends.

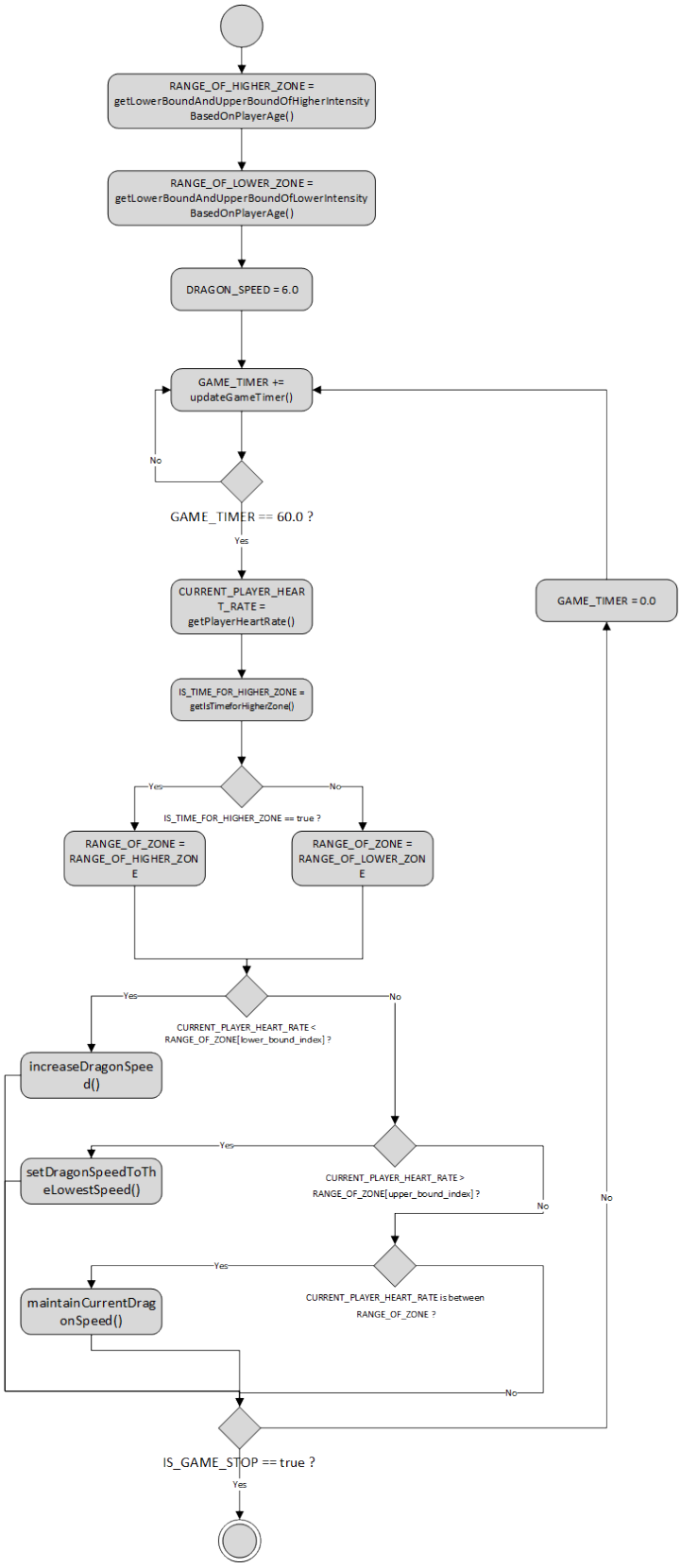

Figure 5.3: DDA2's flow chart showing how interval exercise intensity-based DDA functions.

Figure 5.3 illustrates how DDA2 works. The game begins with the dragon at the lowest speed, similar to DDA1. However, there are two exercise intensity zones: low and high. The low intensity zone spans from light to the fat-burning zone, while the high intensity zone covers aerobic exercise and above.

The game counter updates every 60 seconds, at which point the player's current heart rate (BPM) is retrieved. Based on this, the decision on which exercise intensity zone to use is made. If the current zone has been in the high-intensity range for 120 seconds (2 minutes), it switches to the low-intensity zone. Conversely, if the zone remains in the low-intensity range for 60 seconds (1 minute), it switches to the high-intensity zone. This timing, adapted from the related works and fine-tuned during the development phase with a player sample, is designed to align with a 10-minute playtime session, providing both easy and hard gameplay experiences.

At the start of the game, the high-intensity zone is selected to increase the player's heart rate. After this, the same concept for difficulty adjustment applies as in DDA1, with decisions on whether to **"increase dragon speed", "lower dragon speed and withdraw the dragon", or "maintain dragon speed".** However, the criteria for adjusting the dragon's speed are now based on the current exercise intensity zone. This process continues in a loop until the game session ends.

5.4 Experimental Method

5.4.1 Experimental Design and Procedure

This experiment used a within-subject design with counterbalancing to compare PX and physical effort under three conditions: (1) continuous EI-based DDA, (2) interval EI-based DDA, and (3) no DDA. A brief overview of each experimental condition is presented in Table 5.1.

As described in Chapter 3, before starting the play sessions, participants were familiarised with the game, performed warm-up exercises, and relaxed. In each session, their resting heart rate was measured, after which they played the exergame under different experimental conditions for 10 minutes (for each condition), while their heart rate was continuously recorded. After each condition, participants relaxed to return their heart rate to resting levels and completed the PX questionnaires. Finally, the study concluded with a debriefing.

Ethical approval for this experiment was granted by the Physical Sciences Ethics Committee, Department of Computer Science, University of York, UK (see Appendix A). Overall, the experiment lasted approximately 2 hours.

Experimental Conditions in Experiment 1	Description
Continuous Exercise Intensity-based DDA (intervention 1, DDA1)	Participants engaged in the exergame with DDA1, which adjusted the speed of the chasing dragon to maintain the player's heart rate within the aerobic zone during playtime.
Interval Exercise Intensity-based DDA (intervention 2, DDA2)	Participants engaged in the exergame, where DDA2 dynamically adjusted the speed of the chasing dragon. This adjustment aimed to maintain the player's heart rate alternating between the low exercise intensity zone and the high exercise intensity zone.
No DDA (control condition, nDDA)	Participants engaged in the exergame without DDA functions, with the speed of the chasing dragon gradually increasing over time (no player data used for adjustment).

Table 5.1: Experimental conditions in Experiment 1.

5.4.2 Variables

Based on the related works, the variables were defined for this experiment to investigate the impact of EI-based DDA on PX and physical effort to address the research questions.

- **Independent Variables:**
  - No DDA (control group, nDDA)
  - Continuous EI-based DDA (intervention 1, DDA1)
  - Interval EI-based DDA (intervention 2, DDA2)
- **Dependent Variables:**
  - IMI: Interest/ Enjoyment
  - IMI: Perceived competence
  - IMI: Effort/ Importance
  - IMI: Pressure/ Tension
  - FSS: Flow
  - FSS: Challenge-skill balance
  - BREP: Perceived exertion
  - Physical effort measured by the average heart rate during playtime.

- **Control Variable:**
  - The running exergame

5.4.3 Participants

Participants were incentivised with an £20 Amazon voucher upon completing the experiment.

A total of 26 participants (10 male, 14 female, and 2 identifying as other) completed the experiment across all three conditions. The participants had an average age of 26.19 years (SD = 5.28). Regarding weekly exercise habits, the majority reported exercising for 3–5 hours per week. In terms of exertion levels during exercise, most participants described their intensity as moderate. The demographic distributions are presented in Table 5.2.

5.4.4 Measures

Physiological metrics and self-reported experiences were collected to provide a comprehensive understanding of player interactions with the exergame across different conditions. The following tools were used to measure the dependent variables for testing the hypotheses:

During gameplay, participants' heart rates were recorded in BPM. Heart rate readings below 60 BPM were excluded, based on the assumption that participants engaged in physical activity should have heart rates above the lower bound of a healthy adult's resting heart rate [184]. The average of the remaining heart rate readings was calculated for each participant and used in the subsequent analysis.

Individual perceived exertion in all experimental conditions was evaluated using the Borg's rating of perceived exertion (BRPE) scale [106], [185].

Participants' intrinsic motivation in all experimental conditions was evaluated using the Intrinsic Motivation Inventory (IMI) [146]. The following sub-scales were considered most relevant to this experiment: enjoyment/ interest, perceived competence, effort/ importance, and pressure/ tension.

The Flow State Scale (FSS) [154] assessed participants' flow state, with a particular focus on the challenge-skill balance sub-scale, which evaluates the balance between the game's challenge and player skill.

5.4.5 Analyses

To test the hypotheses, the collected data were analysed using IBM SPSS 28.0.1.1. Data were pre-processed to test for normality and identify potential outliers. To explore the differences in player experience across three different conditions, a Friedman test was used, followed by post-hoc pairwise comparisons with Wilcoxon signed-rank tests. Kendall's W quantified the magnitude of significant effects. Since the heart rate data were assumed to be normally distributed, a repeated-measures ANOVA (F) was used to analyse the difference in average

Participant Demographics in Experiment 1	
N	26
Age	M ± SD = 26.19 ± 5.28
Gender	**N**
Man	10
Woman	14
Non-binary	1
Prefer not to disclose	1
Prefer to self-describe	-
How many hours do you exercise per week?	**N**
Less than 1 hour	2
1 - 2 hours	3
3 - 5 hours	13
6 - 9 hours	4
10 - 15 hours	2
16 - 20 hours	-
More than 20 hours	2
Please indicate how hard your body is working during exercise.	**N**
Light (Maintain for hours/ Breathe easily/ Carry conversations)	8
Moderate (Exercise for hours/ Breathe heavily/ Short conversations)	15
Vigorous (Uncomfortable/ Shortness of breath/ Speak a sentence)	3
Very hard (Difficult intensity/ Barely breathe/ Single word)	-

Table 5.2: Participant demographics in Experiment 1

heart rates between conditions. Post-hoc tests employed Bonferroni correction. The alpha level was set to .05.

5.4.6 Materials and Tools

The main materials required for the experiment were as follows:

- TV: Used to display the game screen. Participants interacted with the game through

this screen.

- Heart rate sensor (Galaxy Watch 4): Used to monitor participants' heart rates during gameplay.
- Acceleration sensor (Galaxy Watch 4): Used to track participants' running movement.
- Smartphones: One smartphone installed with the game application and another with a posture detector application.
- Vysor software: Used to transfer the game display from the smartphone to the TV.
- Qualtrics system: Used for documentation and administering questionnaires.
- Personal computer: Used to access the Qualtrics system.

5.5 Results

This section presents the statistical test results for the hypotheses. The normality test results are shown in Table 5.3.

A reliability test result (Cronbach's α) for the FSS and IMI is shown in Table 5.4. Variations in N across the scale factors and three experimental conditions are acknowledged. The reason for the variation is that some participants did not answer all items in each factor.

In the hypothesis testing phase, given the relatively small number of missing items per participant, participants who did not answer all items were not excluded. Instead, the average of the answered items was used to represent each factor.

A summary of descriptive statistics and the statistical test results is shown in Tables 5.5 and 5.6.

Variables	**nDDA (Shapiro-Wilk)**			**DDA1 (Shapiro-Wilk)**			**DDA2 (Shapiro-Wilk)**		
	Statistic	df	Sig.	Statistic	df	Sig.	Statistic	df	Sig.
Physical Effort (average heart rate)	.978	26	.836	.967	26	.554	.968	26	.568
BRPE: Perceived Exertion	.973	26	.701	.959	26	.370	.944	26	.165
FSS: Flow	.967	26	.541	.965	26	.491	.972	26	.689
FSS: Challenge-skill Balance	.888	26	.009	.918	26	.040	.923	26	.053
IMI: Interest/ Enjoyment	.862	26	.002	.898	26	.014	.876	26	.005
IMI: Perceived Competence	.951	26	.238	.953	26	.277	.935	26	.120
IMI: Pressure/ Tension	.924	26	.057	.898	26	.014	.889	26	.009
IMI: Effort/ Importance	.929	26	.073	.925	26	.060	.915	26	.035

Table 5.3: Shapiro-Wilk test results for different DDA conditions in Experiment 1.

Scale/ Dimension	Number of Items	nDDA		DDA1		DDA2	
		N	Cronbach's α	N	Cronbach's α	N	Cronbach's α
FSS: Flow	36	24	.937	24	.944	24	.940
FSS: Challenge-skill Balance	4	25	.775	26	.697	24	.691
IMI: Interest/ Enjoyment	7	26	.915	25	.805	26	.904
IMI: Perceived Competence	6	25	.816	25	.803	25	.757
IMI: Effort/ Importance	5	26	.822	26	.853	26	.853
IMI: Pressure/ Tension	5	26	.477	25	.664	25	.554

Table 5.4: Reliability analysis results (Cronbach's α) for different DDA conditions in Experiment 1.

Variables	N			M ± SD			SEM		
	nDDA	DDA1	DDA2	nDDA	DDA1	DDA2	nDDA	DDA1	DDA2
Average Resting Heart Rate	26	26	26	84.73 ± 13.69	84.26 ± 14.09	84.07 ± 12.67	2.69	2.76	2.49
Average Heart Rate	26	26	26	132.33 ± 16.63	141.39 ± 14.75	138.88 ± 17.93	3.26	2.89	3.52

Variables	95% CI			Repeated-Measures ANOVA		
	nDDA	DDA1	DDA2	F(df1,df2)	p	η_p^2
Average Resting Heart Rate	[79.20, 90.26]	[78.57, 89.95]	[78.95, 89.18]	F(1.592, 39.798) = .084	.879	.003
Average Heart Rate	[125.61, 139.04]	[131.63, 147.34]	[135.43, 146.12]	F(1.549, 38.728) = 8.828	.002*	.261

Table 5.5: Descriptive statistics and Repeated-Measures ANOVA results for variables in nDDA, DDA1, and DDA2 conditions in Experiment 1.

Variables	N			M ± SD			Mdn			IQR			Friedman Test		
	nDDA	DDA1	DDA2	nDDA	DDA1	DDA2	nDDA	DDA1	DDA2	nDDA	DDA1	DDA2	$\chi^2(2)$	p	W
BRPE: Perceived Exertion	26	26	26	12.73 ± 2.34	13.76 ± 2.34	13.12 ± 2.50	13.00	14.00	12.50	3.25	3.25	4.25	6.222	.045*	.120
FSS: Flow	26	26	26	5.78 ± .70	5.77 ± .74	5.83 ± .65	5.78	5.73	5.83	1.04	1.23	1.07	.060	.970	.001
FSS: Challenge-skill balance	26	26	26	5.86 ± .83	5.92 ± .86	5.88 ± .90	5.50	6.00	6.00	1.56	1.50	1.56	1.500	.472	.029
IMI: Interest/ Enjoyment	26	26	26	6.03 ± 1.05	6.00 ± .87	5.92 ± 1.07	6.29	6.00	6.14	1.75	1.75	1.75	1.21	.546	.023
IMI: Perceived Competence	26	26	26	5.33 ± 1.08	5.39 ± 1.08	5.59 ± 1.00	5.50	5.42	5.83	1.71	1.92	1.25	.264	.876	.005
IMI: Pressure/ Tension	26	26	26	2.01 ± .80	2.32 ± 1.04	1.91 ± .77	2.00	2.20	2.00	2.00	1.32	1.45	.610	.737	.012
IMI: Effort/ Importance	26	26	26	5.13 ± 1.30	5.36 ± 1.32	5.38 ± 1.25	5.50	5.50	5.60	2.10	1.75	2.40	1.07	.587	.021

Table 5.6: Descriptive statistics and Friedman test results for variables in nDDA, DDA1, and DDA2 conditions in Experiment 1.

5.5.1 Average Heart Rate

Participants' resting heart rates at the beginning of each session did not vary significantly between conditions, indicating no order effect: $F(1.592, 39.789) = .084$, $p = .879$, $\eta_p^2 = .003$.

Figure 5.4 presents box plots illustrating the distributions of resting heart rates across three conditions: nDDA, DDA1, and DDA2.

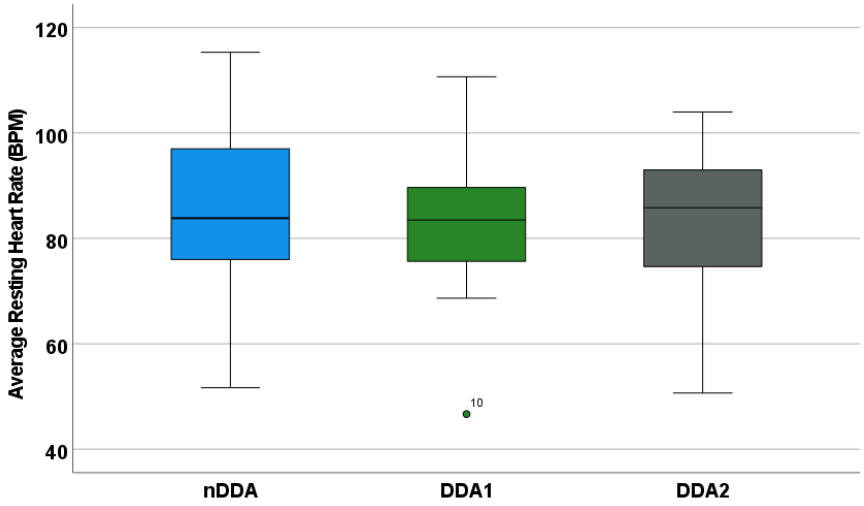

Figure 5.4: Box plots of Resting Heart Rate for the three conditions: no DDA (nDDA), continuous EI-based DDA (DDA1), and interval EI-based DDA (DDA2) in Experiment 1.

Mauchly's test of sphericity assessed the sphericity of the heart rate data during gameplay, indicating a violation, $p = .016$. Therefore, a repeated-measures ANOVA with Greenhouse-Geisser correction was performed to address sphericity violations. The analysis showed a significant difference in the average heart rate (AHR) of participants during gameplay in different conditions: $F(1.549, 38.728) = 8.828$, $p = .002$, $\eta_p^2 = .261$ (a large effect). So, the null hypothesis of H_1 was rejected, indicating that AHR differed significantly between the experimental conditions.

Specifically, AHR in DDA1 condition ($M \pm SD = 141.39 \pm 14.75$) was higher than in the nDDA ($M \pm SD = 132.33 \pm 16.63$), this difference was significant: $p < .001$, $d = 1.00$ (large effect). The average heart rate in the DDA2 condition ($M \pm SD = 138.88 \pm 17.93$) was higher than in the nDDA condition, this difference was also significant: $p = .011$, $d = .64$ (medium effect). There was no significant difference between the DDA1 and DDA2 conditions, $p = 1.000$, $d = .18$ (small effect).

Figure 5.5 presents box plots illustrating the distribution of AHR during playtime across the three conditions.

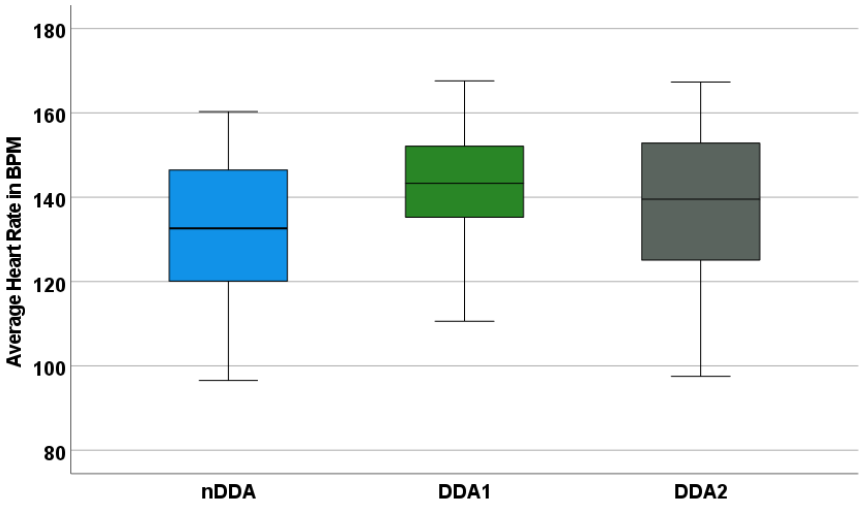

Figure 5.5: Box plots of Average Heart Rate for the three conditions: no DDA (nDDA), continuous EI-based DDA (DDA1), and interval EI-based DDA (DDA2) in Experiment 1.

5.5.2 BRPE: Perceived Exertion

Perceived exertion differed significantly across the three conditions: $\chi^2(2) = 6.222$, $p = .045$, Kendall's W = .120. Thus, the null hypothesis of H_2 was rejected.

A post-hoc analysis using the Wilcoxon signed-rank test with a Bonferroni correction (adjusted alpha level = .0167) revealed that participants reported higher perceived exertion scores in the DDA1 condition ($M \pm SD = 13.76 \pm 2.34$, Mdn = 14.00, IQR = 3.25) compared to the nDDA condition ($M \pm SD = 12.73 \pm 2.34$, Mdn = 13.00, IQR = 3.25), $Z = -2.730$, $p = .006$, $r = .54$ (large effect). Similarly, the DDA1 condition was perceived as more exertional than the DDA2 condition ($M \pm SD = 13.12 \pm 2.50$, Mdn = 12.50, IQR = 4.25), $Z = -2.433$, $p = .015$, $r = .48$ (medium effect). However, there was no significant difference between the DDA2 and nDDA conditions, $Z = -.988$, $p = .323$, $r = .19$ (small effect).

Figure 5.6 shows the box plots of BRPE: perceived exertion for all three conditions: nDDA, DDA1, and DDA2.

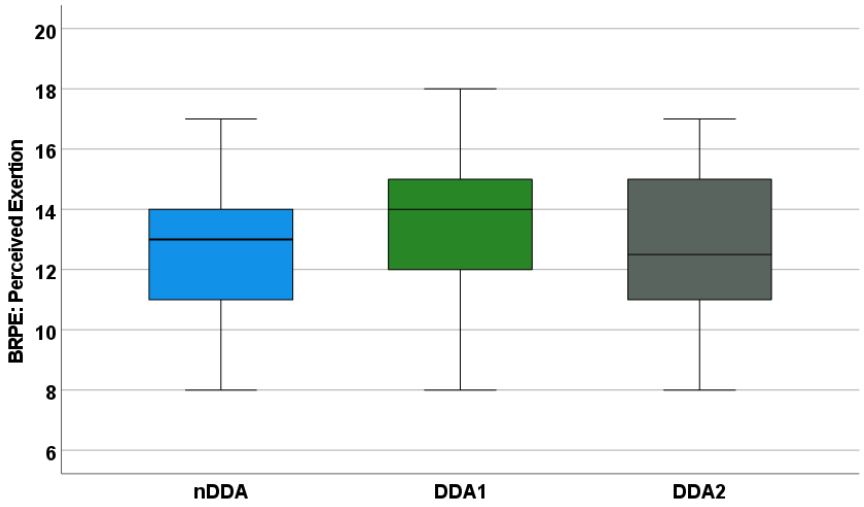

Figure 5.6: Box plots of BRPE: Perceived Exertion for the three conditions: no DDA (nDDA), continuous EI-based DDA (DDA1), and interval EI-based DDA (DDA2) in Experiment 1.

5.5.3 IMI: Intrinsic Motivation

Participants' interest / enjoyment of the game did not differ significantly between conditions: $\chi^2(2) = 1.951$, $p = .377$, Kendall's W = .038. Similar results were regarding their perceived competence: $\chi^2(2) = .264$, $p = .876$, Kendall's W = .005; effort / importance: $\chi^2(2) = 1.067$, $p = .587$, Kendall's W = .021; and pressure / tension: $\chi^2(2) = .610$, $p = .737$, Kendall's W = .012. So, the null hypotheses of ($H_{3.A}$, $H_{3.B}$, $H_{3.C}$, and $H_{3.D}$) were supported.

Figure 5.7 presents box plots illustrating the distribution of IMI: Interest/ Enjoyment.

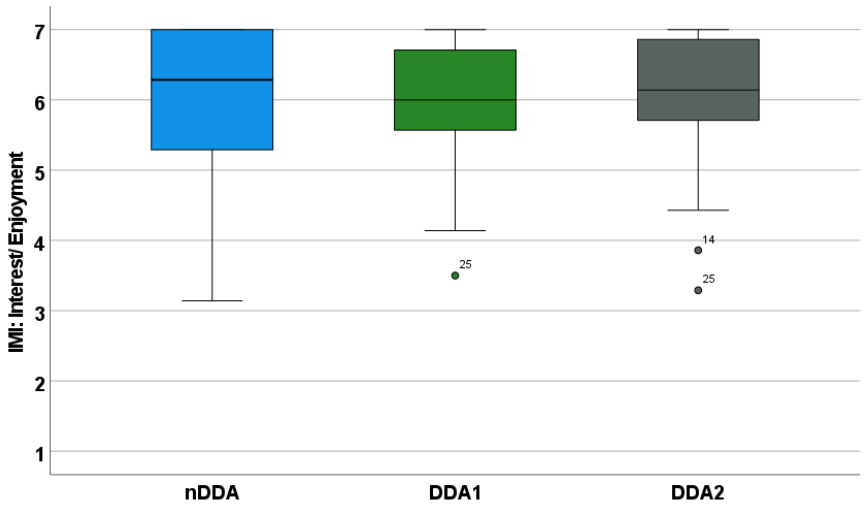

Figure 5.7: Box plots of IMI: Interest/ Enjoyment for the three conditions: no DDA (nDDA), continuous EI-based DDA (DDA1), and interval EI-based DDA (DDA2) in Experiment 1.

Figure 5.8 presents box plots illustrating the distribution of IMI: Perceived Competence.

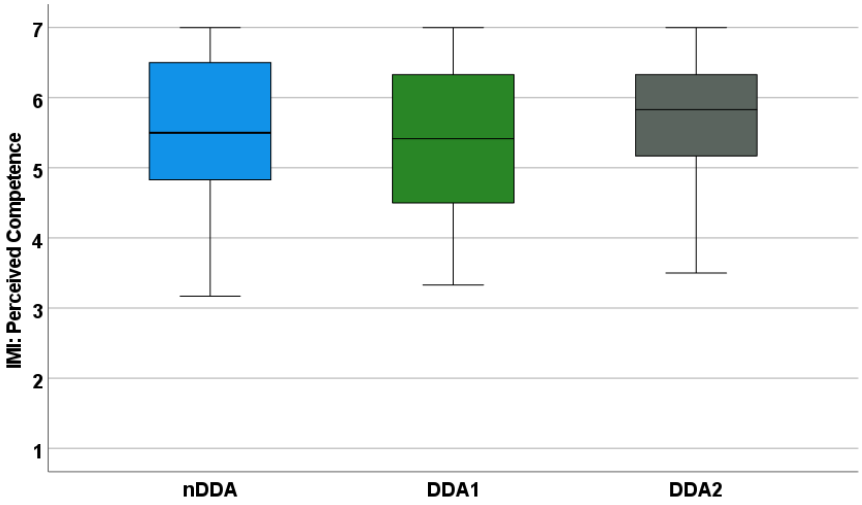

Figure 5.8: Box plots of IMI: Perceived Competence for the three conditions: no DDA (nDDA), continuous EI-based DDA (DDA1), and interval EI-based DDA (DDA2) in Experiment 1.

Figure 5.9 displays box plots that show the distribution of IMI: Effort/Importance.

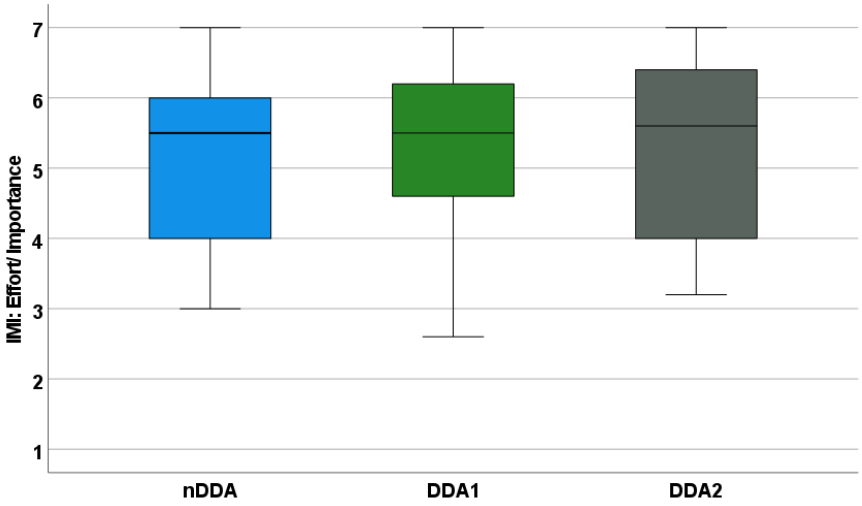

Figure 5.9: Box plots of IMI: Effort/ Importance for the three conditions: no DDA (nDDA), continuous EI-based DDA (DDA1), and interval EI-based DDA (DDA2) in Experiment 1.

Figure 5.10 illustrates the distribution of IMI: Pressure/Tension using box plots.

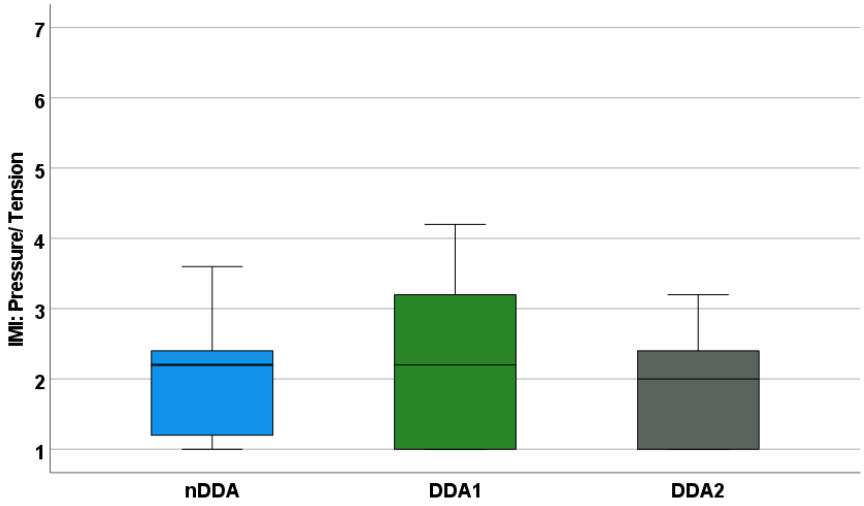

Figure 5.10: Box plots of IMI: Pressure/ Tension for the three conditions: no DDA (nDDA), continuous EI-based DDA (DDA1), and interval EI-based DDA (DDA2) in Experiment 1.

5.5.4 FSS: Flow

Flow did not differ significantly between conditions: $\chi^2(2) = .060$, $p = .970$, Kendall's W = .001 and neither was the challenge-skill balance: $\chi^2(2) = 1.500$, $p = .472$, Kendall's W = .029. Therefore, the null hypotheses of $H_{4.A}$ and $H_{4.B}$ were not rejected.

Figure 5.11 presents box plots illustrating the distribution of FSS: Flow.

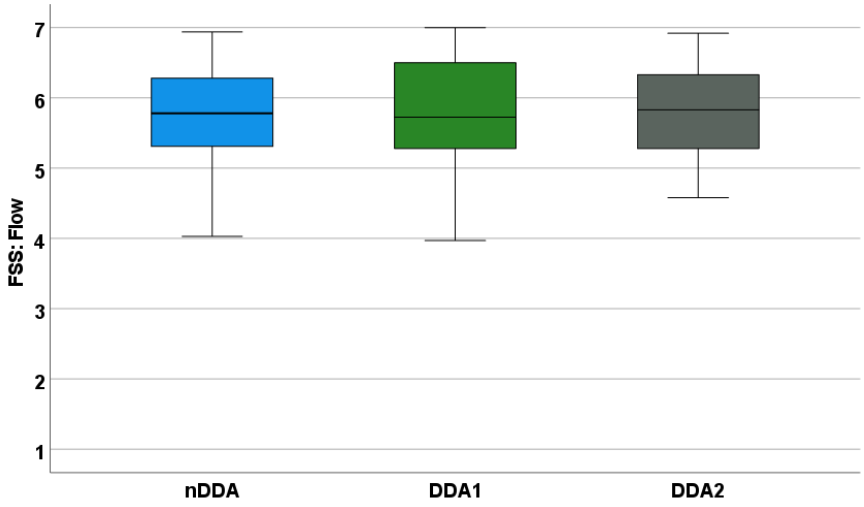

Figure 5.11: Box plots of FSS: Flow for the three conditions: no DDA (nDDA), continuous EI-based DDA (DDA1), and interval EI-based DDA (DDA2) in Experiment 1.

Figure 5.12 shows box plots depicting the distribution of FSS: Challenge-skill Balance.

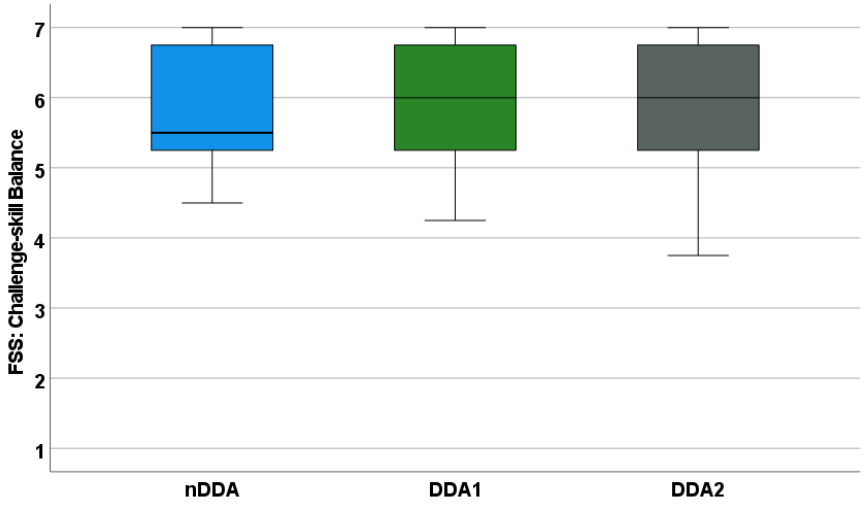

Figure 5.12: Box plots of FSS: Challenge-skill Balance for the three conditions: no DDA (nDDA), continuous EI-based DDA (DDA1), and interval EI-based DDA (DDA2) in Experiment 1.

5.6 Discussion

The impact of DDA1 (continuous EI-based DDA) and DDA2 (interval EI-based DDA) on PX and AHR during playtime was examined in comparison to the nDDA condition (no DDA used). Results indicate that DDA1, designed to maintain player heart rates within aerobic zones, led to greater physical effort than nDDA but also increased perceived exertion. Interestingly, DDA2 similarly encouraged higher physical effort without increasing perceived exertion compared to nDDA. Additionally, neither flow nor intrinsic motivation in DDA1 and DDA2 differed from the nDDA condition.

The following sections discuss these findings in the context of existing research on exergame adaptations using exercise intensity-based data and explore implications for future adaptive exergame design.

5.6.1 Average Heart Rates and Perceived Exertion

This experiment investigated the effects of EI-based DDA, designed to maintain players' exertion levels within exercise intensity zones, on physical effort. Research on this approach has been limited, with few studies directly comparing DDA to nDDA [31]–[34]. Some studies relied on manual adjustments instead of full DDA implementation [24], had small sample sizes, participants who were not fully active in experiments, or used different indicators to measure physical effort (e.g. heart rate and leg movement frequency and intensity) [26], [33]. Additionally, prior research has reported mixed results [18], [24], [26].

This experiment supports previous studies suggesting that EI-based DDA can potentially increase players' physical effort, as demonstrated in prior research [18], [31], [32], [34]. Compared to nDDA, this EI-based DDA resulted in higher physical effort. While the mechanisms behind the increased physical effort differ from those described by Ketcheson *et al.* [18] and Wünsche *et al.* [26]—participants were motivated to invest more effort to reach the target zone and receive rewards—this experiment showed a potential increase in average heart rate even without extrinsic rewards.

The potential explanation for why EI-based DDA in this experiment increased higher physical effort compared to nDDA, without the need for rewards, might be related to the nature of the difficulty adjustment in DDA1 and DDA2, which might keep players more physically active. In nDDA, the gradual increase in the dragon's speed could lead to disengagement if the difficulty escalated steadily and became overwhelming. Participants might experience repeated setbacks as the challenge exceeded their skill level and physical capacity, causing frustration and fatigue [13], [19]. Besides, the constant difficulty escalation could lead to a monotonous experience, reducing motivation. Even if players tried to outrun the dragon, the game would continue increasing difficulty, making it feel futile to adjust their effort and potentially resulting in a lower average heart rate.

In contrast, DDA1 and DDA2 created dynamic gameplay by adjusting the difficulty based on participants' heart rates. In DDA1, although the function aimed to maintain heart rate within a target range, the experience was not the same as the nDDA condition.

- In DDA1, although the function aimed to maintain heart rate within a target range, the gameplay experience was more dynamic. When players became fatigued or their heart rates exceeded the target zone, they might disengage and allow the dragon to attack, or DDA1 would decrease the dragon's speed, providing a recovery period. Once their heart rates dropped, DDA1 would increase the dragon's speed again to keep their heart rates within the target zone. This fluctuation in the dragon's presence and speed likely contributed to a more engaging and physically active experience.
- In contrast, nDDA maintained a steady increase in difficulty, with the dragon continuously chasing players. Players might feel fatigue in the later minutes, potentially leading them to disengage from the gameplay. Since the dragon was always present, players might eventually neglect the attacks and focus only on completing the session rather than actively responding to the challenge.

Similar to DDA1, DDA2 also provides players with a dynamic game experience, as the absence and presence of the dragon vary due to difficulty adjustments based on current AHR. However, DDA2 explicitly includes a low-intensity phase, allowing players to recover before becoming active again in the next high-intensity phase.

Even though both DDA1 and DDA2 potentially promote higher AHR compared to nDDA, and no significant difference in AHR is found between DDA1 and DDA2, they provide different game experiences. As shown in Figure 5.5, the IQR of AHR in DDA1 is narrower than in DDA2, indicating less variation in AHR among the middle 50% of participants in the DDA1 condition. This can be interpreted as DDA1 potentially maintaining players' heart rates within a targeted exercise intensity zone, leading to more consistent AHR values across

participants. Conversely, DDA2, which provides a game experience with alternations between high and low intensity, results in a wider IQR, likely due to the fluctuations of exercise intensity causing variation in AHR of individuals during gameplay.

Due to the limited research on perceived exertion in EI-based compared to nDDA, the findings indicate that DDA1 (continuous aerobic exercise) led to higher perceived exertion than nDDA. This increase may be linked to the greater physical effort in DDA1. Similarly, Ketcheson *et al.* [18] found that their DDA, designed to keep players' heart rates within a target zone (a concept similar to DDA1), also resulted in higher perceived exertion. This suggests that while DDA1 keeps players more physically active (increasing AHR), its continuous exertion demands may lead to excessive perceived exertion, which should be carefully considered in exergame and DDA design, as it could negatively impact player's affective responses [186].

Unlike DDA1, DDA2 (which incorporates intervals of low and high intensity) did not significantly differ from nDDA in perceived exertion. This contrast suggests that the impact of EI-based DDA on perceived exertion depends on its design and the physical activity patterns it generates. DDA2 emerges as a promising approach for exergames, as it potentially increases heart rate—comparable to DDA1—without elevating perceived exertion. This advantage may stem from its interval-based physical activity, where alternating lower-intensity periods prevent sustained high-intensity effort, potentially reducing the risk of overexertion.

Overall, these results suggest that both DDA1 and DDA2 have the potential to promote physical effort, as indicated by an increase in AHR compared to nDDA. However, it is important to note that this rise (approximately 10 BPM) does not necessarily translate into health benefits over the nDDA condition.

However, in the gaming context, an increase in AHR can be beneficial, as EI-based DDA may help promote physical activity levels of players, enhancing the effectiveness of exergames. In contrast, the nDDA condition, which progressively increases difficulty without considering player data, may lead to disengagement in later minutes as physical demands exceed a player's current physical state.

Regarding the results, this experiment suggests that when the design of exergames focuses on reaching and maintaining a target exercise intensity zone, DDA1 can be a suitable choice. However, it also leads to higher perceived exertion compared to DDA2 or nDDA within the same playtime (around 10 minutes), indicating that in longer sessions, players might feel more exhausted, potentially reducing engagement.

In contrast, if maintaining a specific exercise intensity is not the main goal, interval EI-based DDA (DDA2) can be a better option. It not only promotes physical effort compared to nDDA but also results in lower perceived exertion than DDA1. This is likely because DDA2 incorporates lower-intensity periods, allowing players to recover before engaging in higher-intensity activity again.

5.6.2 Flow and Intrinsic Motivation

This experiment addresses gaps in the dual flow model [19], [29], which lacks detail on how exergames that balance exercise intensity impact PX. It also builds on prior studies that

used exercise intensity-based data for difficulty adjustment but had limitations such as small sample sizes [26] and inactive participants [33]. By using AHR during gameplay with DDA1 and DDA2 to assess physical challenge levels, the results indicate no significant differences in flow (including challenge-skill balance) or intrinsic motivation—interest/enjoyment, perceived competence, pressure/tension, and effort/importance. These findings align with previous research [18], [26], [33].

This outcome may be from the design of the DDA functions, which primarily focused on maintaining players' exertion levels within a target intensity zone rather than adapting to in-game performance. This approach may have failed to fulfil players' basic need for competence, as defined by SDT [16], which emphasises the sense of achievement gained from overcoming in-game challenges.

By prioritising exertion levels over performance adaptation, the DDA functions may have created two problematic scenarios. Skilled players who successfully avoided the dragon (engaging in high physical activity) might have been forced to run faster to maintain their target heart rate within any exercise intensity zones. Over time, the lack of recognition for their successful avoidance may have led to a perception of competence and challenge-skill balance similar to the nDDA condition, where difficulty did not respond to players' performance.

Conversely, less skilled players who struggled to avoid the dragon and engaged in lower physical activity may have experienced frustration as the game's difficulty continued to increase to elevate their heart rate to the target zone. Due to their lower skill level or physical engagement, these players may have found it difficult to keep up, leading to repeated failures. This frustration with the game's inability to adapt to individual performance may have undermined their sense of competence in a manner similar to the nDDA condition.

When difficulty adjustments rely solely on heart rate without considering player skill, invested effort of players may feel disconnected from success, weakening intrinsic motivation. Flow theory highlights the importance of challenge-skill balance in achieving flow [13], yet DDA1 and DDA2 may not fulfil this balance, resulting in similar flow scores across conditions. Moreover, while flow theory identifies multiple components essential for achieving flow, DDA1 and DDA2 focus only on balancing fitness and exertion intensity, which may be insufficient.

This experiment also provides further insight into the dual flow model [19], [29], suggesting that the proposed effectiveness relationship—which balances exercise intensity in exergames with players' fitness levels—may not necessarily enhance PX (the attractiveness of exergames) compared to nDDA.

This experiment addresses gaps in related studies, particularly the limited focus on interest/enjoyment. Enjoyment is a complex construct influenced by multiple factors. For example, it might depend on whether the game satisfies players' needs or motivates them to play [41]. Also, it can be shaped by whether the DDA was designed to enhance enjoyment or create an engaging experience, such as suspense [187].

In the case of DDA1 and DDA2, which primarily focus on maintaining exertion levels and addressing a single physical challenge, these functions did not differentially enhance interest/enjoyment compared to nDDA. This may be due to the narrow scope of DDA1 and DDA2, as they only adjust physical challenge, which may not have been impactful enough

for players to perceive it as an engaging task.

Similar to the related works [18], [26], [33], this experience found no difference in pressure/ tension. Participants generally rated pressure/tension low across nDDA, DDA1, and DDA2, despite higher average heart rates in DDA1 and DDA2 compared to nDDA, and higher perceived exertion in DDA1 relative to both nDDA and DDA2.

This suggests that stress in this experiment can be categorised into physical stress, reflected in increased heart rate and perceived exertion, and psychological stress (such as from setbacks/ failures and punishment) with the latter potentially influencing pressure/tension as measured by the subjective IMI scale. The lack of differences in pressure/tension ratings could be due to the game lacking elements that induce emotional stress, while DDA1 and DDA2 were designed to regulate physical challenge only rather than stress from game contents, leading participants to perceive the overall game experience as similar across conditions.

Moreover, since exergames inherently involve physical activity, exertion may be the primary source of stress rather than psychological factors. Physical stress might have a greater impact on players' perceptions and emotions [186] and could overshadow gameplay-related stress, making players focus more on exertion-related stress (as shown in heart rate and perceived exertion) while perceiving less psychological stress.

Regarding effort/ importance, the lack of difference in effort/importance despite increased physical effort (AHR) may suggest that greater physical exertion during gameplay does not necessarily translate into higher motivational effort. One possible explanation is that the design of DDA1, DDA2, and the game itself did not incorporate elements specifically intended to enhance players' motivational effort to seek for playing the game. This finding aligns with previous studies [18], [26], which also used DDA based on exercise intensity to manage exertion levels in exergames without significantly affecting motivational effort.

Overall, EI-based DDA has limitations in enhancing the attractiveness of exergames. While it can improve the effectiveness of exergames by increasing physical effort, maintaining players' AHR alone does not seem to fulfil their needs in playing games, resulting in no improvement in PX. This experiment suggests that if exergames are not designed to target an exercise intensity zone, relying solely on EI-based DDA might not be an ideal approach.

5.6.3 Limitations

This experiment has several limitations that should be acknowledged. First, the sample size is relatively small, which may limit statistical power in detecting subtle effects. Consequently, findings with small effect sizes should be interpreted with caution.

Also, it is important to note that this experiment is conducted within a gaming context, not a health-related study. The relationship between heart rate and exertion is examined under the assumption that participants are healthy and that no external factors (e.g. caffeine, stress, or medical conditions) influence heart rate in a way that could affect the DDA functions or the age-related maximal heart rate formula.

5.7 Suggestions for Exercise intensity-based DDA And Next Experiment

An unexpected player behaviour observed in this experiment may be of interest to game designers developing exergames and DDA functions based on exercise intensity data. Some participants continued running rigorously even when the difficulty level decreased and the dragon disappeared from the game screen. This suggests that certain players might have been highly focused on maintaining a specific pace or exertion level, potentially leading to overexertion.

This finding highlights a limitation in current EI-based DDA design. To address this and mitigate the risk of overexertion, incorporating biofeedback techniques that provide real-time feedback could be a promising approach, enabling players to better regulate their bodily functions [188]. In the context of exergames, this could involve displaying players' average heart rate in real time alongside guidance on adjusting running intensity. Some studies have demonstrated the potential benefits of integrating biofeedback into video games to enhance player awareness and satisfaction with performance (e.g. [128]). A feedback loop displaying real-time exertion data could encourage players to self-regulate exercise intensity and prevent overexertion.

An interesting strategy by She *et al.* [34] integrates biofeedback into the game interface to inform players. Instead of displaying current AHR and exercise intensity zones as text in the corner of the screen, as in this research's exergame, She *et al.* [34] incorporate it into gameplay. The heart rate graph changes colour based on AHR: red when exceeding the target zone, green within it, and blue when below (Figure 5.13). Moreover, if the game intends to increase or decrease players' physical effort, ring obstacles turn red or yellow, respectively (Figure 5.14).

This technique allows players to focus on gameplay, as biofeedback is seamlessly integrated. In contrast, in this research's exergame, players may overlook or ignore the AHR text because they are fully focused on the centre of the game screen.

Figure 5.13: A game interface displaying the player's current AHR with text inside a graph icon, where different colours indicate heart rate zones: blue for below the target zone, green for within, and red for above from [34]

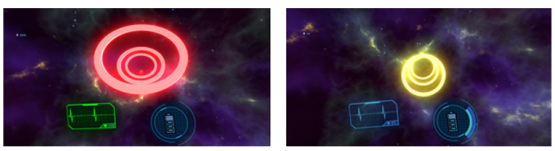

Figure 5.14: A game interface where biofeedback is integrated into gameplay: when the game wants the player to exert more, the ring obstacles turn red; when a cooldown is needed, they turn yellow from [34]

Moreover, these DDA functions might not be suitable for all players. Some participants exhibited rapid heart rate increases, reaching the target zone within seconds of starting the game. For these players, the DDA functions would attempt to maintain or decrease heart rate by keeping the difficulty level the same or lowering it. This could result in a monotonous experience that lacks challenge.

Building on the dual flow model for exertion games [19], [29], which emphasises the balance between challenge and skill (attractiveness) and fitness and exercise intensity (effectiveness), these findings suggest the need to refine how player fitness is assessed. Heart rate and age-predicted maximal heart rate are commonly used in exercise science to determine suitable intensity zones and their associated physical benefits. However, relying solely on heart rate for adjustment may not be sufficient to achieve flow, as even the first entry: challenge-skill balance cannot be achieved. These results raise the question of whether this approach effectively guides players toward the flow state.

Overall, based on these findings, EI-based DDA (DDA1 and DDA2) has the potential to promote AHR, contributing to the effectiveness of exergames in promoting physical activity. However, the results suggest that this DDA approach lacks the potential to enhance player experience as EI-based DDA functions might not satisfy players' needs.

Existing research highlights an alternative approach—performance-based DDA—which focuses on players' in-game performance and has been shown to potentially influence player experience. However, the studies on performance-based DDA remain limited, with mixed findings regarding its impact on player experience, particularly in relation to flow and intrinsic motivation.

To address this gap, the next experiment investigates the impact of performance-based DDA in this exergame on player experience and physical effort. The findings may inform future DDA designs that integrate both EI-based and performance-based approaches, aligning with the dual flow model [19] to enhance both the attractiveness and effectiveness of exergames.

5.8 Chapter Summary

This experiment used a within-subject design with 26 participants and three experimental conditions: the control condition (nDDA), continuous EI-based DDA (DDA1), and interval EI-based DDA (DDA2). The key takeaways from this experiment are:

1. This experiment examined the effects of EI-based DDA on physical effort. The findings indicate that both DDA1 and DDA2 increased AHR compared to nDDA, suggesting greater physical effort. One possible explanation for this increase is that the steady difficulty progression in nDDA may create a monotonous experience, potentially leading to overexertion or reduced physical engagement as exertion demands exceed players' skills or physical state over time. In contrast, DDA1 and DDA2 offer a more dynamic experience by stimulating players when their heart rate falls below the threshold and allowing them to recover when it exceeds the threshold. This adaptive approach may encourage players to stay physically active in response to changing game demands.

DDA1 and DDA2 differed in their impact on perceived exertion. While DDA1 maintained heart rate within a target range, its sustained exercise intensity may have led to higher perceived exertion. In contrast, DDA2's interval-based structure balanced high-intensity effort with recovery periods, sustaining physical engagement without excessive exertion.

2. This experiment found no significant differences in flow, challenge-skill balance, or intrinsic motivation (interest/enjoyment, perceived competence, pressure/tension, and effort/importance) across nDDA, DDA1, and DDA2. The results suggest that EI-based DDA, which focuses on maintaining exertion levels, does not enhance PX, as it may not fully satisfy players' needs in exergames.

Given the limited exploration of performance-based DDA in exergames, the next chapter presents an experiment examining its impact on player experience and physical effort.

Chapter 6

The Effects of Performance-Based DDA in the Exergame on Player Experience and Physical Effort

6.1 Introduction

Experiment 1 revealed that exercise intensity (EI)-based DDA functions have the potential to increase players' average heart rate (AHR) during gameplay compared to the no-DDA condition (nDDA). Also, perceived exertion was higher in EI-based DDA conditions. However, this type of DDA did not significantly impact observed player experience, suggesting that it primarily regulates players' heart rate within exertion zones rather than adapting to how well they play. As a result, players may feel that their effort is not recognised, leading to PX similar to the nDDA condition.

While EI-based DDA focuses on maintaining physiological effort, another common approach in previous research shown in the review is performance (P)-based DDA, which adjusts game difficulty based on player performance metrics during gameplay. These metrics can vary depending on how researchers or game developers define and quantify player performance (e.g. speed, accuracy, completion time, or error rate).

P-based DDA is often grounded in Flow Theory [13], aiming to balance challenge and skill to sustain an optimal experience. However, the impact of P-based DDA on flow state remains inconclusive. Some studies [23], [28] indicate that using DDA to balance challenge and skill does not necessarily lead to a significant increase in flow compared to a nDDA condition. Similarly, prior research [23], [24], [27], [28], [38] has reported mixed effects on intrinsic motivation, enjoyment, pressure, and effort, with particularly inconsistent findings regarding competence. According to SDT [16], DDA functions aiming to balance difficulty should enhance a player's sense of achievement by providing stimulating yet attainable challenges. However, some studies [28], [38] contradict this principle, showing no significant difference in competence levels between P-based DDA and nDDA conditions.

Moreover, there is a notable gap in the literature regarding the impact of P-based DDA on

physical effort and perceived exertion. Since P-based DDA primarily focuses on balancing challenge and skill, it may overlook the role of sustaining physical effort—a key component in exergames.

Given the unclear effects of P-based DDA on various aspects of player experience and physical effort, this experiment seeks to further investigate its influence in an exergaming context. By examining both PX and physical effort outcomes, this experiment aims to provide deeper insights into the impact of P-based DDA. These findings could inform future exergame design and DDA functions to foster a more engaging and physically adaptive gameplay experience.

6.2 Hypotheses

Based on the review, the following hypotheses were formulated for statistical tests to address the research gaps and research questions:

H_1 : Players' average heart rates differ when playing exergames with and without P-based DDA.

H_2 : Players' perceived exertion differs when playing exergames with and without P-based DDA.

H_3 : Players' performative perceived challenge differs when playing exergames with and without P-based DDA.

Previous studies [23], [24], [27], [28], [38] have not fully explored the effects of P-based DDA on physical effort (measured by AHR), perceived exertion, and perceived challenge. In nDDA, difficulty gradually increases over time, forming a rising difficulty curve. Initially, this may encourage higher physical effort as players respond to the dragon's approach and avoid its attacks, perceiving a need for quick physical reactions (performative perceived challenge). However, as difficulty surpasses their skill level or fatigue sets in, players may struggle to keep up, leading to reduced physical engagement and a decreased perception that they need to react physically fast, as the challenge becomes too difficult to overcome.

In contrast, P-based DDA dynamically adjusts the dragon's speed based on player performance, creating an adaptive difficulty curve. When players struggle or become fatigued, difficulty decreases, allowing recovery periods that may lower exertion and lessen the sense that they need to react physically fast. Conversely, when they exceed the challenge, difficulty increases, sustaining or raising exertion and reinforcing the perception that quick reactions are necessary.

Given these different difficulty curves, P-based DDA may influence physical effort, perceived exertion, and performative perceived challenge differently compared to nDDA. This experiment hypothesises that P-based DDA will lead to differences in AHR, perceived exertion, and performative perceived challenge compared to nDDA (H_1, H_2, and H_3). The justification behind using undirectional hypotheses is to avoid presupposing outcomes due to the lack of related studies exploring the effects of P-based DDA on these variables.

H_4 : Players' intrinsic motivation: enjoyment/interest ($H_{4.A}$), perceived competence ($H_{4.B}$), effort/importance ($H_{4.C}$), and pressure/tension ($H_{4.D}$) differ when playing exergames with and without P-based DDA.

H_5 : Players' flow experience: flow ($H_{5.A}$) and its challenge-skill balance ($H_{5.B}$) differ when playing exergames with and without P-based DDA.

H_6 : Players' setback count differs when playing exergames with and without P-based DDA.

P-based DDA in this experiment was implemented based on Flow Theory [13], [19] to maintain a balance between challenge and skill during gameplay. To assess whether this DDA created a different game experience compared to nDDA, setback count—the number of times the player's avatar was attacked by the chasing dragon—was used as a key metric. Frequent setbacks may indicate that the challenge exceeds the player's skill level, disrupting challenge-skill balance of flow, while fewer setbacks suggest that the difficulty remains within an achievable range. Therefore, this experiment hypothesised that setback count in P-based DDA will differ from that in the nDDA condition (H_6).

Moreover, this experiment uses P-based DDA to provide a balanced gameplay experience and facilitate entry into the flow state [14]. By dynamically aligning challenge with player skill (modulating dragon speed in response to setbacks), the P-based DDA aims to sustain player engagement within the flow channel. However, prior studies [23], [24], [27], [28] report mixed findings on whether DDA enhances flow and challenge-skill balance. Given the unclear directional effect, this experiment hypothesised that playing with P-based DDA will lead to a different flow experience compared to playing without DDA (H_5).

P-based DDA aims to adjust game challenges, and these changes may impact the player's overall game experience. According to SDT [16], P-based DDA may lead to more successful gameplay experiences compared to nDDA, potentially enhancing players' sense of competence. Additionally, differences in game experiences may influence how players perceive enjoyment, pressure, and effort across conditions. However, the literature on exergames is limited, and existing findings on these PX factors remain mixed [23], [24], [27], [28], [38]. Given the unclear impact of P-based DDA, playing with P-based DDA is expected to result in differences in interest/enjoyment, perceived competence, pressure/tension, and motivational effort/importance compared to nDDA (H_4).

The following section details the design of the P-based DDA used in this experiment.

6.3 No DDA and DDA Experimental Condition

6.3.1 No DDA (nDDA)

This condition is identical to that used in Experiment 1.

6.3.2 Performance-based DDA (DDA3)

Previous studies (e.g. [23], [27], [28]) that implement P-based DDA functions commonly align with the challenge-skill balance principle of flow theory [13], where difficulty is adjusted to match player abilities to facilitate flow and avoid frustration or boredom. These studies typically use performance metrics such as success/error rates, for example, the number of times a player is unable to avoid obstacles [23] or missed ball interactions in Pong-like exergames [27]. These metrics help describe player performance and ensure that the difficulty adjustments correspond to their gameplay abilities.

Similarly, in this experiment, DDA3 is grounded in the challenge-skill balance principle and aims to maintain an optimal balance between challenge and skill. As described in Chapter 4, the game challenge (a physical challenge) involves the dragon continuously chasing the player, requiring them to adjust their running speed to evade attacks, avoid punishment, and reach the finish line as quickly as possible. Player skill, in this context, refers to their ability to regulate their running speed to escape the dragon and successfully reach the game's destination.

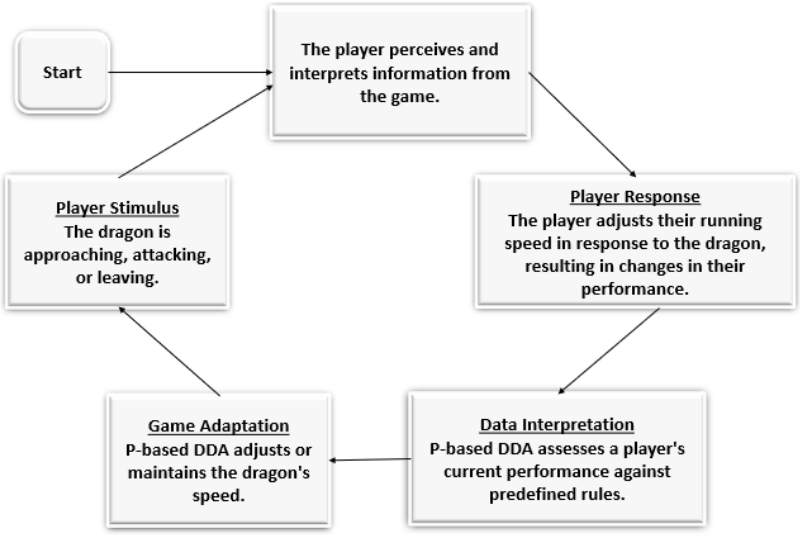

Figure 6.1: A feedback loop illustrating how performance-based DDA influences players' behaviour and performance.

Figure 6.1 shows a feedback loop illustrating the general concept of how P-based DDA impacts players' behaviours and performance during gameplay. P-based DDA continuously observes and evaluates player performance in real-time, feeding this data into its evaluation function to determine difficulty adjustments. It then modifies the dragon's speed based on the function's outcome, prompting players to react accordingly. This loop repeats until the game ends.

To assess player performance, the number of times a player is hit by the dragon (setback count) is used. If the setback count reaches a predefined threshold, DDA3 triggers difficulty adjustments. Moreover, this approach builds on previous studies but extends them in two key ways: incorporating the concept of rubber-banding and introducing periods of lower exercise intensity when players successfully overcome in-game challenges. These mechanisms are further explained in this section.

This design builds on the previous studies and demonstrates that DDA3 represents another approach to DDA functions in exergames, using player performance data to adapt the game and explore the research questions. The following paragraphs detail how DDA3 works.

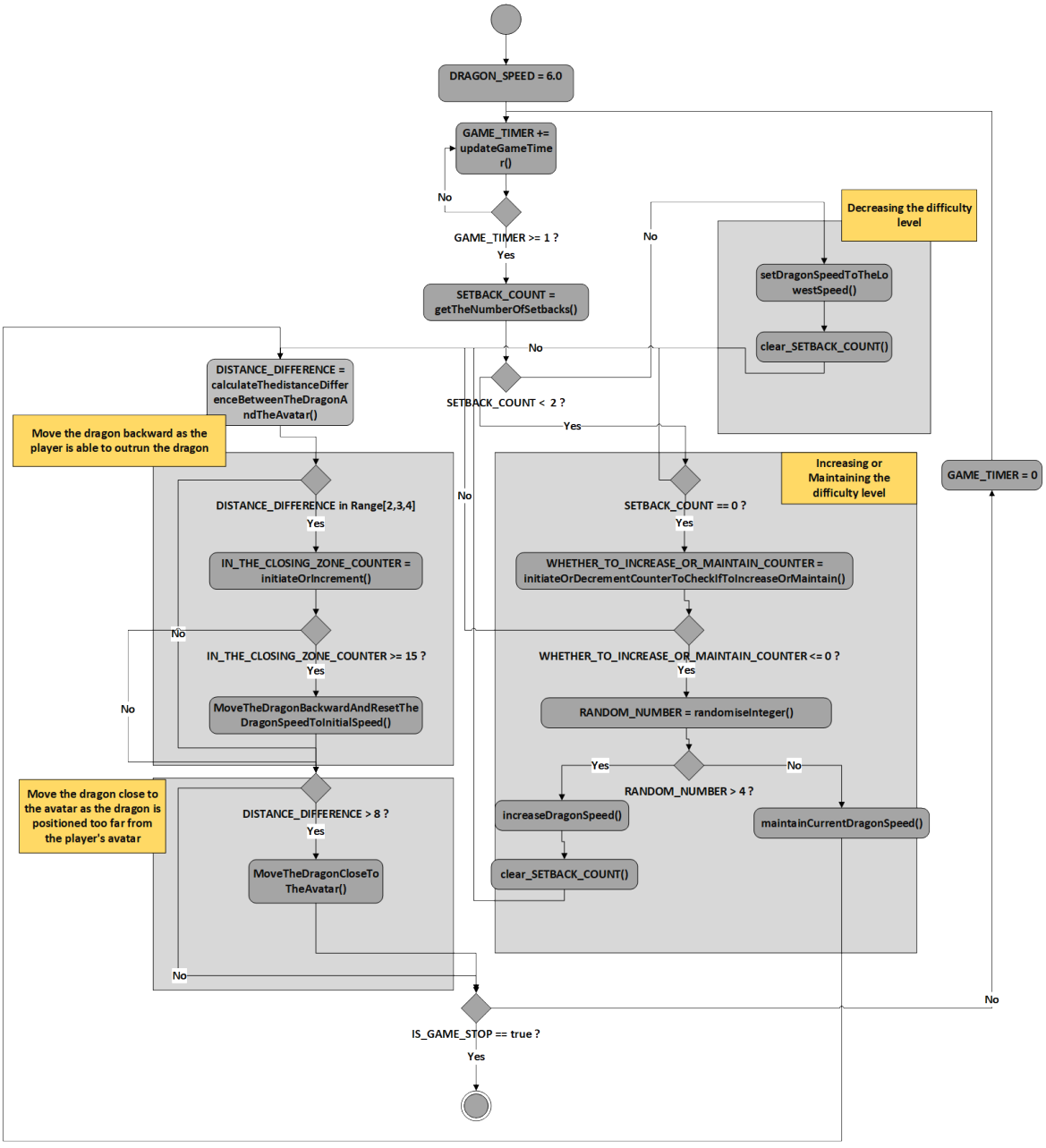

Figure 6.2: DDA3's flow chart showing how performance-based DDA functions.

Figure 6.2 illustrates how DDA3 functions. At the start of the game, the dragon's speed is set to its lowest, giving players time to adjust to the physical activity. Once the game begins, a timer starts counting. Every second, the following steps occur, with each condition evaluated sequentially:

At the beginning of the game, the setback count is zero since the player has not yet been hit by the dragon. The game then evaluates the following conditions:

- **Decreasing the difficulty level:** If the setback count is greater than or equal to 2 (this number was fine-tuned during development and player testing), the game may be too challenging for the player. In this case: the dragon's speed is reset to the slowest level. Also, the dragon is removed from the player's sight, allowing a period of low-intensity gameplay.

  The decision to reset the dragon to the slowest speed and remove it from the player's view, rather than simply reducing its speed by a few points, is based on the nature of exergames, which involve physical activity. Unlike common video games, even if the dragon moves slowly, its presence may still encourage players to keep running, making it difficult for them to lower their effort. This scenario was observed during the development and testing phase. Therefore, this approach is applied to reduce the player's mindset of constantly fleeing from the dragon. To avoid abruptly removing the dragon, which might disrupt the player's sense of realism, the transition is made smoother by gradually moving the dragon back while the player continues running, making it appear as if the dragon is falling behind naturally.

- **Increasing or Maintaining the difficulty level:** Otherwise, DDA3 checks the following conditions:

  - If the player's setback count is zero. At this point, DDA3 begins a 10-second countdown to ensure that the absence of setbacks is due to the player's ability rather than random chance. If the player maintains a setback count of zero throughout this period, DDA3 decides whether to maintain the current difficulty or increase it. Skill progression is a common feature in both video games and exergames (e.g. [23], [24], [189]) and serves to prevent a monotonous gameplay experience while potentially promoting physical activity during play.

    To make this decision, DDA3 generates a random number between 1 and 10. If the number exceeds 4—indicating a 60% chance to progress the player's skill (while still retaining a 40% chance to keep the current difficulty to avoid overly rapid progression)—the dragon's speed increases by 1 point. This gradual increase prevents the dragon from becoming unrealistically fast and gives the player time to adjust. Otherwise, the difficulty remains unchanged.

- **Move the dragon backward as the player is able to outrun the dragon:** If the dragon enters the closing-to-the-attacking zone (see Figure 4.14—a zone where the dragon is chasing close to the avatar but has not yet reached the attacking zone) for 15 seconds for DDA3 visited round, the dragon moves backward and resets to its initial speed. This mechanism prevents DDA3 from continuously increasing the dragon's speed when no setbacks occur, avoiding excessive adjustments that could lead to fatigue or frustration. Without this adjustment, players who successfully evade the dragon might

experience a lack of reward as the dragon persistently chases them despite their efforts. By providing a period of lower-intensity movement, this design choice aims to reinforce a sense of achievement from overcoming challenges to encourage continued engagement.

Moreover, this approach advances previous DDA implementations found in the related works. In those studies, the DDA functions typically increase difficulty when players do not fail and only decrease it after failures. Such a strategy may encourage persistent players to continually push against increasing challenges, potentially resulting in fatigue. In contrast, the DDA3's design moderates the difficulty adjustment to reward successful evasive actions of players and prevent over-escalation of challenge.

To determine the distance between the dragon and the avatar, the game uses floor cube IDs. The virtual running track consists of interconnected floor cubes, as shown in Figure 6.4. Each newly generated floor cube receives a greater ID than the previous one, creating a sequential numbering system. The distance difference is then calculated as the absolute difference between the floor ID of the dragon and that of the avatar.

This experiment uses floor IDs instead of Euclidean distance (based on x and y coordinates) because the running track is not always a straight path. The game allows players to stretch their arms to turn left or right, resulting in different track layouts such as L-shaped, U-shaped, or straight-line paths. In cases where the dragon and the avatar are on opposite ends of a U-shaped track, their x and y coordinates might appear close in Euclidean terms. However, the dragon would still need to traverse multiple floor cubes to reach the avatar, making Euclidean distance not usable for measuring in-game distance, as illustrated in Figure 6.4.

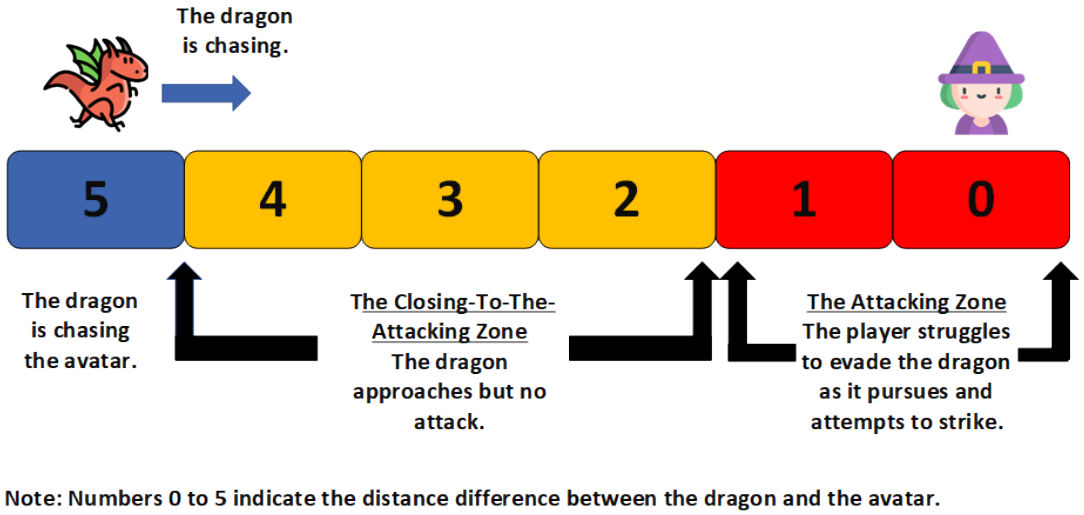

Figure 4.14: Restated figure showing the attacking zone and the closing-to-the-attacking zone in the ExerWitch game.

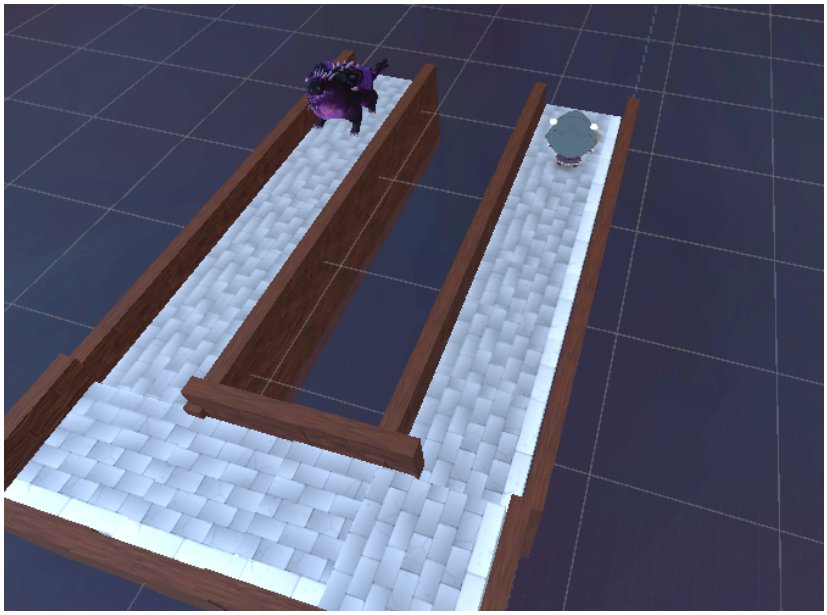

Figure 6.4: The game generates a U-shaped running track, with the dragon and the avatar positioned at opposite ends of the U.

- **Move the dragon close to the avatar as the dragon is positioned too far from the player's avatar (adopting the Rubber-banding concept):** If the dragon is too far from the player's avatar (determined by a distance difference exceeding 8 floor cubes, a value chosen during the development phase based on game simulation, as beyond or around this distance, it becomes difficult for DDA3 to increase the dragon's speed by 1 point to catch up with the avatar), the dragon moves closer by being repositioned to a floor cube at 8 cubes away from the avatar. This adjustment helps maintain player engagement and encourages continuous physical activity by ensuring the dragon remains within the player's sight.

DDA3 was integrated into the exergame and playtested with a small sample of participants (N = 3) to identify and resolve potential bugs in both the game and the DDA3 function. This preliminary phase was important to ensure that the game—using DDA3 as a tool to address the research questions in the main experiment—remained stable and could run smoothly. Moreover, the playtesting phase was used to fine-tune key game parameters, such as the DDA3 evaluation rounds and the number of setbacks required to trigger a decrease in difficulty. These parameters were adjusted based on participant observations to ensure that DDA3's adjustments were neither too sensitive nor too slow, aligning with the intended 10-minute play session. The fine-tuning process involved iterative cycles, with each participant playing the game, followed by parameter adjustments based on how DDA3 adjusted the difficulty, and subsequent sessions incorporating feedback from previous participants until the developer was satisfied with the settings.

6.4 Experimental Method

6.4.1 Experimental Design and Procedure

This experiment was approved by the departmental Physical Science Ethics Committee (see Appendix A). Each participant was incentivised with a £10 Amazon e-voucher and completed a one-hour experiment. The experimental design and procedure were similar to that of Experiment 1; however, this time, participants took part in two experimental conditions shown in Table 6.1.

Condition	Description
No DDA (nDDA)	In this condition, no DDA function was applied. The dragon's speed increased over time. This nDDA condition is similar to Experiment 1.
Performance-based DDA (DDA3)	In this condition, the dragon's speed was adjusted by DDA3 based on player performance (the number of setbacks).

Table 6.1: Experimental conditions used in Experiment 2.

The materials and tools are the same as those used in Experiment 1.

6.4.2 Variables

Based on the review of existing literature on DDA in exergaming, the following variables were defined for testing the hypotheses to answer the research questions:

- Independent Variables:
  - No DDA (nDDA)
  - Performance-based DDA (DDA3)
- Dependent Variables:
  - Setback Count
  - Average Heart Rate
  - BRPE: Perceived Exertion
  - CORGIS: Performative Challenge
  - IMI: Interest/ Enjoyment
  - IMI: Perceived Competence
  - IMI: Pressure/ Tension
  - IMI: Effort/ Importance
  - SFSS: Flow
  - SFSS: Challenge-skill Balance

- Control Variable:
  - The running exergame

6.4.3 Participants

A total of 43 participants (14 males, 26 females, and 3 others) participated in and completed the entire experiment. The average age of the participants was 24.07 years (SD = 5.57).

Regarding physical activity, participants were asked about their exercise habits. However, the questions used in Experiment 1 were abandoned because it was difficult to identify the intensity levels of all the exercises participants engaged in, especially when they performed various types of exercises with differing intensities within a week. Instead, three new questions (adapted from Marcus *et al.* [190]) were introduced to collect information about participants' past and current engagement in physical activity, as well as their intentions to be physically active.

Of the 43 participants, 27 reported currently engaging in regular physical activity, while 32 indicated they had been regularly physically active over the past three months. Additionally, 35 participants expressed an intention to become more physically active in the next three months. Participant demographic data for Experiment 2 are summarised in Table 6.2.

Participant Demographics in Experiment 2	
N	43
Age	M ± SD = 24.07 ± 5.57
Gender	**N**
Man	14
Woman	26
Other	3
Do you currently engage in regular physical activity?	**N**
Yes	27
No	16
Have you been regular physically active for the past 3 months?	**N**
Yes	32
No	11
Do you intend to become more physically active in the next 3 months?	**N**
Yes	35
No	8

Table 6.2: Participant Demographics in Experiment 2

6.4.4 Measures

AHR, perceived exertion, and intrinsic motivation were measured as described in Experiment 1. However, Experiment 2 aimed to provide deeper insights into how players perceive challenge under DDA, as excessive or insufficient challenge can negatively impact PX. To address this, the Challenge Originating from Recent Gameplay Interaction Scale (CORGIS) [15] was used.

Flow, including its challenge-skill balance, was also examined in this experiment. To facilitate completion of the experiment within the allocated time frame, the original Flow State Scale [154] was replaced with the 10-item Flow Short Scale [156], [157]. This scale measures flow, with one item specifically addressing the challenge-skill balance.

Participants' performance in the game was measured by their "setback count", defined as the number of times one's avatar was hit by the dragon during a single gaming session. This data, ranging from 0 (indicating no hits throughout the session) to the maximum integer limit in C#, was automatically recorded by the game application.

6.4.5 Analyses

A paired samples t-test (t) or a Wilcoxon signed-rank test (Z) was used, depending on the data distribution. Spearman's ρ evaluated the relationships between setback count and different player experiences. The alpha level was set at .05.

6.5 Results

This section presents the statistical results of Experiment 2. Table 6.3 shows the results of the normality test.

Reliability (Cronbach's alpha) for the IMI, SFSS, and CORGIS scales is presented in Table 6.4. This experiment acknowledges that some participants did not respond to all items in some factors; therefore, the same method used in Experiment 1 was conducted.

Descriptive statistics and Wilcoxon signed-rank test results are shown in Table 6.6, while descriptive statistics and t-test results for resting and AHR are presented in Table 6.5.

Variables	nDDA (Shapiro-Wilk)			DDA3 (Shapiro-Wilk)		
	Statistic	df	Sig.	Statistic	df	Sig.
Setback Count	.967	43	.256	.801	43	$< .001$
Average Heart Rate	.968	43	.263	.990	43	.962
BRPE: Perceived Exertion	.954	43	.084	.942	43	.030
CORGIS: Performative Challenge	.887	43	$< .001$	.927	43	.009
IMI: Interest/Enjoyment	.956	43	.098	.966	43	.231
IMI: Perceived Competence	.963	43	.179	.909	43	.002
IMI: Pressure/Tension	.949	43	.057	.943	43	.034
IMI: Effort/Importance	.953	43	.078	.950	43	.060
SFSS: Flow	.977	43	.529	.981	43	.676
SFSS: Challenge-skill Balance	.900	43	.001	.881	43	$< .001$

Table 6.3: Shapiro-Wilk normality test results for variables in Experiment 2

Scale/Dimension	Number of Items	nDDA		DDA3	
		N	Cronbach's α	N	Cronbach's α
CORGIS: Performative Challenge	5	42	.884	42	.811
IMI: Interest/Enjoyment	7	43	.877	43	.853
IMI: Perceived Competence	6	41	.910	42	.860
IMI: Pressure/Tension	5	43	.785	43	.716
IMI: Effort/Importance	5	43	.888	43	.844
SFSS: Flow	10	43	.794	43	.718

Table 6.4: Reliability Statistics (Cronbach's α) in Experiment 2

Variables	N	M ± SD		SEM		95% CI		t(42)	p	d
		nDDA	DDA3	nDDA	DDA3	nDDA	DDA3			
Average Resting Heart Rate	43	84.78 ± 14.89	85.92 ± 13.16	2.27	2.01	[80.20, 89.36]	[81.87, 89.97]	-.427	.672	.07
Average Heart Rate	43	140.23 ± 19.27	144.67 ± 18.34	2.94	2.80	[134.30, 146.16]	[139.03, 150.31]	-2.167	.036	.33

Table 6.5: t-test results for resting heart rate and average heart rate in nDDA and DDA2 conditions in Experiment 2.

Variables	N	M ± SD		Mdn		IQR		Ties	Z	p	r
		nDDA	DDA3	nDDA	DDA3	nDDA	DDA3				
Setback Count	43	34.12 ± 19.12	18.23 ± 14.98	34	10	28	18	1	-3.670	< .001*	.56
BRPE: Perceived Exertion	43	13.79 ± 2.59	13.40 ± 2.49	13.00	13.00	2.00	2.00	11	-.866	.386	.13
CORGIS: Performative Perceived Challenge	43	5.64 ± .91	5.67 ± .78	5.80	5.80	1.00	.60	9	-.060	.952	.01
IMI: Interest/Enjoyment	43	5.36 ± .97	5.50 ± .94	5.29	5.43	1.43	1.43	10	-1.673	.094	.25
IMI: Perceived Competence	43	4.74 ± 1.16	5.10 ± 1.02	5.00	5.33	1.70	2.00	1	-2.367	.018*	.36
IMI: Pressure/Tension	43	2.79 ± 1.23	2.69 ± 1.13	3.00	2.60	2.00	1.80	7	-.750	.454	.11
IMI: Effort/Importance	43	5.10 ± 1.33	5.22 ± 1.18	5.40	5.20	2.00	2.00	5	-.881	.379	.13
SFSS: Flow	43	5.10 ± .78	5.17 ± .75	5.20	5.20	1.30	1.20	2	-.701	.483	.11
SFSS: Challenge-skill Balance	43	5.05 ± 1.23	5.47 ± .96	5.00	5.00	2.00	1.00	19	-2.229	.026*	.34

Table 6.6: Descriptive statistics and Wilcoxon Signed-Rank test results for variables in Experiment 2

6.5.1 Setback Count

The analysis revealed a significant difference between conditions, $Z = -3.670, N = 43, p < .001, r = .56$ (large effect). Using DDA3 ($M \pm SD = 18.23 \pm 14.98$, Mdn = 10, IQR = 18) in the exergame resulted in fewer setbacks compared to nDDA ($M \pm SD = 34.12 \pm 19.12$, Mdn = 34, IQR = 28), suggesting that DDA3 has effectively reduced the number of setbacks. Therefore, the null hypothesis of H_6 was rejected.

Figure 6.5 presents boxplots of Setback Count, showing the distribution.

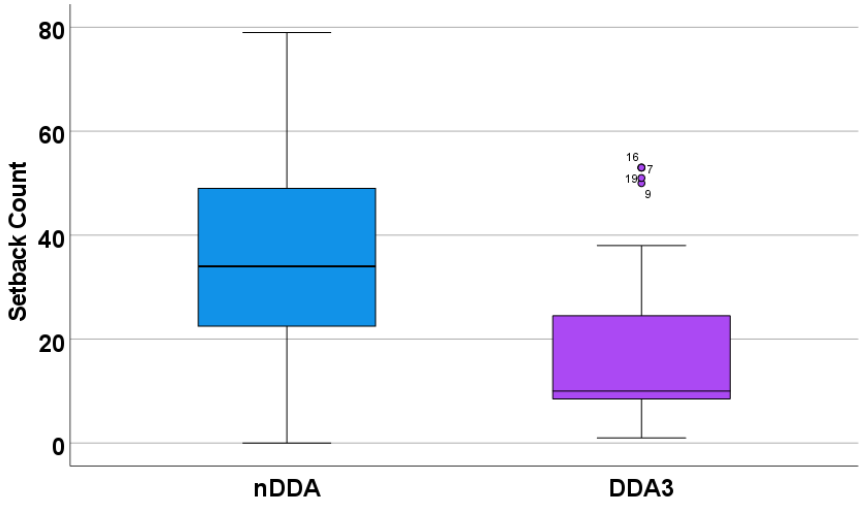

Figure 6.5: Box plots illustrating the Setback Count in No DDA condition (nDDA) and Performance-based DDA condition (DDA3) in Experiment 2.

6.5.2 Average Heart Rate

First, the order effect was examined by comparing the average resting heart rates between the two conditions, measured before the game started. No significant difference was found, $t(42) = -.427, p = .672, d = .07$ (negligible effect size), suggesting the absence of an order effect.

Figure 6.6 shows box plots depicting the distribution of resting heart rate (in BPM) in nDDA and DDA3 conditions.

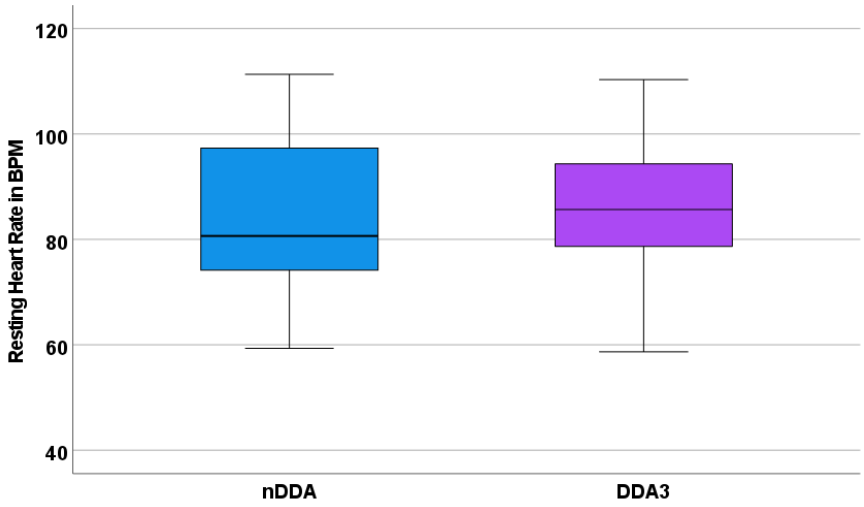

Figure 6.6: Box plots illustrating Resting Heart Rate (in BPM) in No DDA (nDDA) and Performance-based DDA (DDA3) conditions in Experiment 2.

During gameplay, however, AHR differed significantly between the conditions: $t(42) = -2.167, p = .036, d = .33$ (small effect). The DDA3 condition resulted in higher AHR ($M \pm SD = 144.67 \pm 18.34$) than the nDDA condition ($M \pm SD = 140.23 \pm 19.27$). Therefore, the null hypothesis of H_1 was rejected.

Figure 6.7 presents box plots illustrating the distribution of average heart rate (in BPM) during playtime in nDDA and DDA3 conditions.

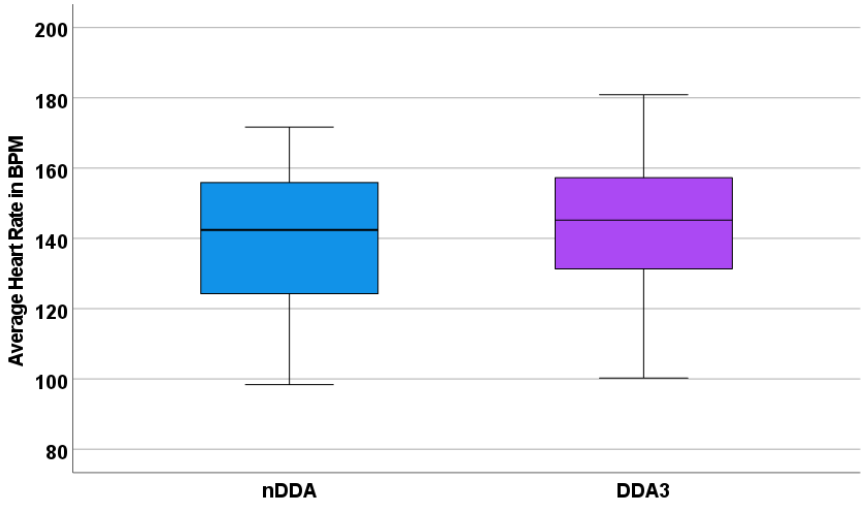

Figure 6.7: Box plots illustrating Average Heart Rate (in BPM) in No DDA (nDDA) and Performance-based DDA (DDA3) conditions in Experiment 2.

6.5.3 BRPE: Perceived Exertion

The result showed no significant difference between the exergame with and without DDA3: $Z = -.866, N = 43, p = .386, r = .13$ (small effect). Therefore, the null hypothesis of H_2 was supported.

Box plots showing the distribution of BRPE: Perceived Exertion in nDDA and DDA3 conditions are presented in Figures 6.8.

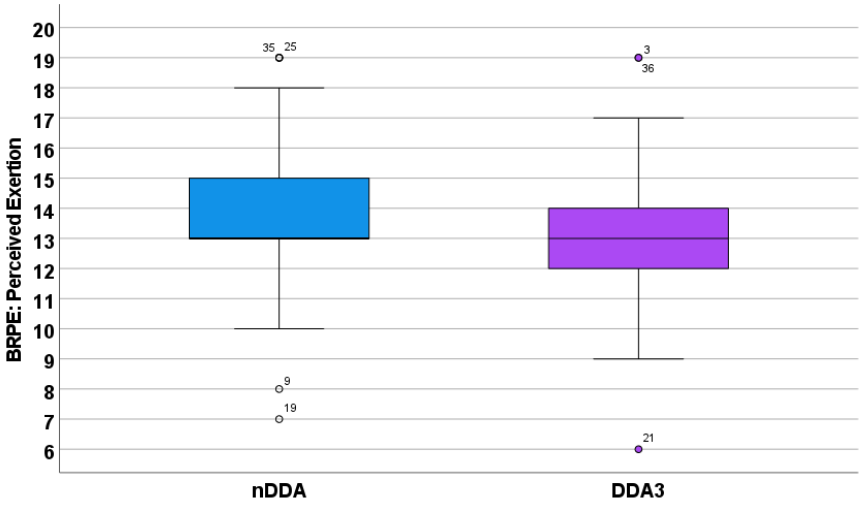

Figure 6.8: Box plots illustrating BRPE: Perceived Exertion in No DDA (nDDA) and Performance-based DDA (DDA3) conditions in Experiment 2.

6.5.4 CORGIS: Performative Perceived Challenge

The null hypothesis of $H_{3.A}$ was not rejected, as the performative perceived challenge did not differ between the conditions: $Z = -.060, N = 43, p = .952, r = .01$, indicating a negligible effect.

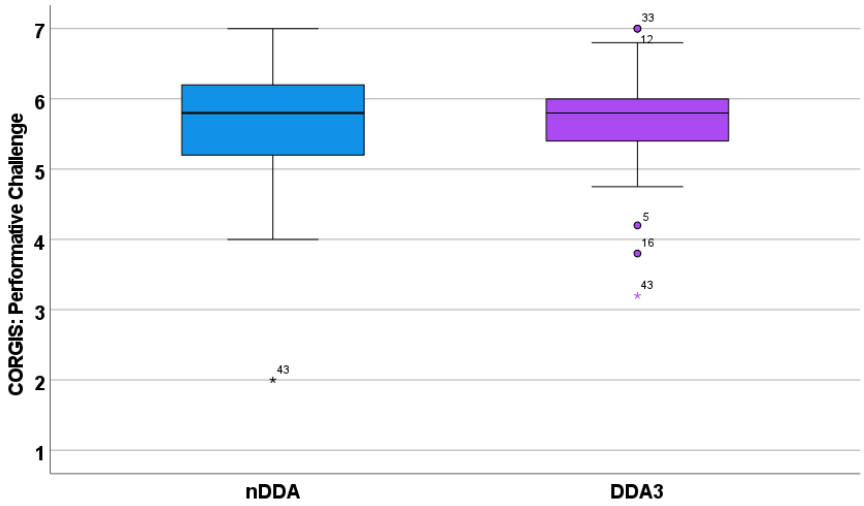

Figure 6.9: Box plots illustrating CORGIS: Performative Perceived Challenge in No DDA (nDDA) and Performance-based DDA (DDA3) conditions in Experiment 2.

6.5.5 IMI: Intrinsic Motivation

Perceived competence was higher in the DDA3 condition ($M \pm SD = 5.10 \pm 1.02$, Mdn = 5.33, IQR = 2.00) than in the nDDA condition ($M \pm SD = 4.74 \pm 1.16$, Mdn = 5.00, IQR = 1.70) and this difference was significant: $Z = -2.367, N = 43, p = .018, r = .36$ (medium effect). Hence, the null hypothesis of $H_{4.B}$ was rejected.

However, there was no significant difference in interest/ enjoyment: $Z = -1.673, N = 43, p = .094, r = .25$ (small effect), effort/ importance: $Z = -.881, p = .379, r = .13$ (small effect), or pressure/ tension: $Z = -.750, p = .454, r = .11$ (small effect). Thus, the null hypotheses of $H_{4.A}$, $H_{4.C}$, and $H_{4.D}$ were not rejected.

Box plots showing the distribution of IMI: Perceived Competence in nDDA and DDA3 conditions are shown in Figures 6.10.

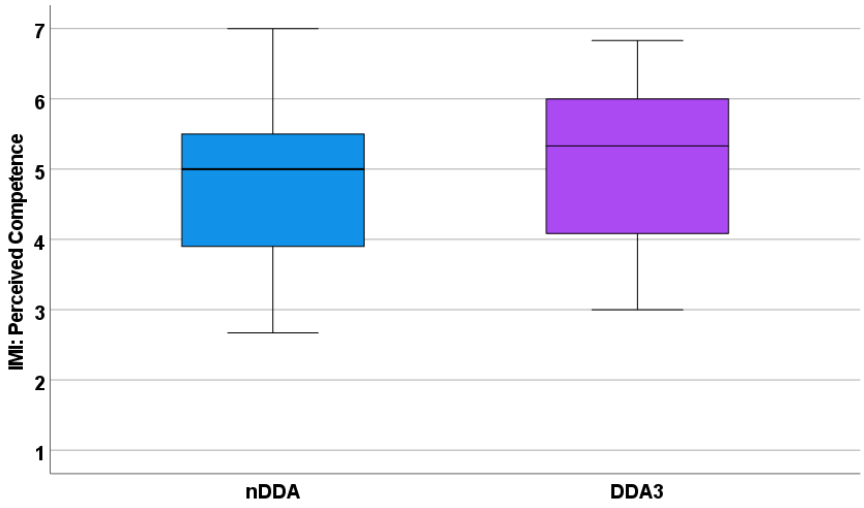

Figure 6.10: Box plots illustrating IMI: Perceived Competence in No DDA (nDDA) and Performance-based DDA (DDA3) conditions in Experiment 2.

Figure 6.11 presents box plots showing the distribution of IMI: Interest/Enjoyment in nDDA and DDA3 conditions.

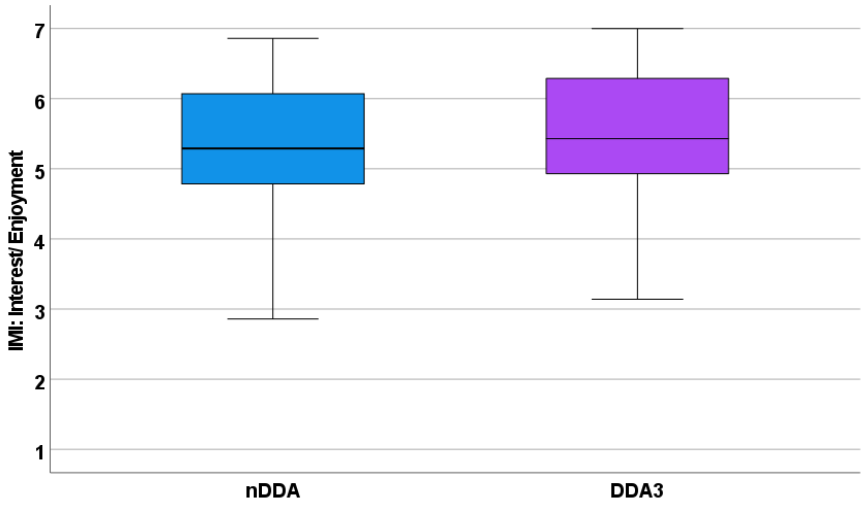

Figure 6.11: Box plots illustrating IMI: Interest/ Enjoyment in No DDA (nDDA) and Performance-based DDA (DDA3) conditions in Experiment 2.

Figure 6.12 shows box plots of the distribution of IMI: Effort/Importance in nDDA and DDA3 conditions.

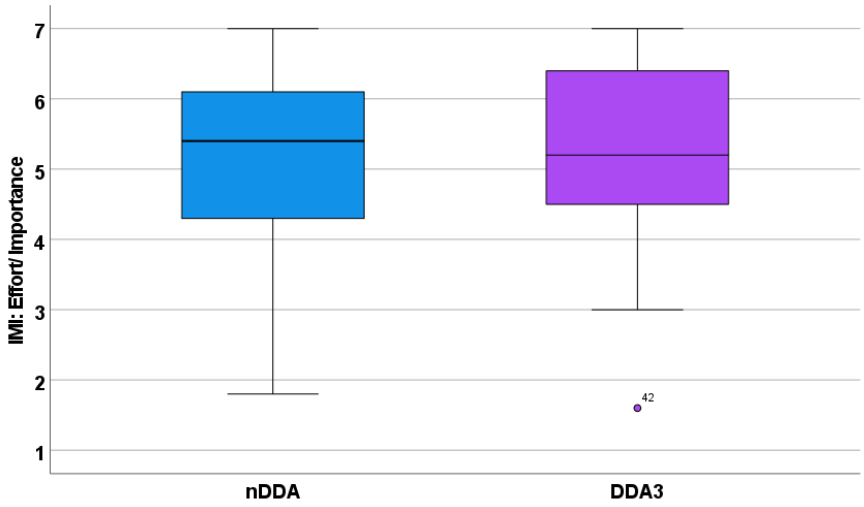

Figure 6.12: Box plots illustrating IMI: Effort/ Importance in No DDA (nDDA) and Performance-based DDA (DDA3) conditions in Experiment 2.

Figure 6.13 shows box plots illustrating the distribution of IMI: Pressure/Tension in nDDA and DDA3 conditions.

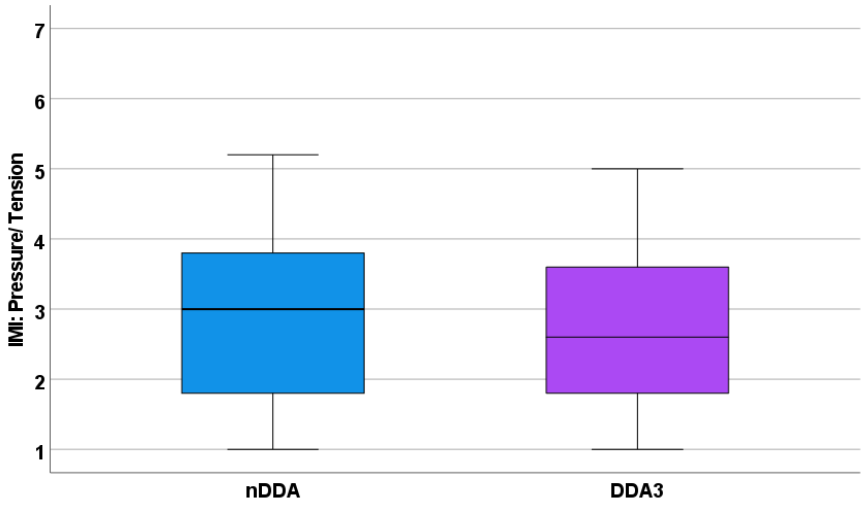

Figure 6.13: Box plots illustrating IMI: Pressure/ Tension in No DDA (nDDA) and Performance-based DDA (DDA3) conditions in Experiment 2.

6.5.6 SPSS: Flow

There was no significant difference in flow between the conditions: $Z = -.701, N = 43$,p= $.483, r = .11$ (small effect). Therefore, the null hypotheses of $H_{5.A}$ was not rejected. However, the challenge-skill balance within flow was significantly higher in DDA3 ($M \pm SD = 5.47 \pm .96$,

Mdn = 5.00, IQR = 1.00) compared to nDDA ($M \pm SD = 5.05 \pm 1.23$, Mdn = 5.00, IQR = 2.00), $Z = -2.229, N = 43, p = .026, r = .34$ (medium effect) This finding suggests a rejection of the null hypothesis of $H_{5.B}$ for the challenge-skill balance.

Figure 6.14 shows box plots of SFSS: Flow in nDDA and DDA3 conditions.

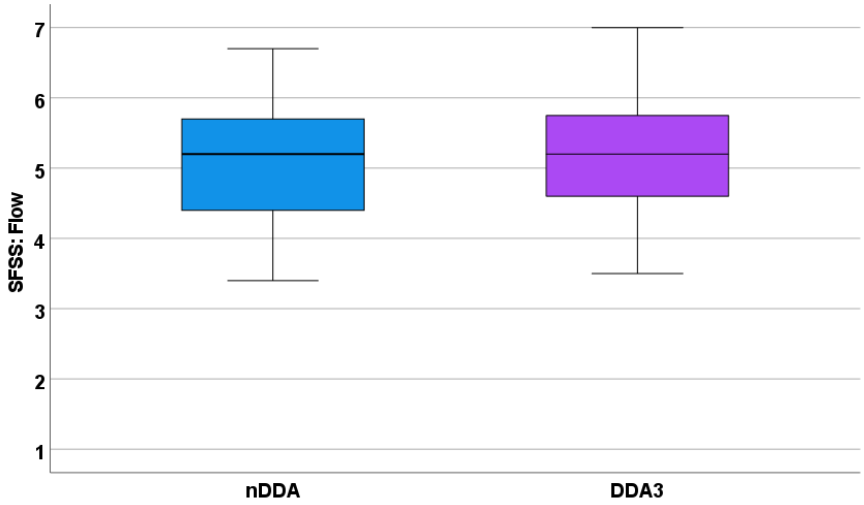

Figure 6.14: Box plots illustrating SFSS: Flow in No DDA (nDDA) and Performance-based DDA (DDA3) conditions in Experiment 2.

Figure 6.15 shows box plots showing distributions of SFSS: Challenge-skill Balance in nDDA and DDA3.

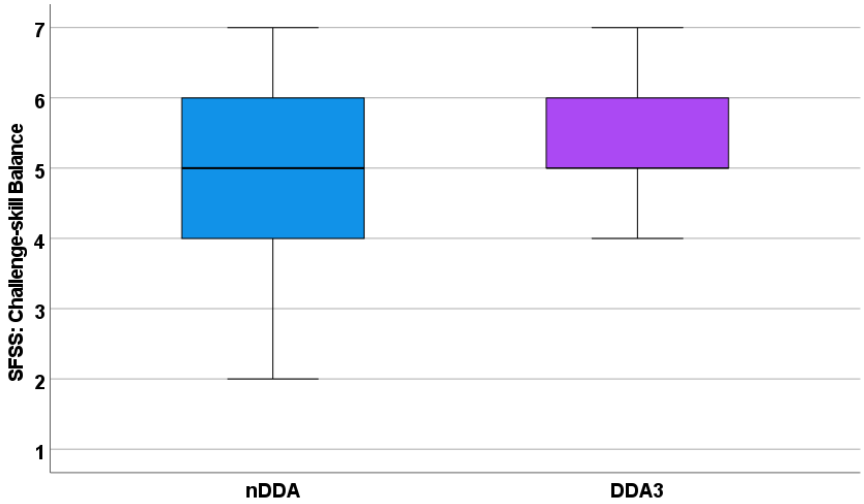

Figure 6.15: Box plots illustrating SFSS: Challenge-skill Balance in No DDA (nDDA) and Performance-based DDA (DDA3) conditions in Experiment 2.

6.5.7 Additional Analysis: Correlations Between Setback Count and Player Experience

During gameplay in both the DDA3 and nDDA conditions, participants were observed, and some expressed decreased motivation and frustration after repeatedly failing to avoid the dragon chase. Given that DDA3 adjusts game difficulty based on player setbacks (performance data), it is worth considering whether this mechanism might be related to any negative PX. To investigate this for future DDA design improvements, the correlation between setback count and PX was analysed.

In the DDA3 condition, there was a negative significant correlation between setback count and perceived competence: r_s = -.363, p = .017, indicating that players who experienced fewer setbacks perceived themselves as more competent.

Figure 6.16: A scatter plot depicting the relationship between perceived competence and setback count in rank for both conditions, with blue strips representing No DDA (nDDA) and purple circles representing Performance-based DDA (DDA3).

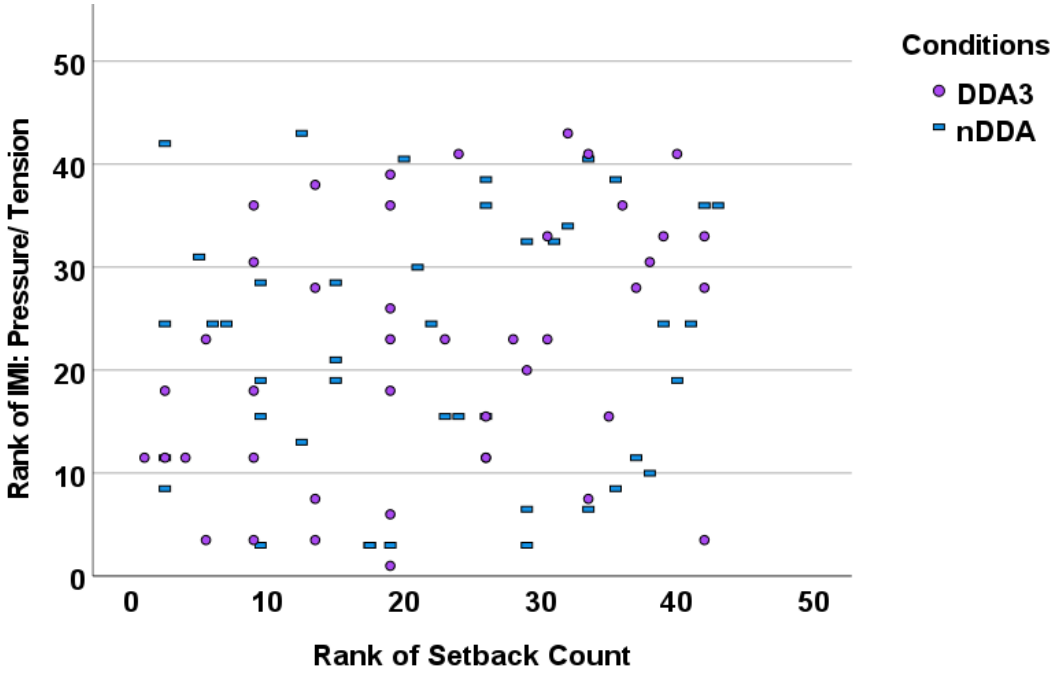

Figure 6.17: A scatter plot depicting the relationship between pressure/ tension and setback count in rank for both conditions, with blue strips representing No DDA (nDDA) and purple circles representing Performance-based DDA (DDA3).

Conversely, there was a positive significant correlation between setback count and pressure/ tension: $r_s = .357$, $p = .019$, suggesting that players with higher setback rates reported feeling more pressure/ tension.

However, no significant correlations were found in the nDDA condition.

6.6 Discussion

This experiment investigated the impact of performance-based DDA (DDA3) on PX and physical effort in a running exergame, compared to a no-DDA condition (nDDA). DDA3 demonstrated efficiency in reducing the number of setbacks while inducing a higher perception of challenge-skill balance than nDDA. Moreover, DDA3 increased perceived competence and encouraged participants to invest more physical effort, as indicated by a higher average heart rate, though no difference was found in perceived exertion.

The results provide insight into another type of DDA function commonly used in exergames, as discussed in the review, highlighting its impact on PX and physical effort within an exergame with a single physical challenge to address the research questions.

This section situates these findings within the context of existing research on in-game adaptations using performance data. Also, the potential implications for the design of DDA in future adaptive exergames are given.

6.6.1 Competence, Flow, and Challenge-Skill Balance

The results align with SDT [16], especially the competence need. The reduced number of setbacks in the DDA3 condition suggests players experienced fewer setbacks, leading them to overcome challenges consistently. This consistency may promote a sense of achievement and mastery, which directly enhances perceived competence. In contrast, the higher setbacks in the nDDA condition likely disrupted this mastery cycle, leading to lower competence satisfaction (as further analysis showed a negative relationship between competence and setback count).

This experiment provides evidence that P-based DDA potentially promotes players' competence in exergames. It also addresses gaps in previous research, particularly the small sample size used by Ajani *et al.* [27] but found no significant difference in perceived competence compared to nDDA.

A key limitation in prior research using P-based DDA in low-intensity exercise games, such as Pong, was the narrow range of exertion levels for difficulty adjustment, which may have reduced players' perception of difficulty changes. This experiment addresses that gap, as previous findings by Ajani *et al.* [27], Darzi *et al.* [28], and Goršič *et al.* [38] report mixed results on the impact of P-based DDA on perceived competence. Besides, this experiment fills a gap left by Martin-Niedecken *et al.* [23], who did not measure competence in high-intensity exergames with P-based DDA compared to nDDA. Therefore, this experiment shows that P-based DDA, when adjusting difficulty across a wide range of exertion levels, can enhance players' perceived competence.

Regarding challenge-skill balance, DDA3 design shows that difficulty adjustment does not always make the game too easy or simply match player skill without progress (as shown in original flow theory [13]). Instead, it should provide an experience that is challenging yet achievable, fluctuating between moments of difficulty and ease, as mentioned by Sorenson *et al.* [105]. DDA3 is designed to activate when players attempt to overcome obstacles for a specific interval, assisting them if they ultimately cannot avoid them. Moreover, if players remain too far from the dragon for a certain period, DDA3 increases the speed of the dragon or moves the dragon closer to challenge them to run faster.

With this mechanism, the game remains as challenging as nDDA, but with DDA3's support when players struggle, helping them feel more competent and reinforcing their sense that their skill matches the challenge, as reflected in a significantly higher challenge-skill balance in DDA3 compared to nDDA.

This is also supported by the box plots in Figure 6.15, which show a noticeably narrower IQR for DDA3 compared to nDDA. This reduced IQR in DDA3 suggests lower variability in participants' perceived challenge-skill balance. Specifically, the central 50% of participants in the DDA3 condition reported more consistent perceptions, whereas the wider IQR in nDDA indicates greater diversity in player perceptions of challenge-skill balance.

However, while DDA3 was designed based on Flow Theory to balance player skill and challenge and it can enhance this factor, the results show no significant difference in flow between conditions. This finding aligns with some previous studies [23], [28] but contrasts with others [24], [27]. It should be noted that the conflicting studies have limitations, such as not fully

automatic DDA or involving lower-intensity exercise.

In Flow Theory [13], [14], multiple factors work together to facilitate an individual to reach the flow channel. This experiment argues that DDA functions (e.g. DDA3) that simply address the challenge-skill balance may not be potential enough to enhance the overall flow state of players, as they are not designed to account for other components of flow.

Overall, this experiment suggests that DDA3 can potentially enhance challenge-skill balance and competence compared to nDDA. In the context of exergames, this can be useful since playing exergames involves not only cognitive demands but also physical demands as a core component. If players encounter repeated failures, especially due to physical challenges, the combination of frustration from being unable to overcome obstacles and fatigue from exertion may intensify negative PX, potentially leading to disengagement.

P-based DDA can help mitigate this scenario by assisting players when they struggle while also providing easier phases for recovery. This adjustment may encourage longer play sessions compared to nDDA, potentially contributing to improved player engagement.

6.6.2 Interest/Enjoyment, Pressure/Tension, and Perceived Challenge

This experiment addresses gaps in previous studies [23], [24] that have reported mixed findings on how players perceive challenge when playing with DDA using performance data. While DDA has been associated with increased perceived challenge in some studies, other findings indicate no difference or suggest that nDDA results in a higher perceived challenge with less optimal balance. Moreover, a limitation of Martin-Niedecken *et al.* [24] is that their DDA was not fully automated, as difficulty adjustments were made manually by the investigator.

Although this experiment does not measure perceived challenge in the exact same way as the mentioned studies—such as defining it in terms of optimal challenge, insufficient challenge, or heightened perceived challenge—the results show that players did not perceive the game as demanding quick any differently in DDA3 compared to nDDA.

One possible explanation for the lack of difference could be the nature of the exergame and when DDA3 takes action. The core gameplay requires players to run away from the dragon, increasing their running speed as the dragon approaches and attacks. In DDA3, players must first experience a setback before getting helps, meaning they have already attempted to outrun the dragon but failed. This may cause a similar experience to nDDA, where players also need to run faster to escape. As a result, they may not perceive a difference in the need to react quickly or slowly, leading to no significant variation in this factor.

Regarding pressure/tension, no significant difference was found between conditions. One possible explanation is that the moderate-to-high physical activity (running) required in this exergame may have overshadowed psychological pressure/ tension. Players may not have perceived the game experience modified by DDA3 as a major factor affecting their pressure/tension, as the physical exertion itself had a more dominant impact on their stress levels, leading to no noticeable difference.

Another explanation could be that DDA3 was not designed to adjust any game elements

directly related to psychological pressure/ tension. This justification may be supported by related works [27], [28], [38], which all used a similar Pong-based game and adjusted the same difficulty parameters—the speed of the ball and the paddle size. In these studies, while players primarily responded to challenges using hand movements, they also needed strategic thinking to outplay opponents (a cognitive challenge might be involved here). Changes in ball speed or paddle size may have intensified the game, requiring players to rethink their strategies, which could explain why Darzi *et al.* [28] and Goršič *et al.* [38] found increased pressure/ tension in DDA compared to nDDA (however, another study [27] reported no difference, which may be due to their relatively small sample size). In the context of this research, P-based DDA was designed to adjust only a single physical challenge, which may explain why no impact on pressure/tension was observed compared to nDDA.

The impact of P-based DDA on enjoyment has shown mixed results in previous studies [23], [24], [27], [28], [38]. Moreover, some studies [27], [28], [38] that used similar games (e.g. Pong), questionnaires, and difficulty parameters adjusted by DDA have reported conflicting findings. However, in this experiment, the analysis showed that P-based DDA did not impact player enjoyment differently from nDDA.

One possible explanation for the lack of difference in enjoyment, as well as the mixed results in the previous studies, may relate to two factors: (1) whether the game was designed with enjoyable elements and whether the goal of DDA aims to address those elements, and (2) whether the game experience adjusted by DDA satisfied players' needs.

First, while the exergame was designed based on flow theory [13] and the gameflow model [96], following these principles does not mean that all players will perceive the game as enjoyable. Although players rated their enjoyment levels in both DDA3 and nDDA as agreeable, this game lacked various enjoyable elements (featuring only a dragon that challenged players to run), and the goal of DDA3 was solely to balance challenge and skill rather than to enhance other game elements related to enjoyment. As a result, the changes in game experience from DDA3—such as the moments when the dragon approached or moved away—may not have been distinct enough for players to perceive them as fun, leading to no difference in enjoyment between conditions.

Although DDA3 enhanced players' competence compared to nDDA, this increase may not have been strong or satisfying enough for players to perceive greater competence as a source of enjoyment. Thus, this experiment argues that, in contrast to some literature [16], [100], [101], increased competence does not always lead to increased enjoyment.

Overall, even though competence and challenge-skill balance increased, P-based DDA, which addresses only a single physical challenge, may not sufficiently enhance the game experience to promote other aspects of PX that could also be considered useful for promoting player engagement.

It should be noted that the exergame and the specific DDA design in this experiment influenced certain observed variables. However, this does not suggest that P-based DDA has no impact on other player experiences in different game contexts, such as relatedness, which has been observed in DDA with competitive or social video games [191].

6.6.3 Average Heart Rate, Perceived Exertion, and Effort/Importance

This experiment provides insights into P-based DDA, addressing the limited number of studies exploring its impact on AHR and perceived exertion. The findings indicate that playing in DDA3 led to greater physical effort, resulting in a higher AHR compared to nDDA. This experiment also fills the gap of Martin-Niedecken *et al.* [24]'s work on a full-body exergame, which found no difference in AHR. However, their DDA is not fully automatic, as difficulty adjustments were made manually by the investigator during the experiment.

Even though AHR increased in DDA3, perceived exertion levels did not differ between conditions. One possible explanation might be from the game experience generated by DDA3. When DDA3 moves the dragon closer or increases its speed, players must stay physically active in anticipation of the dragon's approach and attack. However, when the dragon slows down or moves away, players experience brief moments of lower exertion or relaxation. This dynamic pacing may have helped balance their perceived exertion while still keeping them physically active, resulting in no noticeable difference between conditions despite the higher AHR.

Compared to nDDA, the dragon's speed increases over time until players can no longer escape, ultimately leading to attacks and setbacks. Even if players attempt to evade the dragon, their efforts may feel unrewarded, leading to a loss of motivation or the perception that exerting more effort is not worthwhile. So, AHR in nDDA was lower than in DDA3.

Even though the results showed a significant increase in AHR, this does not indicate that playing in DDA3 promotes greater physical benefits in a health-related context. In this research, AHR is used only to describe the level of physical effort. Although there is a small difference in AHR (approximately 5 BPM) between the conditions, this experiment suggests that applying P-based DDA encourages players to stay physically active. However, if the goal of the game is to reach and maintain higher exercise intensity zones, incorporating other types of DDA (e.g. DDA1) or further exploring alternative techniques may be a more suitable approach.

With the mixed results in previous studies [27], [28], [38] on effort/importance, this experiment addresses gaps related to the limited number of participants [27], [28] and the use of low-intensity exergames such as Pong [28], [38]. In the context of a moderate-to-high-intensity exergame, where one main physical challenge is adjusted by P-based DDA, the results show no significant difference in effort/importance compared to nDDA.

One possible explanation comes from Sewell *et al.* [44], who suggests that motivational effort requires both (1) sustained engagement (frequency—beyond the scope of this single-session experiment) and (2) invested effort (intensity). While DDA3 effectively balanced a challenge-skill factor, the exergame lacked motivational design elements, such as rewards, a sense of control, or social interaction (autonomy and relatedness in SDT [16]), which may also influence players' effort. Moreover, DDA3 was not designed to address effort-related game elements.

Although DDA3 potentially enhanced players' perceived competence compared to nDDA, this increase in competence may not have been strong enough or the key factor driving players to invest greater motivational effort in the game to regain a sense of competence. This could

explain the lack of difference in effort/importance between conditions.

6.6.4 Correlation between Setback Counts, Perceived Competence, and Pressure/ Tension

The correlation analysis indicates that the number of setbacks is associated with increased pressure/tension and decreased perceived competence in the DDA3 condition.

This finding aligns with observations of players frequently showing negative facial expressions (e.g. frustration) during repeated setbacks before DDA3 adjusted the dragon's speed. While DDA3 did not impact pressure/tension differently compared to nDDA, the accumulation of setbacks appears to have unintended psychological effects.

According to previous studies [10]–[12], setbacks or failures in video games can sometimes be beneficial, promoting a sense of accomplishment, enjoyment, or self-improvement. However, in an exergame context where physical activity is involved, players invest both physical and mental effort. With this, experiencing setbacks frequently and getting punishment from being attacked by the dragon before DDA3 takes action may lead players to perceive them as repeated failures, potentially negatively impacting PX. This could result in a decreased sense of competence and increased frustration, which may, in turn, lead to heightened pressure.

Although DDA3 promotes competence and challenge-skill balance without inducing pressure/tension differently compared to nDDA, its reliance on setbacks for difficulty adjustment may lead to unintended negative consequences. This opens an opportunity to explore an alternative approach to P-based DDA to mitigate this issue, as explained in Section 6.8.

6.6.5 Limitations

Although the sample size is comparable to related work [23], [24], some observed variables should be interpreted with caution due to small effect sizes.

The analysis revealed a significant difference in challenge-skill balance between conditions; however, this factor was measured using a single-item self-report measure, which may limit its internal consistency.

6.7 Suggestions for Performance-Based DDA Design

Observations revealed a limitation of DDA3 when applied to high-skill players. This issue became evident in two participants who identified as frequent exercisers. Their exceptional performance, with minimal failures (rarely being hit by the dragon), led the DDA to continuously increase the game's difficulty. However, the DDA function's reliance solely on performance data overlooked the players' physical exertion, potentially leading to a negative PX due to excessive exercise intensity.

To address this limitation, future research could explore a combined DDA function that incorporates both performance-related data and physiological data related to exercise intensity. This integrated approach might offer a more comprehensive assessment for optimal difficulty adjustment, taking into account both a player's skill level and their physical capabilities.

6.8 Next Experiment

The current DDA3 design, which adjusts difficulty based on player setbacks when players cannot overcome challenges, may negatively impact PX. Correlation analysis revealed a negative relationship between the number of setbacks and perceived competence, while setback frequency was positively associated with increased pressure/ tension.

Hunicke *et al.* [137] described that DDA functions commonly assist players when struggling through two approaches: reactive action, which adjusts difficulty in response to players' real-time interactions with challenges (as seen in this experiment), and proactive DDA, which anticipates potential failures or setbacks and adjusts difficulty before challenges are presented to players. Given that the current DDA3 relies solely on setback-based adjustments, future research could explore alternative DDA mechanisms that do not depend only on player setbacks as the trigger for difficulty adjustment.

One potential approach involves adjusting the dragon's speed based on its distance from the avatar. If the dragon gets too close, the function could slow it down to prevent immediate setback and frustration. Conversely, if the dragon falls too far behind, it could accelerate to maintain a challenging pace and prevent monotony. By implementing this proactive approach, player experience may improve through increased competence satisfaction, reduced pressure/ tension, and decreased frustration, potentially leading to more engaging game experience compared to DDA3.

6.9 Chapter Summary

This experiment adopted a within-subjects design with 43 participants across two experimental conditions: a control condition (nDDA) and a P-based DDA condition (DDA3). The key takeaways from this experiment are as follows:

1. This experiment aligns with SDT in supporting perceived competence satisfaction. In DDA3, players experienced fewer setbacks, potentially fostering a sense of achievement and mastery, which reinforced their perceived competence. In contrast, the nDDA condition resulted in more frequent setbacks, potentially disrupting the mastery cycle and leading to lower competence satisfaction.

   DDA3 was designed to provide a balanced experience by adjusting difficulty dynamically. When players struggled, it reduced difficulty to prevent negative PX. Conversely, when the game became too easy, it increased difficulty to sustain the challenge-skill balance and progress players' skills. This adaptive function helped promote a sense of competence and a balanced level of challenge in DDA3 compared to nDDA.

However, the findings indicate no significant difference in flow between conditions. While P-based DDA influenced competence satisfaction and challenge-skill balance, it may not be sufficient to impact the overall flow experience, which depends on multiple factors.

2. This experiment addresses gaps in previous studies regarding players' perceived challenge when playing with DDA using performance data. Previous findings have been mixed, with some studies indicating increased perceived challenge with DDA, while others show no difference or suggest higher perceived challenge without DDA.

   The results of this experiment show that players did not perceive the game as demanding quick (performative perceived challenge) any differently in DDA3 compared to nDDA. This could be due to the nature of the exergame and the limited scope of difficulty adjustment, focusing on a single physical challenge. Both DDA3 and nDDA created a comparable gameplay experience, where players must run faster to evade the dragon, leading to no significant variation in the need to react quickly or slowly.

   Regarding pressure/tension, no significant difference was found between the conditions. The physical activity required in the exergame may have overshadowed psychological pressure, and DDA3 was not designed to adjust elements related to psychological stress.

   The impact of DDA on enjoyment has shown mixed results in previous studies. In this experiment, P-based DDA did not impact player enjoyment differently from nDDA. Factors contributing to this could include the design of the game with enjoyable elements and the goal of DDA, as well as whether the game experience satisfied players' needs.

3. In this exergame, which involves moderate-to-high exercise intensity with P-based DDA, the increase in AHR suggests greater physical effort. However, perceived exertion did not differ from nDDA. This outcome may be influenced by dynamic pacing in DDA3, which balances periods of high and low exertion. Although DDA3 led to higher AHR, this did not necessarily translate to a greater sense of motivational effort/ importance.

The next chapter presents Experiment 3, which further explores P-based DDA in the exergame, examining both reactive and proactive adjustments as mentioned in Section 6.8.

Chapter 7

Experiment 3: Further Exploration of Performance-based DDA: Reactive and Proactive actions

7.1 Introduction

Experiment 2 demonstrated both the strengths and limitations of DDA3. While DDA3 enhanced perceived competence and the balance between challenge and skill compared to nDDA, the findings also revealed unintended negative experiences, particularly related to setbacks. The correlation analysis from Experiment 2 (see additional analysis) indicated that the number of setbacks during playtime was associated with increased pressure/tension and reduced competence. This suggests that while overcoming setbacks can be beneficial to promote sense of achievement, frequent or prolonged setbacks may negatively impact PX, especially in exergames where physical exertion is involved.

According to Hunicke *et al.* [137], DDA functions can operate in two ways: reactive and proactive actions. As mentioned earlier in the review, reactive action is when DDA adjusts difficulty while the player is struggling with game challenges, while proactive DDA takes action before challenges are presented to the player, anticipating that the player is likely to encounter failures from the upcoming challenges.

Reflecting on this research, the reactive approach (DDA3) adjusts the game's difficulty based on player interactions with the chasing dragon. Specifically, the dragon appears in the area, initiates an attack, and causes setbacks. In addition, the dragon's speed increases to maintain the challenge, depending on the setback count.

This reactive action ensures that players struggle to overcome challenges before the game adapts, which can be beneficial in several ways. Research [10]–[12], [86] in traditional video games suggests that struggling to overcome setbacks or failures can enhance a sense of accomplishment and enjoyment. Moreover, setbacks may encourage players to refine their skills [12]. This argument might be reflected in exergames, as the reactive DDA approach (DDA3), which adjusts game difficulty based on setbacks, might motivate players to invest

more physical effort to improve their performance and avoid future setbacks.

However, some players might perceive the prolonged struggle before DDA3 is triggered or the frequency of setbacks they encounter as repeated setbacks or failures, which could lead to frustration rather than motivation. Studies argue that frequent setbacks and their consequences can heighten pressure, tension, and frustration while reducing enjoyment [12], [83], [90]. In exergames, where physical exertion is a key element, these negative emotions may be intensified by fatigue after extended play, potentially reducing players' persistence to continue [37].

While reactive P-based DDA has been adopted in prior exergame studies (e.g. [23], [24], [27]), proactive P-based DDA (DDA4) remains under-explored in this context, particularly regarding its impact on players. This experiment proposes a proactive DDA function designed to prevent player setbacks while maintaining challenge during gameplay.

Unlike reactive approaches, which trigger adjustments based on the number of setbacks a player gets while the dragon is in an attacking zone, this proactive function monitors the distance between the dragon and the player to dynamically adjust the dragon's speed. If the player gets too close to the dragon (indicating the game is too difficult), the dragon's speed decreases pre-emptively to avoid setbacks. Conversely, if the player remains far ahead for a sustained interval (suggesting the game is too easy), the dragon's speed increases to sustain challenge.

By adjusting the difficulty proactively, this function aims to reduce frustration and provide a smoother experience (as the avatar does not become immobile for a while after the dragon's attacks). However, it is important to note that by eliminating setbacks, the proactive P-based DDA may forfeit the benefits of reactive P-based DDA, such as enhanced enjoyment or increased player effort, which typically arise from overcoming challenges and experiencing a sense of accomplishment.

Given the limited exploration of how proactive P-based DDA (DDA4) impacts PX and physical effort compared to the reactive approach (DDA3), this experiment aims to investigate this and answer Research Question 3:

This experiment aims to offer insights into how different DDA functions (DDA3 and DDA4) shape player experience and physical effort. It also aims to provide insights for game designers about the potential trade-offs between proactive and reactive approaches to DDA in exergames.

7.2 Hypotheses

The following hypotheses were created based on the review to address the research questions:

H_1: Average heart rate during playtime differs between exergames with proactive P-based DDA and those with reactive P-based DDA.

H_2: Perceived exertion differs between exergames with proactive P-based DDA and those

with reactive P-based DDA.

In reactive P-based DDA, during the dragon's attack phase, players may run faster to evade the dragon and avoid setbacks before the DDA adjusts the difficulty if players fail to escape. With this approach, they may exert greater physical effort, potentially leading to higher average heart rate (AHR) and perceived exertion. In contrast, proactive P-based DDA adjusts difficulty before setbacks occur, meaning players may not need to exert as much effort to avoid setbacks. So, without the pressure of setbacks, they may also engage less actively.

Although existing research has not directly examined this effect, it is possible that different game experiences influenced by different DDA functions may lead to differences in AHR and perceived exertion. This is supported by findings in Experiment 1 and 2, where the different DDA functions resulted in differences in AHR and perceived exertion compared to nDDA.

Since there is a lack of research investigating the effects of proactive P-based DDA on AHR and perceived exertion compared to reactive P-based DDA, this experiment hypothesises (without assuming a specific direction) that playing the running exergame with proactive P-based DDA will lead to differences in AHR and perceived exertion compared to playing with reactive P-based DDA (H_1 and H_2).

H_3: Needs satisfaction: competence ($H_{3.A}$) and needs frustration: competence ($H_{3.B}$) differ between exergames with proactive P-based and those with reactive P-based DDA.

H_4: The challenge-skill balance differs between exergames with proactive P-based and those with reactive P-based DDA.

H_5 Intrinsic motivation: pressure/tension ($H_{5.A}$), interest/ enjoyment ($H_{5.B}$), and effort/ importance ($H_{5.C}$) differ between exergames with proactive P-based and those with reactive P-based DDA.

H_6: Performative perceived challenge differs between exergames with proactive P-based and those with reactive P-based DDA.

In this experiment, both DDA3 and DDA4 were implemented based on the challenge-skill balance in flow theory [13] to assist players when they struggle and increase the challenge when the game is too easy. However, DDA4, which adjusts the game difficulty before players are likely to encounter setbacks, may enhance their perception that they can escape the dragon by their own effort compared to DDA3. Nevertheless, the absence of setbacks could also make the game feel less challenging compared to DDA3. With the unclear impacts of DDA4 compared to DDA3 and lack of existing works, Therefore, this experiment expects differences in the challenge-skill balance between the conditions.

The additional analysis in Experiment 2 shows that the number of setbacks in the game with DDA3 is related to increased pressure/tension and decreased perceived competence. However, the proposed DDA4 in this experiment adjusts the game difficulty to prevent players from facing setbacks. Therefore, this experiment expects different experiences in pressure/tension and competence between DDA3 and DDA4.

Research (e.g. [10], [11], [78], [86]) in conventional video games suggests that setbacks or failures in games can increase intense gameplay experience, potentially leading to a negative experience. However, if players are able to overcome these setbacks, they may cause more enjoyment [10], [11]. Furthermore, setbacks or failures can encourage players to invest more effort to adapt their strategy or improve their skills to overcome challenges [12].

DDA adjusts the game difficulty based on the number of setbacks, which may promote these observed experiences: enjoyment, motivational effort, and performative perceived challenge. However, if players perceive setbacks or failures as repetitive, this could negatively affect their experience [12], [83]. In contrast, proactive P-based DDA may lack the benefits of setbacks or failures in engaging players. Since these two DDA functions use different techniques for difficulty adjustment, this experiment expects to observe differences in levels of interest/enjoyment, effort/importance, and performative perceived challenge between the two conditions.

Thus, this experiment hypothesises that playing with DDA4 will lead to different intrinsic motivation, challenge-skill balance, and performative perceived challenge compared to DDA3 (H_3,H_4,H_5, and H_6), without assuming specific directions due to a lack of related works and unclear effects.

7.3 DDA Experimental Conditions

This experiment used the same game as in Experiments 1 and 2, where the primary challenge adjusted by the DDA functions is the dragon chase. However, as described in Game Design and Development Chapter, the game included an additional interaction in which players had to punch to cast a spell and destroy an approaching angry log monster. Failing to do so in time resulted in the avatar being stunned, giving the dragon a chance to catch up.

Since players might perceive their inability to deal with the angry log as a separate failure unrelated to the main challenge (as described in [82], [83], where player-defined goals may differ from those intended by the game), this game interaction was removed to ensure that the experiment focused solely on the player's ability to handle the dragon chase. However, the interaction that required players to stretch their arms to shift the avatar's view to the left or right was retained. This feature was not considered a challenge but rather a way to introduce dynamic environmental changes, allowing players to experience different in-game perspectives without the pressure of reacting quickly, as they were notified beforehand.

The following sections describe the DDA functions used in this experiment.

7.3.1 Reactive P-based DDA (DDA3)

In a reactive action (sometimes referred to as in-play adjustment [192]), DDA takes action while the player is actively dealing with challenges, meaning the challenges are already present to the player [193]. In this approach, DDA assists struggling players by adjusting the difficulty based on their current data [194].

However, since the challenge is already in place and helping is provided only after the player surpasses a defined critical threshold, this may reduce motivation [194]. Experiment 2 also observed a similar trend, where an increase in setback count was associated with a decrease in perceived competence (one of the factors that, when satisfied, can potentially lead to intrinsic motivation) in DDA3.

The attributes of the reactive approach are shown in DDA3 (in Experiment 2) as follows: (1) it assists players while they are struggling with the dragon chase and when the number of hits exceeds predefined values, and (2) the dragon is in the attacking zone and has started attacking. Therefore, this condition in Experiment 3 is identical to the DDA3 condition in Experiment 2.

7.3.2 Proactive P-based DDA (DDA4)

DDA4, like DDA3, is based on the challenge-skill balance factor of flow theory [13] and adjusts difficulty using player performance data. However, unlike DDA3 and existing approaches (e.g. [23], [27]), which typically operate reactively, DDA4 takes a proactive approach.

Unlike reactive action, where DDA take action after players encounter challenges, proactive action (also known as off-play adjustment [192]) adjusts game challenge elements before they appear, using previous in-game data to predict future player performance [193], [194].

To apply proactive P-based DDA in this exergame, this experiment explores how it can be implemented in an exergame context, where research on this approach remains limited. First, proactive P-based DDA must prevent players from entering a critical game state. In ExerWitch, this is defined as preventing the dragon from entering the attacking zone (as shown in Figure 4.14), since once the dragon reaches this zone, it starts attacking players, causing setbacks and delaying progress toward the finish line.

Second, proactive P-based DDA must adjust game challenge elements before they are presented to players. In traditional video games, this could be modifying the number or type of enemies before they respawn or providing more weapons and potions in the inventory before players face challenges [109], [192], [193].

However, directly applying these scenarios to ExerWitch is not entirely feasible due to the game's design. Unlike conventional games where enemies respawn, ExerWitch features a single, physical challenge: the dragon chase. Moreover, the dragon should remain visible on the screen to keep players motivated to run, making it impractical to adjust the dragon's game attributes before appearing. Instead, this experiment adapts the concept of adjusting challenges before presentation by modifying the dragon's speed before it fully enters the attacking zone. Specifically, when the dragon reaches the last threshold of the closing-to-the-attacking-zone area (as shown in Figure 4.14), its speed is reduced to delay its entry into the zone and withdraw the dragon if players are still unable to run away.

To align with the attributes of proactive action and the nature of this exergame, this experiment uses the distance between the dragon and the avatar as the performance metric. The overall concept of proactive P-based DDA (DDA4) in Experiment 3 is that DDA4 continuously calculates distance differences and, if the dragon is about to enter the attacking zone,

it moves the dragon back to prevent the critical state where the avatar gets attacked. With this design, DDA4 serves as a representative implementation of proactive P-based DDA in this research and introduces a new form of DDA function in exergames.

The details of DDA4 are presented in the following paragraphs.

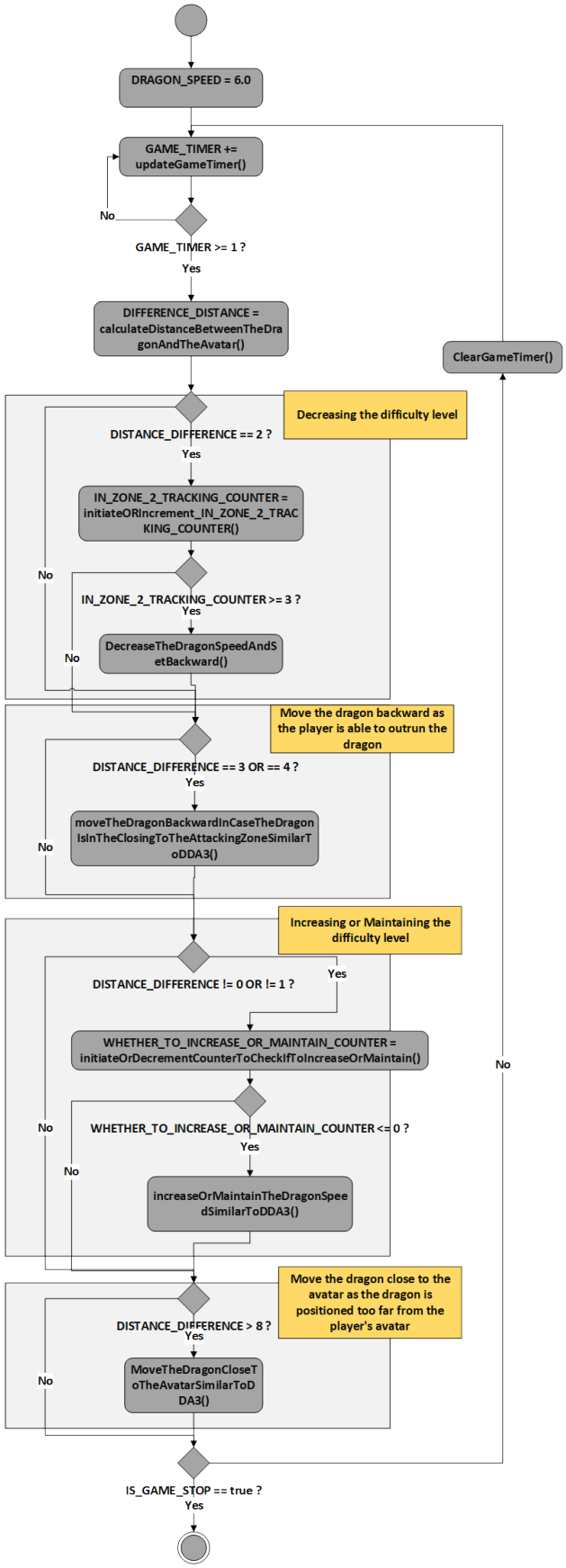

Figure 7.1: DDA4's flow chart showing how proactive performance-based DDA functions.

Figure 7.1 illustrates how DDA4 functions. Initially, the dragon's speed is set to the lowest level, allowing players time to adjust to the physical activity in the game. Once the game begins, a timer starts counting. When the timer reaches 1 second, DDA4 is triggered to evaluate whether a difficulty adjustment is needed.

First, the function calculates the distance between the dragon and the avatar, using a method similar to DDA3. The game determines whether the dragon is too far from the avatar, in the attacking zone, or in the closing-to-the-attacking zone. To calculate this distance, the function retrieves the floor cube IDs on which both the dragon and the avatar are positioned. The absolute difference between these IDs serves as the distance measure, which is then used in the following conditions:

- **Decreasing the difficulty level:**
  - If the distance difference is 2 (as a distance of 0 or 1 indicates the attacking zone, where the player struggles with the dragon chasing and attacking, as shown in Figure 4.14), the dragon is in the final threshold before entering the attacking zone. At this point, DDA4 begins tracking this state with a counter that increments with each DDA4 visit cycle.

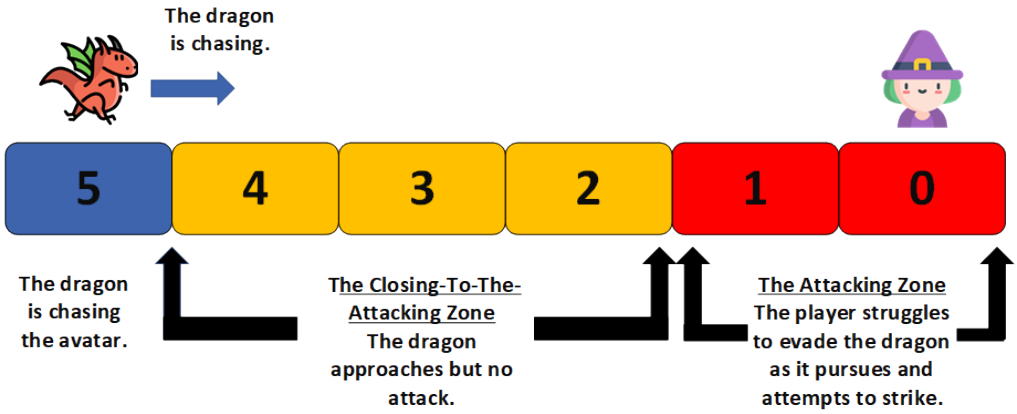

Figure 4.14: Restated figure showing the attacking zone and the closing-to-the-attacking zone in the ExerWitch game, depicting the spatial relationship between the dragon and the avatar.

  - If the counter is 2 or lower (fine-tuned during the testing phase), the dragon remains in this zone, allowing the player a chance to escape.
  - If the player fails to escape after three DDA4 visit cycles, DDA4 determines that the current difficulty level exceeds the player's ability. If this situation persists, the player is likely to enter the attacking zone and experience a setback or punishment. To prevent this, DDA4 reduces the dragon's speed to its lowest level and gradually moves it out of the player's sight, creating an easier gameplay phase to help avoid potential setbacks.

- **Move the dragon backward as the player is able to outrun the dragon:**
  - This follows the same approach as DDA3. If the dragon remains in the closing-to-the-attacking zone (distance difference of 3 or 4) and the player manages to keep

running without entering the attacking zone, the dragon moves backward. This adjustment rewards the player's effort by temporarily lowering the challenge.

- **Increasing or Maintaining the difficulty level:**
  - As long as the dragon is not in the attacking zone, DDA4 decides whether to maintain or increase the difficulty, following a process similar to DDA3.
- **Move the dragon close to the avatar as the dragon is positioned too far from the player's avatar:**
  - This follows the same principle as DDA3. If the dragon is too far away, it moves closer to keep it within the player's sight. This ensures the dragon remains a motivating factor, encouraging the player to keep running fast.

DDA4 was integrated into the exergame and playtested with a small sample of participants (N = 3) to identify potential bugs in both the game and DDA4, ensuring that the main experiment could run without interruptions. Also, DDA4's parameters were fine-tuned at this stage to ensure that difficulty adjustments were neither too sensitive nor delayed within the 10-minute play session (similar approach as Experiment 2).

Although proactive DDA implementations can vary across game designs or gameplay, DDA4 exemplifies a proactive approach to difficulty adjustment by anticipating player struggles before failures occur. This contrasts with reactive DDA functions (e.g. DDA3), which respond to setbacks or failures after they happen.

Overall, DDA4 introduces a distinct approach to difficulty adjustment using performance-based data. While both DDA3 and DDA4 rely on performance metrics, they differ in the type of data used and the timing of adjustments. DDA4 adjusts difficulty based on the distance between the dragon and the avatar, whereas DDA3 relies on the number of setbacks. In DDA4, if the dragon gets too close and the player appears to struggle with avoiding attacks, DDA4 pre-emptively reduces the dragon's speed before a setback occurs. In contrast, DDA3 lowers the difficulty while the player is struggling and gets attacked by the dragon.

7.4 Experimental Method

7.4.1 Experimental Design and Procedure

The experiment was approved by the departmental Physical Science Ethics Committee (see Appendix A). It adopted a within-subjects design (similar to Experiments 1 and 2), with participants took part in two experimental conditions with counter balancing to reduce order effects:

- Reactive P-based DDA (DDA3): adjusts the dragon's speed determined by assessing the number of setbacks players experience.

- Proactive P-based DDA (DDA4): adjusts the dragon's speed determined by assessing the distance between the dragon and the player to prevent players encounter with setbacks.

A control condition was not included in this study, as the primary aim was to compare DDA4 with DDA3 to examine its impact on PX and physical effort. This comparison seeks to determine whether the newly proposed DDA4 function offers improvements over DDA3 or falls short in certain aspects.

Each participant, incentivised with a £12 Amazon e-voucher, completed a one-hour experiment. They were unaware of the specific differences between the conditions. The procedure followed in this experiment was identical to that of Experiments 1 and 2. However, at the beginning of both the first and second play sessions, participants were reminded of the game's goal and punishment: you need to run as fast as you can to reach the finish line in the shortest time possible. While you're running, there's going to be a dragon chasing you. If it catches up and attacks you, your avatar will freeze for a moment, which will increase your time used. So, try your best to avoid getting caught by the dragon.

This explanation was emphasised to ensure players clearly understood the game's goal and consequences. It aimed to mitigate the risk of players setting their own, unintended goals or successes or deviating from the intended gameplay experience as potentially found in the review [82], [83], [189]. This was particularly important to ensure that participants perceived being attacked by the dragon and failing to reach the finish line as a form of setback or failure.

The materials and tools were used as in Experiment 1.

7.4.2 Variables

Based on the review and hypotheses, the following research variables were defined for hypothesis testing to address the research questions:

- **Independent Variables:**
  - Reactive Performance-based DDA (DDA3)
  - Proactive Performance-based DDA (DDA4)
- **Dependent Variables:**
  - Average Heart Rate
  - BRPE: Perceived Exertion
  - BANGS: Competence Satisfaction
  - BANGS: Competence Frustration
  - FSS: Challenge-Skill Balance
  - IMI: Interest/Enjoyment
  - IMI: Pressure/Tension

  - IMI: Effort/Importance
  - CORGIS: Performative Perceived Challenge

- **Control Variable:**
  - The exergame

7.4.3 Participants

36 participants completed the study (Male: 18, Female: 18) with an average age of 28 years ($SD = 7.18$). Out of 36 participants, 31 described themselves as having regular physical activity, 27 indicated they had regular physical activity in the last 3 months, and 34 expressed an intention to have physical activity in the next 3 months. Participant demographic data in Experiment 3 are summarised in Table 7.1.

Participant Demographics in Experiment 3	
N	36
Age	M ± SD = 28.00 ± 7.18
Gender	**N**
Man	18
Woman	18
Other	0
Do you currently engage in regular physical activity?	**N**
Yes	31
No	5
Have you been regular physically active for the past 3 months?	**N**
Yes	27
No	9
Do you intend to become more physically active in the next 3 months?	**N**
Yes	34
No	2

Table 7.1: Participant demographics in Experiment 3

7.4.4 Measures

To understand how players experienced the exergame under two different conditions, data were collected on their AHR and playing experience. Players' heart rates, measured in BPM using a Samsung Galaxy Watch 4, were monitored throughout the gameplay sessions to calculate AHR. Perceived exertion was assessed using the Borg Rating of Perceived Exertion (BRPE) scale [195].

In this experiment, the IMI: Perceived Competence subscale was replaced with the Basic Needs in Games Scale (BANGS) [147]: competence satisfaction and competence frustration. While both tools are grounded in SDT, the IMI is a robust measure designed for broader motivational contexts, whereas BANGS specifically focuses on gaming experiences. This replacement was made to better align with the experiment's focus on competence satisfaction and frustration—factors not directly captured by the IMI—and to avoid redundancy in using multiple tools to measure perceived competence.

IMI: interest/ enjoyment, IMI: pressure/ tension, and IMI: effort/ importance were assessed using the Intrinsic Motivation Inventory (IMI) [146].

To investigate players' perception of challenge-skill balance presented the game with different conditions, 4 items describing the challenge-skill balance factor in the Flow State Scale [154] was used.

Players' perception of the performative challenge presented in the game was assessed using the Challenge Originating from Recent Gameplay Interaction Scale (CORGIS) [15].

7.4.5 Analyses

The data were pre-processed to test for normality and identify potential outliers. For measures assuming a non-normal distribution, a Wilcoxon signed-rank test was conducted to examine differences in player experience. In contrast, as the AHR during gameplay was assumed to follow a normal distribution, a paired-samples t-test was used to compare heart rate differences across conditions. The alpha level was set at .05.

7.5 Results

This section presents the analysis results. The normality test results are shown in Table 7.2.

The internal consistency (Cronbach's alpha) results are displayed in Table 7.3.

A summary of the descriptive statistics and statistical test results is provided in Table 7.4 (t-test) and Table 7.5 (Wilcoxon-Signed Rank test).

Variables	**DDA3 (Shapiro-Wilk)**			**DDA4 (Shapiro-Wilk)**		
	Statistic	**df**	**Sig.**	**Statistic**	**df**	**Sig.**
Average Heart Rate	.954	32	.187	.979	32	.764
BRPE: Perceived Exertion	.920	36	.013	.972	36	.475
BANGS: Competence Satisfaction	.934	36	.033	.903	36	.004
BANGS: Competence Frustration	.941	36	.055	.938	36	.043
FSS: Challenge-skill Balance	.979	36	.700	.951	36	.111
IMI: Interest/Enjoyment	.959	36	.203	.946	36	.081
IMI: Pressure/Tension	.960	36	.215	.964	36	.280
IMI: Effort/Importance	.890	36	.002	.866	36	$< .001$
CORGIS: Performative Perceived Challenge	.965	36	.298	.936	36	.038

Table 7.2: Shapiro-Wilk normality test results for variables in DDA3 and DDA4 in Experiment 3

Scale/Dimension	**Number of Items**	**DDA3**		**DDA4**	
		N	**Cronbach's α**	**N**	**Cronbach's α**
BANGS: Competence Satisfaction	3	36	.878	36	.792
BANGS: Competence Frustration	3	36	.859	36	.571
FSS: Challenge-skill Balance	4	36	.840	36	.813
IMI: Interest/Enjoyment	7	36	.846	36	.824
IMI: Effort/Importance	5	36	.869	36	.883
IMI: Pressure/Tension	5	36	.775	36	.774
CORGIS: Performative Perceived Challenge	5	36	.847	36	.917

Table 7.3: Cronbach's α of BANGS, FSS, IMI, and CORGIS for DDA3 and DDA4 in Experiment 3

Variables	N	M ± SD		SEM		95% CI		t (df)	p	d
		DDA3	DDA4	DDA3	DDA4	DDA3	DDA4			
Average Resting Heart Rate	36	84.57 ± 13.58	82.36 ± 12.88	2.26	2.15	[79.97, 89.16]	[78.00, 86.72]	.766 (35)	.449	.13
Average Heart Rate	32	148.85 ± 16.43	146.13 ± 17.64	2.90	3.12	[142.92, 154.77]	[139.77, 152.49]	1.144 (31)	.261	.20

Table 7.4: Descriptive statistics and t-test results for resting and average heart rate in the DDA3 and DDA4 in Experiment 3.

Variables	N	M ± SD		Mdn		IQR		Ties	Z	p	r
		DDA3	DDA4	DDA3	DDA4	DDA3	DDA4				
BRPE: Perceived Exertion	36	14.42 ± 2.25	14.31 ± 2.34	14.00	14.00	2.75	3.00	10	-.489	.625	.08
BANGS: Competence Satisfaction	36	5.28 ± 1.31	6.07 ± .81	5.17	6.33	2.26	1.25	6	-3.048	.002*	.51
BANGS: Competence Frustration	36	3.09 ± 1.61	2.51 ± 1.17	3.00	2.50	2.75	2.26	6	-2.052	.040*	.34
FSS: Challenge-Skill Balance	36	5.15 ± 1.00	5.57 ± .97	5.13	5.63	1.50	1.69	9	-2.388	.017*	.40
IMI: Interest/Enjoyment	36	5.31 ± 1.04	5.41 ± 1.02	5.07	5.29	1.67	1.64	8	-1.452	.146	.24
IMI: Pressure/Tension	36	3.21 ± 1.33	2.93 ± 1.18	3.10	2.90	1.70	1.55	6	-1.353	.176	.23
IMI: Effort/Importance	36	5.64 ± 1.22	5.69 ± 1.23	5.60	6.20	1.80	1.70	4	-.151	.880	.03
CORGIS: Performative Perceived Challenge	36	4.87 ± 1.36	4.97 ± 1.53	5.00	5.00	1.85	1.90	8	-.674	.501	.11

Table 7.5: Descriptive statistics and Wilcoxon signed-rank test results for variables under DDA3 and DDA4 in Experiment 3.

7.5.1 Average Heart Rate

To examine if an order effect impacted AHR during playtime in each condition, the resting heart rates of both conditions were compared. These resting heart rates were measured before each playtime session started. The analysis showed no significant difference between conditions, $t(35) = .766$, $p = .449$, Cohen's $d = .13$ (suggesting negligible effect). This suggests there was no carry-over effect on average heart rates at the start of gameplay in each condition.

The distribution of resting heart rate (in BPM) in the DDA3 and DDA4 conditions is shown in box plots in Figure 7.3.

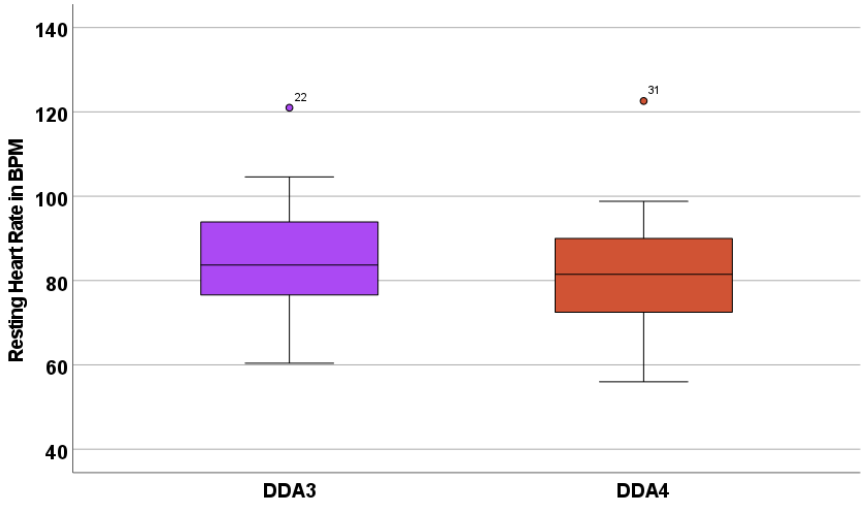

Figure 7.3: Box plots illustrating Resting Average Heart Rate (in BPM) in the DDA3 and DDA4 conditions in Experiment 3.

The analysis compared the AHR during the playtime sessions to test the hypothesis H_1. Due to an application failure in the heart rate recorder, the average heart rates of 32 out of 36 participants were recorded and used for analysis. The results indicated that the AHR in DDA3 ($M \pm SD = 148.85 \pm 16.43$) did not significantly differ from the AHR in DDA4 ($M \pm SD = 146.13 \pm 17.64$), $t(31) = 1.144$, $p = .261$, Cohen's $d = .20$ (small effect). Therefore, the null hypothesis of H_1 was not rejected.

The distribution of AHR (in BPM) during playtime in the DDA3 and DDA4 conditions is shown in box plots in Figure 7.4.

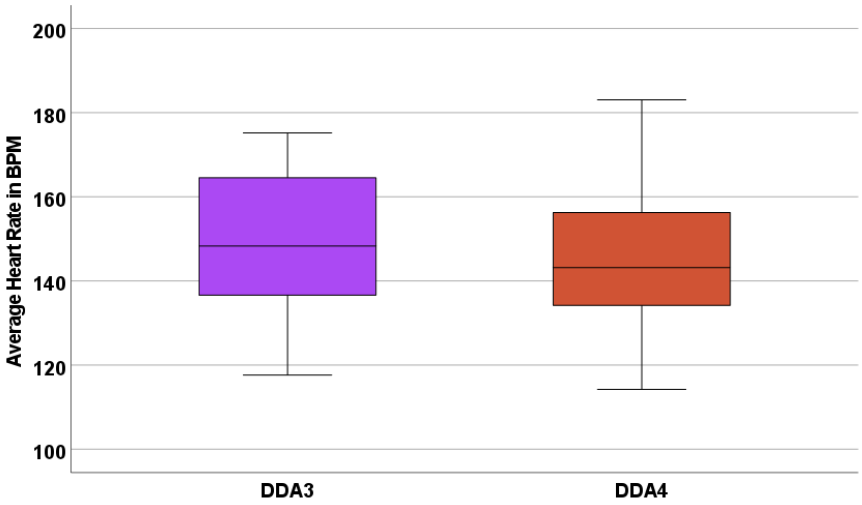

Figure 7.4: Box plots illustrating Average Heart Rate (in BPM) in Reactive performance-based DDA (DDA3) and Proactive performance-based DDA (DDA4) conditions in Experiment 3.

7.5.2 BRPE: Perceived Exertion

The analysis revealed no significant difference in perceived exertion between the conditions, $Z = -.489$, $N = 36$, $p = .625$, $r = .08$ (small effect). Therefore, the null hypothesis of H_2 was not rejected.

Figure 7.5 shows the distribution of BRPE: Perceived Exertion in the DDA3 and DDA4 conditions using box plots.

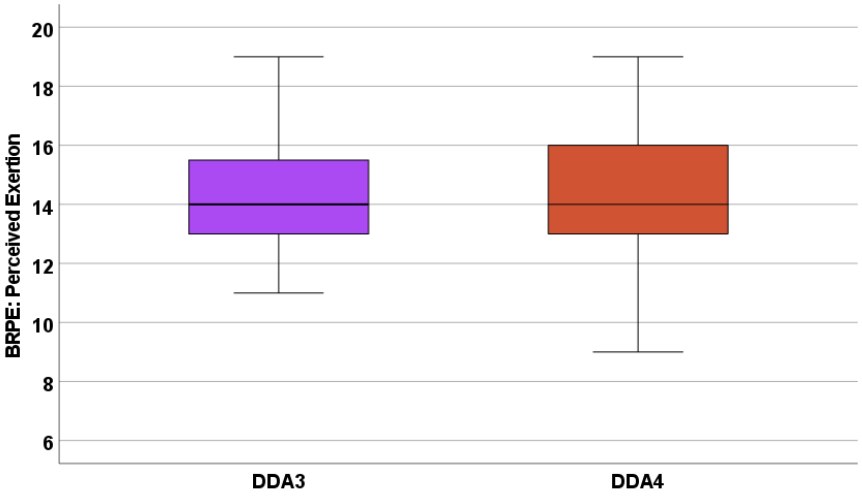

Figure 7.5: Box plots illustrating BRPE: Perceived Exertion in Reactive performance-based DDA (DDA3) and Proactive performance-based DDA (DDA4) conditions in Experiment 3.

7.5.3 BANGS: Competence Satisfaction and Frustration

The analysis showed that playing the exergame with DDA4 ($M \pm SD = 6.07 \pm .81$, $Mdn = 6.33$, $IQR = 1.25$) resulted in higher competence satisfaction compared to DDA3 ($M \pm SD = 5.28 \pm 1.31$, $Mdn = 5.17$, $IQR = 2.26$), $Z = -3.048$, $N = 36$, $p = .002$, $r = .51$ (large effect). Therefore, the null hypothesis of $H_{3.A}$ was rejected.

Figure 7.6 presents box plots illustrating the distribution of BANGS: Competence Satisfaction under the DDA3 and DDA4 conditions.

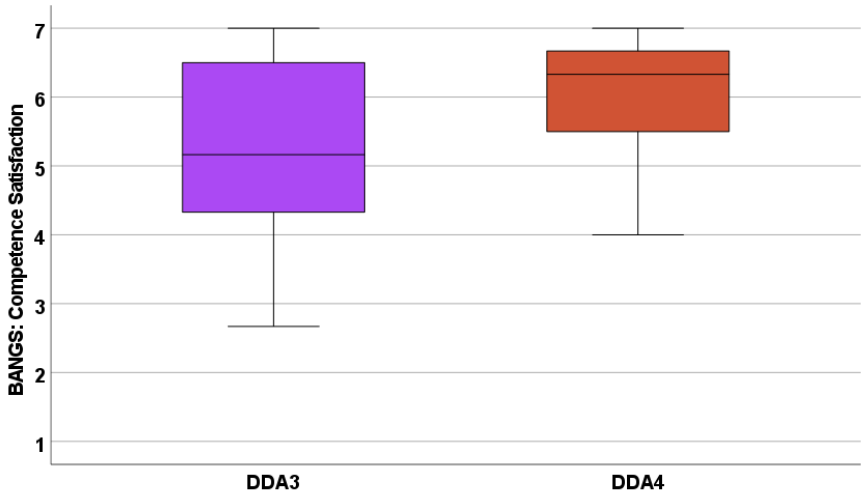

Figure 7.6: Box plots illustrating BANGS: Competence Satisfaction in Reactive performance-based DDA (DDA3) and Proactive performance-based DDA (DDA4) conditions in Experiment 3.

Moreover, the analysis revealed that playing the exergame with DDA4 ($M \pm SD = 2.51 \pm 1.17$, $Mdn = 2.50$, $IQR = 2.26$) resulted in less competence frustration compared to DDA3 ($M \pm SD = 3.09 \pm 1.61$, $Mdn = 3.00$, $IQR = 2.75$), $Z = -2.052$, $N = 36$, $p = .040$, $r = .34$ (medium effect). Therefore, the null hypothesis of $H_{3.B}$ was rejected.

The distribution of BANGS: Competence Frustration in the DDA3 and DDA4 conditions is shown in box plots in Figure 7.7.

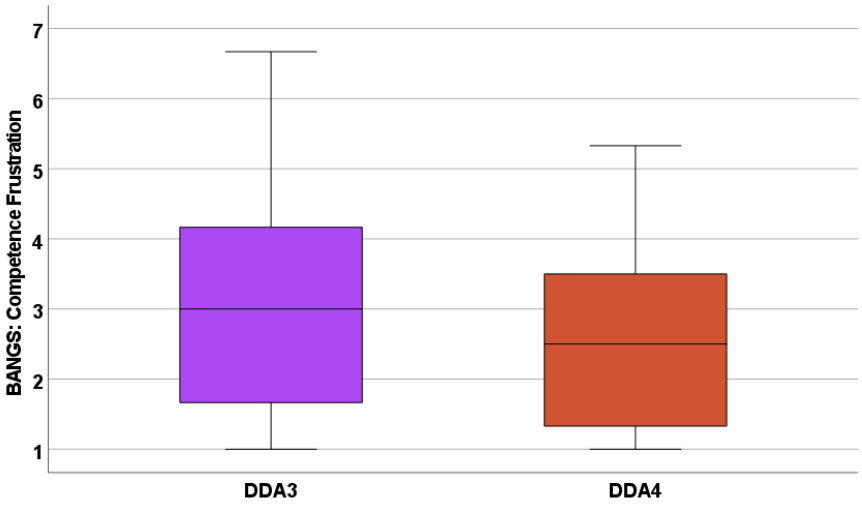

Figure 7.7: Box plots illustrating BANGS: Competence Frustration in Reactive performance-based DDA (DDA3) and Proactive performance-based DDA (DDA4) conditions in Experiment 3.

7.5.4 FSS: Challenge-Skill Balance

The analysis revealed a significant difference in challenge-skill balance between the conditions, $Z = -2.388$, $N = 36$, $p = .017$, $r = .40$ (medium effect). Playing the exergame with DDA4 ($M \pm SD = 5.57 \pm .97$, $Mdn = 5.63$, $IQR = 1.69$) was perceived as having a higher challenge-skill balance compared to playing with DDA3 ($M \pm SD = 5.15 \pm 1.00$, $Mdn = 5.13$, $IQR = 1.50$). Consequently, the null hypothesis of H_4 was rejected.

The distribution of FSS: Challenge-Skill Balance in the DDA3 and DDA4 conditions is shown in box plots in Figure 7.8.

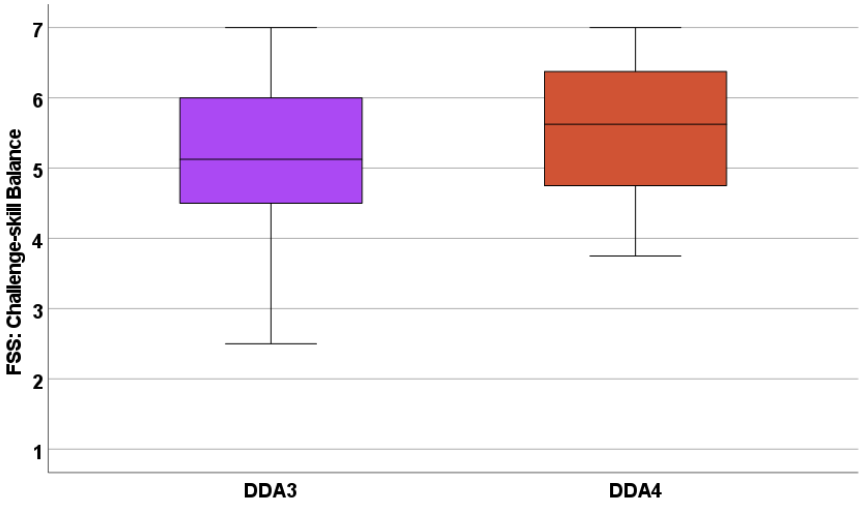

Figure 7.8: Box plots illustrating FSS: Challenge-skill Balance in Reactive performance-based DDA (DDA3) and Reactive performance-based DDA (DDA4) conditions in Experiment 3.

7.5.5 IMI: Intrinsic Motivation

The analysis showed that interest/enjoyment was not significantly different between the conditions, $Z = -1.452$, $N = 36$, $p = .146$, $r = .24$ (small effect). Also, pressure/tension in DDA3 did not differ from DDA4, $Z = -1.353$, $N = 36$, $p = .176$, $r = .23$ (small effect). There was also no significant difference in effort/importance between DDA3 and DDA4, $Z = -.151$, $N = 36$, $p = .880$, $r = .03$ (suggesting negligible effect).

Thus, the null hypotheses of $H_{5.A}$, $H_{5.B}$, and $H_{5.C}$ were not rejected.

Figure 7.9 presents box plots illustrating the distribution of IMI: Interest/ Enjoyment under the DDA3 and DDA4 conditions.

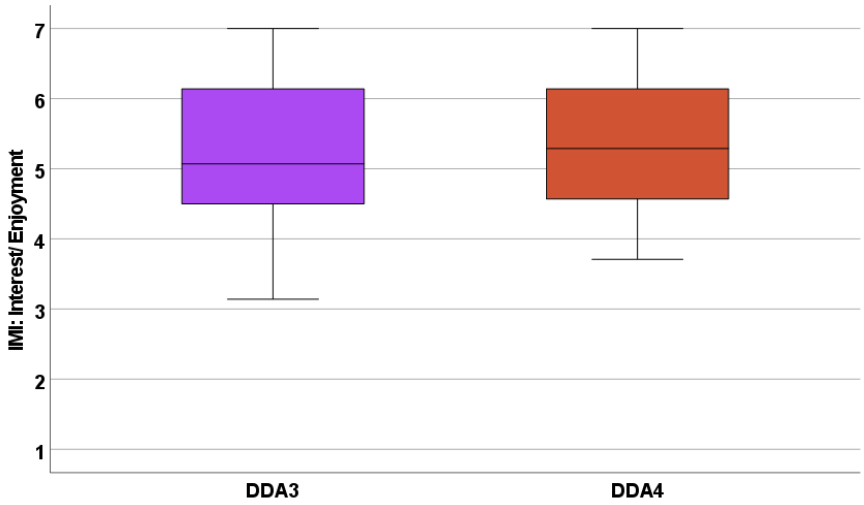

Figure 7.9: Box plots illustrating IMI: Interest/ Enjoyment in Reactive performance-based DDA (DDA3) and Proactive performance-based DDA (DDA4) conditions in Experiment 3.

A box plot (Figure 7.10) illustrates the distribution of IMI: Pressure/ Tension in the DDA3 and DDA4 conditions.

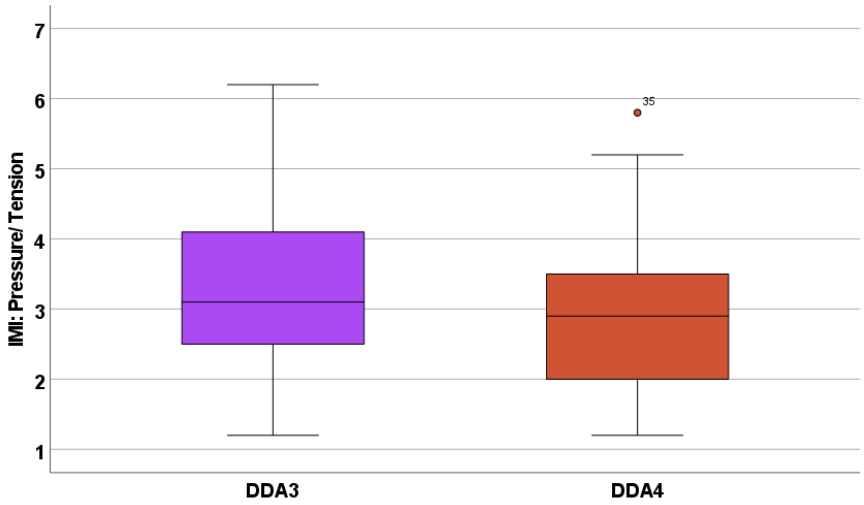

Figure 7.10: Box plots illustrating IMI: Pressure/ Tension in Reactive performance-based DDA (DDA3) and Proactive performance-based DDA (DDA4) conditions in Experiment 3.

IMI: Effort/ Importance distributions under DDA3 and DDA4 are shown in Figures 7.11.

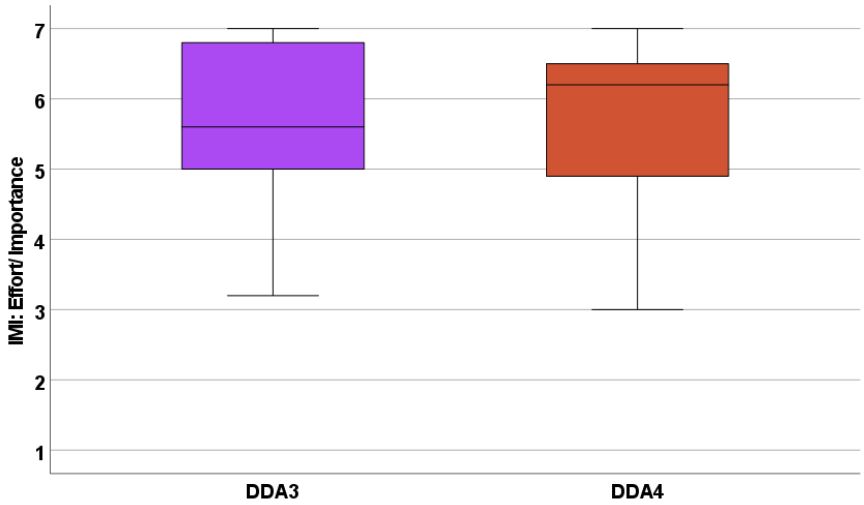

Figure 7.11: Box plots illustrating IMI: Effort/ Importance in Reactive performance-based DDA (DDA3) and Proactive performance-based DDA (DDA4) conditions in Experiment 3.

7.5.6 CORGIS: Performative Perceived Challenge

The analysis showed that players' perception of performative challenge in DDA3 did not significantly differ from DDA4, $Z = -.674$, $N = 36$, $p = .501$, $r = .11$ (small effect). Thus, the null hypothesis of H_6 was not rejected.

The distribution of CORGIS: Performative Perceived Challenge in the DDA3 and DDA4 conditions is illustrated by box plots in Figure 7.12.

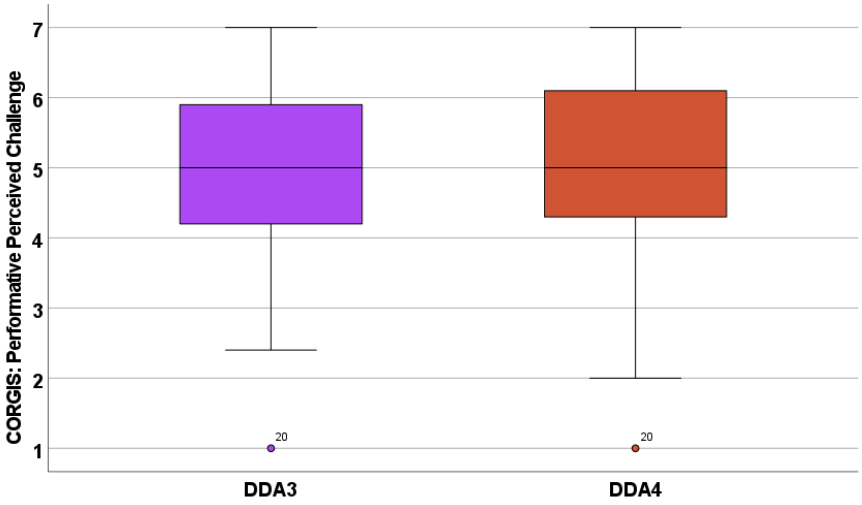

Figure 7.12: Box plots illustrating CORGIS: Performative Perceived Challenge in Reactive performance-based DDA (DDA3) and Proactive performance-based DDA (DDA4) conditions in Experiment 3.

7.6 Discussion

This experiment extends the concept of proactive and reactive DDA actions, as described by Hunicke *et al.* [137], by proposing a proactive P-based DDA function that has been under-explored in exergames. Moreover, this experiment examined the impact of the proposed proactive performance-based DDA (DDA4) on PX and physical effort compared to reactive performance-based DDA (DDA3).

The findings address **the research question 3** (How does proactive performance-based DDA impact player experience and physical effort compared to reactive performance-based DDA?) by showing that DDA4, which adjusts difficulty pre-emptively based on the distance between the dragon and the player, led to higher competence satisfaction and better challenge-skill balance, while reducing competence frustration compared to DDA3.

However, no significant differences were found between the conditions in terms of AHR, perceived exertion, interest/ enjoyment, pressure/ tension, effort/ importance, or performative perceived challenge. The following sections provide possible justifications for these effects and relate them to relevant studies.

7.6.1 Competence And Challenge-Skill Balance

The findings from this experiment support the correlation analysis in Experiment 2, as DDA3's reliance on setbacks negatively impacts players' sense of competence. The results indicate that DDA3, which adjusts game difficulty reactively based on players' setbacks, leads to greater competence frustration compared to DDA4. In contrast, DDA4, which adjusts difficulty proactively based on distance prevents setbacks and increases competence satisfaction compared to DDA3. These findings highlight the potential limitations of the reactive approach, which has been commonly used in previous exergame studies (e.g. [23], [27], [28]).

Interestingly, even though DDA4 lacks the intense experience of setbacks and punishment, the perception of challenge-skill balance is not inferior to DDA3 (i.e. the game is not perceived as too easy or boring). In fact, this factor is higher in DDA4 compared to DDA3, suggesting that proactive adjustments can sustain engagement by maintaining a balance between the dragon's speed and player skill—ensuring the game remains challenging but not excessively difficult—without the disruptive frustration of setbacks and their consequences.

A possible reason why DDA4 remains challenging is that its design still pushes players to run faster by moving the dragon closer when the dragon fall behind at specific distances and intervals, similar to DDA3. However, if players are unable to flee, DDA4 sets the dragon farther back instead of letting the dragon attack players, enabling players to perceive the game as challenging yet manageable through their own effort.

In the context of SDT [16], DDA4 aligns with the principle that success can enhance competence compared to DDA3 that players can more experience setbacks/ failures. However, in video games, players do not always seek effortless success; rather, they desire challenges that test their abilities, making their achievements feel meaningful [78]. The review (e.g. [10]) argues that overcoming failures or setbacks fosters a stronger sense of accomplishment and competence. However, the findings challenge this argument, suggesting that setbacks do not always enhance competence when overcome, especially when they are from physical challenges in exergames, compared to game experiences that provide challenges without setbacks.

In both DDA3 and DDA4, participants strongly agreed that the game's difficulty appropriately matched their skill. However, in DDA3, players—who were unable to flee from the dragon and got attacks, followed by the DDA3 slowing down and repositioning the dragon after repeated setbacks, or those who managed to escape through their own efforts—may not have felt a sense of achievement. Instead, this experience may have been perceived as a cycle of repeated setbacks, increasing frustration rather than enhancing competence.

Although players' perceptions of setbacks or failures vary, such as state-oriented or action-oriented players [82], [83], [88], the game in this research focused primarily on goal-reaching and physical challenge without engaging or fantasy elements. As a result, setbacks likely felt more like tedious interruptions than engaging obstacles from other kinds of game challenges (e.g. cognitive or emotional challenges) over time.

In exergames, where physical fatigue might be a key factor, repeated setbacks may have led to both exhaustion and irritation. This could explain why the reactive difficulty adjustments in DDA3 increased frustration rather than enhancing competence, even when players

successfully achieved the goal or obstacles, compared to DDA4.

Overall, this experiment shows that even though both DDA3 and DDA4 aim to promote a challenge-skill balance experience in exergames, the timing of their adjustments provides distinct gameplay experiences. DDA3, which adjusts difficulty in response to players struggling with challenges or setback counts, does not necessarily enhance competence when challenges are overcome. Instead, it increases frustration and lowers the perceived challenge-skill balance compared to DDA4. In contrast, DDA4, which proactively adjusts difficulty based on the likelihood of setbacks, leads to higher competence and a stronger challenge-skill balance while also reducing frustration.

Even though frustration ratings in both DDA3 and DDA4 remain relatively low (approximately 3 points out of 7), and competence satisfaction remains high (approximately 6 points out of 7), these results support the potential of P-based DDA to facilitate positive PX. However, frustration arising from physical challenges—where the only way to overcome them is by exerting more physical effort—may not be beneficial and could contribute to negative PX. This may differ from frustration in other types of game challenges, where players can use more complex strategies to find ways to overcome challenges.

So, this experiment suggests that when addressing only physical challenges, proactive P-based DDA may be a more suitable choice in exergames as it potentially reduces frustration from physical challenges. However, this does not imply that setbacks or failures should be removed from video games entirely, as they can lead to a more intense gameplay experience. Instead, setbacks or failures could be integrated into other types of challenges alongside reactive P-based DDA, allowing players to engage with a broader range of strategies rather than relying solely on physical effort to overcome challenges. This approach could make frustration feel more engaging while ensuring that reactive P-based DDA prevents frustration from becoming overwhelming.

7.6.2 Interest/Enjoyment, Pressure/Tension, And Perceived Challenge

Experiment 2 showed that the number of setbacks was associated with increased pressure/ tension. Moreover, the review (e.g. [10], [11]) suggests that game experiences become more intense when players encounter setbacks or failures, which may potentially lead to negative emotions. However, since DDA4 prevents players from experiencing setbacks, its design did not lead to different pressure/ tension levels compared to DDA3.

One possible explanation, consistent with findings from Experiments 1 and 2, is that in exergames, physical activity (e.g. running) may be the primary stressor that players focus on. This physical demand could overshadow psychological tension from gameplay mechanics, making players less sensitive to stress caused by game experiences, such as dragon speed, approach patterns, or setbacks, adjusted by the DDA functions.

Moreover, the types of challenges presented in the game may result in no differences in pressure/ tension. Since the challenge in this game is solely physical, it may limit the ability of DDA to influence psychological pressure/ tension. For example, studies by Darzi *et al.* [28] and Goršič *et al.* [38] on Pong-based exergames found that players had to use both physical movement and cognitive strategies to outplay opponents. The added complexity made the

game feel more intense compared to nDDA. In contrast, studies by Ketcheson *et al.* [18] and Wünsche *et al.* [26] on exergames where players relied mainly on physical effort (e.g. body movement and cycling) similar to this research reported no significant differences in pressure/tension between DDA and non-DDA conditions. This suggests that in only physical challenges, DDA may have a limited effect on psychological pressure/ tension.

Regarding perceived performance challenge, the findings show no difference in this variable between the two conditions, suggesting that players did not perceive a difference in the need to react quickly to the dragon's approach. One possible justification behind this is that both DDA functions were designed to assist players when the dragon is approaching and attacking, while also increasing the challenge when the game becomes too easy. In both DDA3 and DDA4, players are required to run faster when the dragon approaches, which likely results in a similar gameplay experience related to performative perceived challenge.

Moreover, when considering a case where the game is too challenging, DDA3 makes the dragon to leave after attacking players more than twice, which induces higher player frustration compared to DDA4. However, as these attacks occur within a short period, players might not invest enough additional physical effort (as shown by no difference in AHR) until they realise they are running faster than in DDA4 during this period. This could lead to the absence of an effect on performative perceived challenge.

The results also indicated that playing in DDA4 did not affect players' enjoyment levels differently compared to DDA3. Previous studies [10]–[12], [86] suggest that experiencing setbacks or failures, followed by overcoming them, can potentially promote enjoyment. However, this experiment challenges this view, showing that setbacks alone do not necessarily enhance enjoyment, as evidenced by DDA3, where game difficulty adjusts based on the number of setbacks. One possible justification behind this could be that overcoming setbacks from physical challenges may not be perceived as an engaging task by players. It might be interpreted as a frustrating and repetitive task that they frequently encounter throughout the gameplay session.

Overall, no differences were observed in other PX measures between DDA3 and DDA4. However, the findings in this experiment support the argument in Experiment 2 that, even though DDA4 uses a different performance metric (i.e. the distance between the dragon and the avatar) compared to DDA3, which relies on error rate (i.e. setback count), no improvements were found in these PX aspects. This supports the argument that P-based DDA, based on challenge-skill balance and addressing only a single physical challenge, may not be sufficient to influence interest/enjoyment, pressure/tension, or perceived challenge.

However, it should be noted that the results from this experiment do not imply that reactive P-based DDA and proactive P-based DDA will have no influence on the non-significant PX observed in this research or other player experiences in different gaming contexts, such as when applied to cognitive or emotional challenges and different game themes.

7.6.3 Average Heart Rate, Perceived Exertion, And Effort/ Importance

Previous studies (e.g. [86]) suggest that in common video games, setbacks or failures can promote skill improvement or encourage players to re-strategise to overcome obstacles. The reactive approach, which introduces a bit of struggle, is expected to motivate players to exert more effort to avoid setbacks. However, the results contradict this notion, showing that players did not invest more motivational or physical effort in DDA3, where setbacks occurred, compared to DDA4, where no setbacks were encountered.

One potential explanation for this lies in the different types of challenges presented in conventional video games versus this exergame. In conventional video games, challenges are often cognitive and emotional, allowing players to analyse mistakes, adapt strategies, and improve through next iteration. In contrast, this exergame focuses solely on physical challenges, which are limited by players' physical limitations. In this context, players cannot easily re-strategise using cognitive thinking to overcome physical barriers; instead, they must rely on increased physical exertion. This reliance on physical effort may lead to frustration rather than learning growth, as shown by the increase in competence frustration in the findings.

Furthermore, the reactive approach in DDA3, similar to DDA4, aims to balance game challenge and player skill. by assisting players when they struggle with the dragon's chase and attacks and also players encounter setbacks for a short inverval before DDA3 takes action, DDA3 may reduce the need for significant effort in escaping, potentially leading to a similar investment in both physical and motivational effort as in DDA4. This is supported by the finding that there was no difference in perceived performative challenge between DDA3 and DDA4. Therefore, this experiment shows no significant difference in AHR, perceived exertion, or effort between DDA3 and DDA4.

Overall, this experiment suggests that when players experience setbacks for only a short period before reactive P-based DDA takes action, it does not lead to a significant investment of effort to avoid future setbacks. In contrast, proactive P-based DDA, which prevents setbacks, does not decrease players' effort, indicating that the brief experience of setbacks in reactive P-based DDA may not be sufficient to motivate players to increase exertion when compared to proactive P-based DDA.

7.6.4 No Right Or Wrong, Just Different Approaches

This experiment contrasts reactive P-based DDA with proactive P-based DDA, using DDA3 and DDA4 as representatives. In the context of exergames, the proactive approach appears to foster more positive experiences by enhancing competence and maintaining a balanced challenge-skill relationship, while the reactive approach lowers these factors and increases frustration. As previously mentioned, the increase in frustration may stem from setbacks in physical challenges, where players can only rely on exertion to overcome obstacles.

Unlike cognitive or emotional challenges, which may encourage problem-solving to overcome, setbacks from physical challenges may not be perceived as engaging but rather as discouraging. In exergames that focus solely on physical challenges, a proactive approach may be a more suitable design choice to prevent setbacks that could lead to decreased motivation and

engagement.

However, in traditional video games that incorporate various types of challenges beyond physical challenges, the results of this experiment do not imply that reactive P-based DDA is inherently ineffective or that it fails to engage players. Allowing players to experience setbacks before reactive P-based DDA takes action may enrich gameplay by adding depth and complexity, which could be appealing to some player groups.

For instance, a study by Macvean *et al.* [189] found that some players were highly motivated to persist in games with difficult and hard-to-achieve goals, despite frequent failures. Conversely, other players preferred to avoid such demanding experiences or opted for easier options.

Therefore, this experiment just provides initial insights into the effects of reactive and proactive approaches in the scenario of exergames. However, game developers can also use these insights more broadly in common video games to design exergames with adaptive functions that suit their target players.

7.6.5 Limitations

Although the sample size is consistent with related studies [23], [24], the small effect sizes should be interpreted with caution, as a larger sample could provide more robust estimates.

7.7 Chapter Summary

This experiment further investigates performance-based DDA from Experiment 2 and the gap between reactive and proactive approaches mentioned by [36], [137] by conducting a within-subjects study with 36 participants. The experiment examines the effects of proactive performance-based DDA (DDA4) on PX and physical effort, in comparison to reactive performance-based DDA (DDA3). Key takeaways in the context of an exergame focused solely on physical challenges include:

1. This experiment demonstrates that DDA3, which adjusts game difficulty based on setbacks, negatively impacts players' sense of competence, leading to increased frustration and decreased satisfaction. In contrast, DDA4, which prevents setbacks by adjusting difficulty according to the distance between the dragon and the player, enhances competence satisfaction, reduces frustration, and improves the challenge-skill balance.

   Challenging the idea from the review that setbacks inherently promote achievement and enhance the sense of competence, the findings suggest that in exergames focused on physical exertion, repeated setbacks from failing to overcome physical challenges might be perceived as tedious interruptions, causing frustration.

2. Physical exertion may be the primary stressor in this exergame, overshadowing psychological tension from gameplay mechanics or elements such as the dragon's speed, which is adjusted by both DDA functions. This could explain the similar levels of psychological pressure/tension between DDA3 and DDA4.

3. Despite the review suggesting that setbacks has a potential to increase enjoyment, the findings show no difference in enjoyment between DDA3 (setback-based) and DDA4. This may be due to the game's narrow focus on physical challenge, with the DDA functions addressing only this aspect. The experiment also suggests that player enjoyment is likely influenced more by overall gameplay and individual preferences/ needs rather than by DDA alone.

4. In comparing DDA3 and DDA4 within an exergame context, it was found that introducing setbacks in DDA3 did not lead to improved physical and motivational effort. The results show no difference in AHR, perceived exertion, or motivational effort between the two conditions.

Finally, this chapter presents the last experiment of this PhD study. The next chapters will summarise the research findings and provide a general discussion of all the difficulty adjustment functions: DDA1, DDA2, DDA3, and DDA4 in Experiment 1, 2, and 3.

Chapter 8

Conclusions

This research investigates the impact of four Dynamic Difficulty Adjustment (DDA) functions on player experience (PX) and physical effort in exergames: continuous EI-based DDA (DDA1), interval EI-based DDA (DDA2), reactive P-based DDA (DDA3), and proactive P-based DDA (DDA4). A within-subject quantitative approach was used. PX was assessed immediately after gameplay using validated questionnaires, while physical effort was measured by average heart rate (AHR) in beats per minute (BPM), recorded during playtime.

This chapter presents a general discussion of the findings across experiments and situates them within the broader body of research on DDA in conventional video games. It then summarises the main results in relation to the research questions, explores their implications, acknowledges limitations, proposes directions for future research, and concludes with final remarks.

The key findings of each experiment and their implications are summarised in Table 8.1.

Experiment	Conditions	Results	Key Implications
Experiment 1	Control (nDDA) vs. Continuous EI-based DDA (DDA1) vs. Interval EI-based DDA (DDA2)	• Playing in DDA1 ($p < .001, d = 1.00$) and DDA2 ($p = .011, d = .64$) increased AHR compared to nDDA, but no significant difference was found between DDA1 and DDA2 ($p = 1.000, d = .18$). •Playing in DDA1 increased perceived exertion compared to DDA2 ($p = .015, r = .48$) and nDDA ($p = .006, r = .54$), while no difference was found between DDA2 and nDDA ($p = .323, r = .19$). •No significant differences were observed in other PX measures.	•This experiment suggests that if the goal of exergames is to maintain players' exertion levels within target zones or to promote physical effort, EI-based DDA can be a suitable choice. However, given the results on perceived exertion, it may be beneficial to provide players with periods of low-intensity or easier gameplay to allow for recovery and prevent overly increases in perceived exertion. •If the main goal of exergames is not focused on achieving specific exercise intensity zone, EI-based DDA may not be an ideal choice, as it lacks mechanisms to enhance the overall attractiveness of the game.

Table 8.1: A summary of statistical test results across experimental conditions and the implications in each experiment.

Experiment	Conditions	Results	Key Implications
Experiment 2	Control (nDDA) vs. Performance-based DDA (DDA3)	• DDA3 showed an increase in perceived competence ($p = .026, r = .34$), challenge-skill balance ($p = .018, r = .36$), and AHR ($p = .036, d = .33$) compared to nDDA. • No significant differences were found in perceived exertion, enjoyment/interest, pressure/tension, effort/importance, or performative perceived challenge.	• This experiment suggests that DDA2 potentially enhances the attractiveness of exergames by providing a more challenging yet achievable game experience compared to nDDA, along with increased physical effort. • However, if the aim of the game is to reach a target exercise intensity zone or promote high physical effort, DDA2 may not be a good choice, as even though AHR is higher, the mean difference is only around 5 BPM.
Experiment 3	Reactive P-based DDA (DDA3) vs. Proactive P-based DDA (DDA4)	• DDA4 showed an increase in challenge-skill balance ($p = .017, r = .40$) and competence satisfaction ($p = .002, r = .51$) and a decrease in competence frustration ($p = .040, r = .34$) compared to DDA3. • No significant differences were found between the conditions in AHR, perceived exertion, interest/enjoyment, pressure/tension, effort/importance, or performative perceived challenge.	• This experiment suggests that when a game consists of a single physical challenge, using DDA4 may be a suitable choice, as it prevents setbacks from physical challenges that players might find frustrating due to the only way to overcome is to use physical effort which may make setbacks less engaging.

Table 8.1: A summary of statistical test results across experimental conditions and the implications in each experiment (Cont.).

Experiment	Conditions	Results	Key Implications
Experiment 3 (Continued)	-	-	• Even though both DDA3 and DDA4 were generally rated low in frustration by participants, this research suggests that setbacks should be from other types of game challenges rather than physical challenges. This approach would encourage players to use various skills to overcome obstacles, rather than relying solely on physical effort, which is less engaging and may become frustrating during extended play.

Table 8.1: A summary of statistical test results across experimental conditions and the implications in each experiment (Cont.).

8.1 General Discussion

This section discusses the findings on how DDA in exergames influences flow and intrinsic motivation, relating them to research on DDA in conventional video games. It also provides suggestions for DDA design.

8.1.1 DDA and Flow

Flow theory [13] has been introduced into game research in both game design (e.g. [96]) and DDA design. In DDA design, many studies (e.g. [23], [24], [27], [28]), including this research, commonly focus on one specific factor of flow theory: challenge-skill balance. This contrasts with its application in game design, where multiple flow factors are typically considered. This difference may be due to the nature of DDA, which the main mechanism is to maintain an optimal level of challenge rather than shaping all aspects of the game experience.

In general, challenge-skill balance-based DDA in both exergames (e.g. P-based DDA in this research and the studies by Martin-Niedecken *et al.* [23], [24]) and non-exergame video games typically aims to align game difficulty with player skill by setting criteria for when DDA should assist players or increase the difficulty for more challenge. However, critics such as Guo *et al.* [196] argue that simplistic implementations—such as targeting a 50% success rate [197] or static thresholds (e.g. two dragon hits in DDA3) to determine whether the current game state is balanced or if difficulty adjustment should be activated—risk oversimplifying what it means to achieve balance.

Despite this, the findings in this research suggest that even straightforward challenge-skill balancing (as seen in DDA3) can improve PX by fostering a better challenge-skill balance compared to nDDA. DDA3 helps players manage challenges when struggling with the dragon while ensuring the game remains engaging by allowing skill progression.

In the context of exergames, this can be seen as useful, as it prevents negative experiences from repeated failures or excessive fatigue by lowering the dragon's speed when players struggle and increasing it when they succeed to encourage physical activity. This research suggests that even a simple rule-based P-based DDA can be useful in exergames. More broadly, in the context of video games, this indicates that while the definition of balance may be simple, it can still have a significant impact on challenge-skill balance, which may help players enter a flow state and maintain engagement without facing gameplay that is either too difficult or too easy [13], [14].

This research also extends the concept of challenge-skill balance-based DDA into non-exergame video games. It appears that when DDA is based on the challenge-skill balance factor from Flow theory [13], it generally promotes challenge-skill balance, regardless of the type of game challenge, such as Tetris [111]: cognitive and physical challenges and this research, Exer-Witch: physical challenge. This can be because challenge-skill balance-based DDA (e.g. P-based DDA in this research) helps players when they struggle by making challenges achievable while still keeping the game challenging.

Regarding overall flow, some previous research (e.g. [131], [132]) on classic games like Space

Invaders and Tetris suggests that DDA can enhance player flow in conventional video games. However, despite the limited research directly comparing flow outcomes with and without DDA, this research argues that challenge-skill balance-based DDA does not always lead to a flow state. Flow is a holistic psychological state that requires not only balanced challenges but also components such as a sense of control, clear goals, and immediate feedback. DDA functions that focus solely on modulating difficulty (e.g. DDA in this research) may fail to address these additional dimensions of flow.

For instance, even if a player experiences balanced difficulty, they may still feel disconnected from the game due to the lack of autotelic experience, as this type of DDA does not account for it. This aligns with Lopes *et al.* [183], who emphasise that effective game adaptation should extend beyond challenge tuning to dynamically adjust multiple game aspects (e.g. environmental ambiance, music, or AI behaviour). For example, a DDA function could dim the lights to heighten tension in a horror game when it detects that the player is completing tasks too easily. Such an adjustment could enhance immersion by fostering a sense of loss of self-consciousness and altering the perception of time as the player becomes fully absorbed in the game. However, these multi-dimensional adaptations are rarely implemented in practice, leaving many DDA functions incomplete in their ability to foster flow. This suggests the need for further exploration into how DDA can consider various elements to promote a flow experience.

Overall, this research and the related studies suggest that DDA designed to maintain challenge-skill balance can enhance this factor in flow theory, regardless of game type (e.g. exergames or conventional video games) or challenge type. This is because DDA dynamically adjusts difficulty based on players' skills, preventing the experience from becoming too easy or overly frustrating. However, while DDA supports challenge-skill balance, it does not necessarily mean it will always promote flow. It is merely one factor that can facilitate flow in games. As Cowley *et al.* [17] noted, video games commonly contain elements that potentially induce flow, but this does not guarantee that every game will lead players to achieve a flow state.

8.1.2 DDA and Intrinsic Motivation: Competence and Enjoyment

This research supports SDT [16] by demonstrating that when DDA aims to balance game difficulty with player skill, as seen in P-based DDA, it potentially leads to a manageable game experience that promotes players' sense of competence. It is argued that regardless of the type of challenge presented in games—whether cognitive challenge [128], [198], [199] or physical challenge, as in this research with ExerWitch—if DDA facilitates players in achieving their goals, competence can be improved. This is evident in P-based DDA, where competence was enhanced, whereas with EI-based DDA, which did not facilitate players, no improvement in competence was observed.

Even though Van Der Spek [200] raised concerns that DDA aimed at balancing challenge-skill in video games might negatively impact competence, this issue does not apply to P-based DDA in this research. For example, in their study, when players encountered enemies stronger than their avatar, DDA would adjust the enemy's skill to match the player's skill, assuming this created a balanced experience. However, this led to a diminished sense of competence, as players felt they were not truly improving—rather, the enemies were simply being adjusted

to their level, reducing their sense of achievement.

In contrast, P-based DDA did not cause this effect because the dragon's speed was not directly correlated with or matched to the player's speed. Instead, in DDA3, the dragon's behaviour—speeding up, attacking, and then retreating (if the player cannot overcome)—ensured that players had opportunities to try to overcome challenges through their own skill. This game experience likely reinforced players' sense of competence.

Some research (e.g. [14], [182], [201]) argues that optimal challenge and competence in video games often lead to increased enjoyment. However, this claim does not always hold true. The results of this research show that while DDA3 improved competence and challenge-skill balance compared to nDDA, it did not result in higher enjoyment. Similarly, a study by Cutting *et al.* [136], which explored DDA in conventional video games, found that while DDA achieved challenge-skill balance, it did not enhance enjoyment.

This research argues that enjoyment is a multifaceted construct that involves more than simply achieving competence satisfaction. It may depend on what players are seeking during gameplay and whether the game or DDA can meet those needs. For example, some players may desire a sense of relatedness for their enjoyment. A study by Mueller *et al.* [191] demonstrated that using the heart rates of two running partners to reduce the pressure of matching each other's pace enhances enjoyment.

Moreover, if players are seeking suspense or uncertainty, satisfying these desires can also lead to increased enjoyment [103], [197], [201]. Thus, achieving challenge-skill balance and increase in competence through DDA alone may not be sufficient to promote player enjoyment in both exergames and conventional video games.

This research also highlights a distinction between two DDA approaches: EI-based DDA (DDA1 and DDA2) and affective DDA (in non-exergame video games [128]). Both utilise heart rate, yet they yield contrasting effects on player competence. EI-based DDA, as demonstrated in DDA1, DDA2, and Ketcheson *et al.* [18], aims to maintain the player's heart rate within a target zone. However, the findings suggest that this approach does not necessarily promote competence. EI-based DDA does not facilitate players in reaching the exercise intensity zone but instead forces them to exert more effort to stay within it.

Conversely, affective DDA, as exemplified by Moschovitis *et al.* [128] in a horror game, demonstrates a different outcome. This approach rewards players for successfully lowering their heart rate within a desired range. In this case, players may perceive regulating their physiological state (stress) as a skill they are improving, leading to an increased sense of competence when they succeed.

This different effect shows that using the same physiological data (heart rate) does not lead to consistent effects. The contrasting outcomes may stem from the different types of DDA functions. Affective DDA, by rewarding players for calming down, creates a game experience that encourages them to improve their ability to control their heart rate. In contrast, EI-based DDA, by often demanding increased physical exertion, may not foster a sense of competence, as players might perceive the exertion as forced effort rather than skill improvement.

Overall, in both exergame and conventional contexts, when DDA aims to facilitate players or

provide opportunities for them to improve their skills to overcome challenges or achieve game goals, it has the potential to promote a sense of competence. However, increased competence does not always lead to increased enjoyment.

8.1.3 DDA Design Suggestions

This section highlights an important observation from the experiments: the design of DDA in exergames should not be limited to EI-based and P-based approaches.

During informal interviews in the experimental sessions, it was observed that not all players engage with exergames with the primary goal of winning or maintaining a target exercise intensity. Instead, their core motivation is to complete the full session to gain physical benefits. However, the P-based DDA and EI-based DDA explored in this study may not fully accommodate this player motivation. The EI-based DDA, which uses heart rate to keep players in a target zone, may compel them to push themselves even when fatigued. Likewise, the P-based DDA aims to maintain a win-loss balance, so as players improve, the increased difficulty can force them to expend more effort to avoid losing, even when they are tired.

So, both EI-based and P-based DDA can potentially lead to overexertion before the session is completed or even cause disengagement, undermining players' primary goal of finishing the session. To better support these players and enhance the overall experience, future DDA mechanisms could integrate real-time data on physical fatigue or stamina. A stamina-oriented DDA, for example, could align game challenges with the player's primary aim of completing the exercise session safely and effectively.

Another important consideration is the potential for players to exploit DDA mechanisms, particularly when P-based approaches are applied. It is common for players to explore game mechanics and seek ways to circumvent or manipulate them. While minor exploitation may not seriously disrupt the goals of exergames, unanticipated major impacts could undermine their effectiveness if not addressed in advance.

For example, the proactive P-based DDA used in this study prevents players from experiencing setbacks or failure. Although this approach can reduce frustration compared to reactive methods, it also introduces risks of exploitation. Over time, players may learn how their actions influence the system and, recognising that the game will not punish failure, may lower their attention and effort. This behaviour can diminish player experience and compromise the exergame's objective of promoting physical activity.

Therefore, if DDA is adopted, designers should carefully consider its limitations and incorporate safeguards to minimise the risk of exploitation.

8.2 Answering Research Questions

This box restates the research questions:

Research Question 1: How do different DDA functions affect player experience in exergames?

Research Question 2: How do different DDA functions affect physical effort (as evaluated through average heart rates) during gameplay in exergames?

Research Question 3: How does proactive performance-based DDA impact player experience and physical effort compared to reactive performance-based DDA?

The following paragraph concludes the research findings in response to the research questions.

Overall, the experimental evidence in this research suggests that different DDA functions (DDA1, DDA2, DDA3, and DDA4) influence PX in exergames where physical challenge is the main challenge **in distinct ways** depending on their design goals.

Experiment 1 explored how EI-based DDA functions affect PX (intrinsic motivation, flow, and perceived exertion) and physical effort (through AHR) by comparing two variations of EI-based DDA: DDA1 and DDA2, against nDDA. The findings suggest that while EI-based DDA does not significantly impact PX compared to nDDA, it potentially increases AHR, indicating higher physical effort.

The increased AHR in DDA1 may result from its function of maintaining players' heart rates within the aerobic zone or above, based on age-related maximal heart rate. DDA1 continuously monitors players' heart rates during gameplay and adjusts the physical challenge accordingly. When a player's AHR falls below the target zone, the function increases the physical challenge to raise physical demands. Conversely, when AHR exceeds the target zone, the function reduces the physical challenge to prevent excessive exertion. If the heart rate remains within the zone, the difficulty level stays the same.

Although this type of DDA does not respond to player performance, the way it adjusts difficulty (assessed by real-time AHR) through the presence or absence of the dragon may cause a dynamic experience. This could encourage players to stay physically active in response to dragon encounters. In contrast, in nDDA, where physical demands gradually increase and the dragon continuously chases the player, the game may be perceived as too difficult or overly demanding in the later minutes due to the lack of low-intensity periods, leading to disengagement and reduced physical effort.

Despite the increase in physical effort, perceived exertion was also higher in DDA1 compared to nDDA and DDA2. This suggests that careful consideration is needed when applying DDA1 in practice, as excessive perceived exertion may negatively impact player experience, such as enjoyment [202].

The increased AHR in DDA2 can be attributed to the fact that DDA2, similar to DDA1,

aims to keep the player's heart rate within the targeted exercise intensity zones. However, by alternating between low and high intensity, it provides players with a dynamic gameplay experience. This allows the player to remain physically active when the dragon's speed increases after recovery. However, unlike DDA1, DDA2 does not lead to an increase in perceived exertion compared to nDDA, as the low intensity phase may help prevent excessive physical strain.

Even though EI-based DDA functions impact AHR and perceived exertion differently from nDDA, neither DDA1 nor DDA2 improves PX. This could be because the goals of these DDA functions do not satisfy players' psychological needs. For instance, the game's primary objective is to reach the finish line in the shortest time possible, but the focus of these DDA functions deviates from this goal. Since the DDA functions do not actively help players achieve the game's objectives or assist them in overcoming challenges, they potentially fail to improve PX.

Therefore, the answer to how EI-based DDA impacts PX and physical effort is that both DDA1 and DDA2 potentially increase physical effort. However, they do not significantly improve PX, except for an increase in perceived exertion in DDA1. **This suggests that while EI-based DDA can enhance the effectiveness of exergames, it does not necessarily improve their attractiveness**, as this type of DDA may not adequately satisfy players' psychological needs related to the game goal.

There might be an argument that some players engage in exergames primarily for exercise, so using EI-based DDA could help meet their needs. However, even in a related study by Ketcheson *et al.* [18], which used reaching a target zone as a game goal to earn rewards, their EI-based DDA also failed to improve PX. This might be because the DDA did not assist players in reaching the goal; instead, they had to achieve it through their own effort to receive rewards by DDA, making the experience similar to nDDA.

This is supported by the results from this experiment and their study, which found no significant differences in perceived competence and challenge-skill balance, suggesting DDA1 and DDA2 failed to address these core psychological aspects.

Given the assumption that EI-based DDA may have limited potential to address players' psychological needs—which may explain its lack of impact on PX compared to nDDA—Experiment 2 investigates a different form of DDA commonly used in exergames: P-based DDA. As outlined in related literature, this approach basically adjusts game difficulty based on player performance, assisting them in overcoming challenges when they struggle and in achieving game goals. Moreover, P-based DDA supports skill development by increasing the challenge level when players' current skills can deal with current difficulty levels.

The results of this research indicate that P-based DDA enhances PX by potentially promoting perceived competence and challenge-skill balance, both of which contribute to the attractiveness of exergames. Specifically, P-based DDA facilitates players in overcoming challenges, as evidenced by a significant reduction in setbacks compared to the nDDA condition. However, rather than making the game overly easy, this approach introduces a skill progression phase when players can handle the current difficulty level without setbacks, allowing them to advance their play skills and increase their physical effort.

By adjusting difficulty in response to player performance, P-based DDA allows players to experience a better alignment between their skill level and game challenges, reinforcing their perception that their abilities are improving. This, in turn, strengthens their sense of challenge-skill balance and competence.

Moreover, P-based DDA impacts physical effort by increasing AHR without significantly raising perceived exertion. Unlike EI-based DDA, which *directly* monitors players' heart rates in real time and adjusts physical demand to keep exertion within target zones, P-based DDA does *not directly* regulate heart rate. Instead, it modifies game difficulty based on performance metrics, potentially encouraging players to exert more effort voluntarily through their in-game behaviour.

By design, P-based DDA provides easier gameplay moments when players struggle with challenges, allowing them to use this period for recovery. Once players perform well during these easier moments, the difficulty increases, making them to become physically active again. This dynamic experience, alternating between easy and challenging phases, may contribute to the observed increase in physical effort without a corresponding rise in perceived exertion, while also preventing overexertion and disengagement.

Overall, **this research suggests that P-based DDA has the potential to enhance both the effectiveness and attractiveness of exergames**. However, its impact on other player experiences remains limited, as it does not significantly influence interest/enjoyment, pressure/tension, effort/importance, performative perceived challenge, or overall flow compared to the nDDA condition. This suggests that P-based DDA, which relies on the challenge-skill balance from flow theory, may not fully address these aspects of PX.

In Experiment 2, the correlation analysis revealed a negative relationship between perceived competence and setback counts, and a positive relationship between pressure/tension and setback counts. This suggests that while P-based DDA has the potential to promote positive PX, its reliance on setbacks for adjustment may lead to unexpected negative outcomes. To further explore this, Experiment 3 adopts the concept of proactive and reactive actions which explain the timing of DDA actions.

Proactive action: DDA adjusts based on the likelihood of a player encountering setbacks, preventing setbacks before they happen. Reactive action: as seen in P-based DDA in Experiment 2 (DDA3), DDA adjusts during the player is dealing with game challenges. Due to the limited research on applying the proactive concept, this experiment propose proactive P-based DDA (DDA4) that aligns with this gameplay. This function adjusts the game difficulty based on the distance between the dragon and the avatar, preventing the dragon from reaching the attacking zone and causing setbacks. In contrast, DDA3 adjusts based on setbacks that occur.

These two DDA functions were compared to explore how they impact PX and physical effort. The results show that DDA4 positively impacts PX by reducing competence frustration and increasing competence satisfaction and challenge-skill balance. However, the absence of setbacks did not lead to any significant differences in interest/enjoyment, effort/importance, pressure/ tension, or performative perceived challenge. This suggests that even though both DDA functions are performance-based, the timing of the DDA action (proactive versus reactive) can have different effects on PX.

Moreover, these findings suggest that in the context of exergames, experiencing setbacks due to an inability to overcome *a physical challenge* may not necessarily enhance enjoyment, especially when players can overcome setbacks either on their own or with the help of DDA3. However, setbacks caused by physical challenges may lead to increased frustration, even though players encounter a few numbers of setbacks before DDA3 intervenes. Repeated setbacks may irritate players rather than motivate them to try harder. This is supported by the fact that DDA3 did not result in increased AHR or perceived exertion compared to DDA4, but did lead to increased frustration.

This research suggests that if game designers intend to use setbacks from physical challenges to create a more intense or uncertain experience to enhance engagement, it may not lead to the desired outcome. Instead, setbacks that are able to make exergames more engaging might stem from other types of challenges (e.g. cognitive challenges).

Therefore, **Experiment 3 suggests that DDA4 has a more positive impact on PX compared to DDA3, particularly in terms of observed player experiences: competence and challenge-skill balance**. However, DDA4 does not significantly differ from DDA3 in terms of physical effort, perceived exertion, and other player experiences.

In conclusion, this research suggests that EI-based DDA impacts the effectiveness of exergames, while P-based DDA affects both effectiveness and attractiveness. When P-based DDA aims to prevent encounters with game setbacks caused by physical challenges (proactive approach), it can improve PX compared to P-based DDA that relies on setbacks for adjustment (reactive approach).

8.3 Research Contributions and Implications

This research contributes to HCI in games by addressing gaps in previous studies on both EI-based DDA and P-based DDA, which have lacked empirical evidence or shown mixed findings. It also addresses the gap identified in [29], which adopted the proposed dual flow model [19] in practice, but did not examine the impacts of EI-based DDA on PX. This research demonstrates that EI-based DDA can potentially enhance the effectiveness of exergames, while P-based DDA has the potential to improve both the effectiveness and attractiveness of exergames.

Empirical insight was provided to game designers and practitioners, demonstrating that different types of in-game player data have distinct impacts on players. This research shows that EI-based DDA has a limited scope, influencing physical effort by increasing AHR but with a limited ability to enhance PX. In contrast, P-based DDA has a broader scope, promoting both physical effort and positive PX. Moreover, with the helps of DDA, players do not perceive the game as too easy; instead, it helps the game remain challenging yet achievable, as indicated by an increased challenge-skill balance and perceived competence.

However, as mentioned earlier, while P-based DDA promotes physical effort, the mean difference is not substantial. This research provides quantitative data to help game designers decide which type of DDA function best fits the game's goal. If the aim is to reach a specific exercise intensity zone, P-based DDA may not be the best choice, opening opportunities to

improve or combine both DDA approaches.

This research also provides further insight that, although DDA uses similar types of player data (e.g. performance-based data), the timing of when DDA functions take action (proactive P-based DDA vs. reactive P-based DDA) can impact players differently. Experiencing setbacks from physical challenges to motivate players to exert more effort, with reactive P-based DDA assisting when they struggle, may not yield the expected results. In fact, it could potentially cause frustration.

In contrast, although proactive P-based DDA prevents setbacks, players do not exert less effort, instead, it enhances their competence and a balance between challenge and skill, which is considered beneficial for motivation and game engagement [13], [16].

These findings suggest to game designers that, while setbacks can be useful, setbacks from physical challenges might be perceived by players as unengaging, focusing solely on physical effort to overcome them. Game designers can use this information to rethink how setbacks are designed in exergames to make them more engaging, such as incorporating setbacks from other types of game challenges that require players to use complex skills to solve (e.g. a series of exercise patterns that combine both cognitive and physical challenges) to promote long-term use of these games.

This research not only provides quantitative data but also includes observations collected while players were playing, offering insights for game designers. These insights highlight important points to consider when designing exergames with DDA functions, such as high-skill players and the use of biofeedback techniques, as discussed in Experiment 1, Experiment 2, and General Discussion.

In summary, this research highlights the importance of DDA for game designers and practitioners in promoting player engagement, as evidenced by this study. Although DDA functions are straightforward rule-based, they can enhance both effectiveness and PX. This is particularly relevant in exergames, which primarily require physical effort in response to in-game physical challenges.

As players' physical state fluctuates throughout gameplay, fatigue often becomes a concern. If the game is too demanding, fatigue can become excessive, potentially leading to disengagement and negative experience. In contrast, if the game is not demanding enough, the goal of exergames to promote physical activity becomes futile [19].

Adopting DDA can assess player in-game data in real time, allowing exertion levels to increase when the game is too easy, promoting players' skill and fitness when they can handle the current level, and incorporating recovery periods. This helps players increase physical effort without excessively raising perceived exertion while also promoting a positive player experience.

8.4 Limitations and Future Research Directions

While this research provides sufficient insights into how different DDA functions in exergames influence PX and physical effort, it is not without limitations. This section list limitation in this research. Also, several aspects remain unexplored, providing directions for future research.

8.4.1 Limited Generalisability

This research focuses on running as a representative aerobic exercise, which allows for exertion levels ranging from light to vigorous intensity based on how participants adjust their speed while playing the game. However, related studies (e.g. [28], [38]) have examined other types of physical activities, such as Pong-style games, which tend to induce lower exertion levels. Activities with lower exertion levels may result in a narrower range of exertion that DDA can adjust. Besides, when focusing on physical effort (AHR), lower-intensity activities might produce smaller differences in AHR due to DDA adjustments.

Given these factors, when DDA functions are applied may provide different results. Therefore, further research is needed to explore how DDA influences PX and physical effort in games with different exertion level ranges.

Also, this research is limited to a single-player context. As a result, the findings related to the DDA functions examined in this research may not generalise to multiplayer settings. For example, in a dual runners scenario, Mueller *et al.* [191] demonstrated that balancing exertion experiences between two runners, based on heart rate, enhanced both enjoyment and social engagement. Such interactions are beyond the scope of this study, but future research could further explore how DDA functions operate in multiplayer exergames and their impact on PX and physical effort.

In Experiment 3 (DDA3 vs. DDA4), a limitation arises from the lack of distinction between different player types. Some players tend to respond positively to failures or setbacks (e.g. action-oriented individuals), while others (e.g. state-oriented individuals) typically react negatively [82], [83], [88]. These differing mindsets may influence attitudes toward DDA3 and DDA4, potentially affecting PX and physical effort. Future research should investigate how these DDA approaches interact with players' action control tendencies in relation to PX, providing a more nuanced understanding of their effects.

8.4.2 DDA Approaches

The DDA approaches (DDA1, DDA2, DDA3, and DDA4) in this research are limited to straightforward rule-based adjustments, using only a single data from the player for adaptation and addressing only physical challenges, as outlined in the research scope. Despite this simplicity, the findings demonstrate that even a straightforward approach can enhance certain aspects of PX and increase physical effort. However, this does not imply that other PX factors (e.g. interest/ enjoyment) remain unaffected by DDA functions.

Video games consist of various elements and challenges, suggesting that DDA can be applied beyond physical challenges. For instance, as shown in Lopes *et al.* [183], adaptive functions can adjust multiple aspects of gameplay (e.g. atmosphere when the game becomes too easy) and work together to create a more engaging experience. Since this research focuses solely on physical challenges and DDA functions designed to address them, it remains unclear how these approaches would perform in exergames with more complex game elements and challenges.

To further explore this might help make the current version of this exergame more engaging and promote long-term engagement, as this exergame lacks a variety of challenges and game elements that players might get used to and bored with after a few uses. Future research could explore how DDA can be applied in more complex exergames and how it impacts PX and physical effort.

In Experiment 1, the age-related maximal heart rate formula was adopted for DDA1 and DDA2 to calculate exercise intensity zones based on individual players' heart rates. However, this approach has limitations in accurately predicting actual maximal heart rate, as discussed in the background chapter. For example, it may be less reliable for elderly individuals or well-trained athletes. If replicated in a clinical or laboratory setting, this limitation could be mitigated or prevented.

However, this research focuses on exergames designed for general gameplay rather than clinical applications or high-performance sports. Moreover, if this game and its DDA functions were implemented in real-world home-based settings, players would likely have limited access to laboratory tests for determining actual maximal heart rate. Considering this, the chosen approach aligns with the gaming environments rather than the precise requirements of clinical or sports settings.

In Experiment 1, EI-based DDA (DDA1 and DDA2) is limited to using heart rate to quantify exercise intensity due to the nature of the gameplay, which involves running as a cardiovascular activity. However, related studies (e.g. [203]) have explored other physiological data, such as muscle activity, to describe exercise intensity. Different player data may lead to different DDA mechanisms for adaptation. Therefore, future research can explore alternative physiological indicators to determine whether this type of DDA functions consistently across different measures or provides additional insights into its effects. This is because different types of exercises or physical activities may use different parts of the body.

8.4.3 Short-Term Evaluation

The scope of this research is to measure PX and physical effort immediately after a 10-minute gameplay session. However, there is a likelihood that players' experiences with exergames, whether with or without DDA, might yield different results in a long-term experimental setting or with longer gameplay sessions. This is because other factors, which may not have been apparent in this short-session experiment, could present over time. For instance, players might become accustomed to the game, leading to a lack of novelty (potentially causing boredom) and greater mastery over the game with long-term or multiple sessions. Moreover, longer play sessions may involve more physical and cognitive fatigue, which were

not considered as interfering variables in this research design.

Moreover, in practical settings (e.g. home fitness), exergames might be used repeatedly over weeks or months. The single-session design does not account for how DDA might sustain or diminish motivation, particularly during long-term usage. Therefore, further research could explore whether the effects found in this research remain consistent across longer gameplay sessions or longer usages.

8.4.4 Heart Rate Measurement Limitations and Carry-over Effect

This experiment acknowledges the limitation of using a smartwatch to record players' heart rates during gameplay. Although investigators ensured that the sensor was properly affixed, the nature of the game, requiring players to move their arms and bodies while also sweating, could have affected the watch's accuracy in measuring AHR. However, this limitation was mitigated by using the same sensor across all conditions and ensuring that players wore it only on their left hand.

However, if this game with EI-based DDA is used outside of research contexts—for instance, in everyday gaming or fitness activities—the use of a smartwatch to record heart rate can be considered acceptable. Consumer-grade devices such as the Galaxy Watch 4 are widely adopted for tracking physical activity, and related studies have also employed similar devices.

Another limitation concerns the potential carry-over effects from preceding sessions, which may have influenced the average heart rate recorded during gameplay. This research processed players' physical effort using average heart rate. Although the within-subject design controls for static differences in fitness, it does not fully mitigate the issue of carry-over effects, such as fatigue. Even with rest periods, measurement of resting heart rate at the beginning of each play session, and confirmation of participants' readiness before continuing, a preceding condition may still have affected their physiological state in the subsequent session. This, in turn, could reduce the robustness of the findings on how the DDA functions impacted physical effort.

To enhance the robustness of future findings concerning physical effort, two key methodological improvements are suggested.

- First, future studies should incorporate heart rate normalisation to provide a more accurate and comparable measure of physical effort. This can be achieved by calculating each participant's Heart Rate Reserve (HRR) for every session, based on their estimated maximum heart rate and session-specific resting heart rate. Expressing the average heart rate during play as a percentage of HRR would provide a more meaningful indicator of relative physical exertion.
- Second, to better identify and account for carry-over effects, future work could adopt a more interval analysis of physiological data. Rather than relying on a single average heart rate across an entire play session, heart rate could be examined in shorter time intervals. This would allow for a more detailed understanding of how physical effort develops over the course of play and whether it is influenced by the preceding condition, even with a counterbalanced design.

8.5 Final Words

This thesis presents empirical insights into how EI-based DDA and P-based DDA in a single-player running exergame (where light-to-vigorous exercise intensity can be involved while playing) impact PX and physical effort. Both approaches encourage players to exert more physical effort compared to when no DDA is applied, which is particularly useful in the exergame context, as it encourages greater physical activity during gameplay. However, in terms of PX, EI-based DDA does not appear to foster PX improvements.

This may be due to the nature of this adaptation, which does not directly support players in overcoming challenges or reaching game goals but instead tries to adjust players' exertion levels within the exercise intensity zones, possibly failing in addressing psychological needs (SDT). In contrast, P-based DDA demonstrates potential in promoting PX. By helping players to overcome excessively difficult challenges while ensuring that the game remains engaging rather than too easy, this approach potentially promotes positive experiences, particularly competence and challenge-skill balance, as it fulfils players' psychological needs.

Moreover, this research proposes a new approach for P-based DDA. Existing works (e.g. [23], [27]) often adjust game difficulty in response to player setbacks or failures, but this method risks causing negative experiences, such as frustration, before the DDA takes action. In exergames, where physical workload is the main factor, relying on setbacks or failures for difficulty adjustments may intensify tiredness during play, potentially leading to discouragement and finally disengagement. To address this, this research uses the concept of proactive DDA, allowing the DDA function to intervene before players encounter setbacks. The findings indicate that this approach mitigates competence frustration while enhancing competence satisfaction and challenge-skill balance, which is beneficial to PX.

Although the DDA functions examined in this research follow straightforward rule-based approaches due to the nature of the game and research context, the findings highlight their potential in fostering positive PX and promoting physical activity. This research contributes to the exergame industry by providing quantitative data on how DDA functions (commonly found in related works) impact players, which they can use as insights for design consideration. Moreover, this research also offers guidance on DDA design that was actually used with players in empirical studies for DDA designers and game developers to take into consideration when designing.

Finally, this research highlights the importance of DDA functions in the exergame context compared to when no DDA is applied, as both EI-based DDA and P-based DDA potentially enhance the effectiveness of exergames. Besides, P-based DDA can satisfy players' need for competence and promote a key factor in entering the flow state: challenge-skill balance, which enhances the attractiveness of the game.

Bibliography

[1] J. Marshall and C. Linehan, "Are exergames exercise? a scoping review of the short-term effects of exertion games," *IEEE Transactions on Games*, vol. 13, no. 2, pp. 160–169, 2020.

[2] I. Bogost, "The rhetoric of exergaming," *Proceedings of the Digital Arts and Cultures (DAC)*, vol. 51, 2005.

[3] J. Sween, S. F. Wallington, V. Sheppard, T. Taylor, A. A. Llanos, and L. L. Adams-Campbell, "The role of exergaming in improving physical activity: A review," *Journal of Physical Activity and Health*, vol. 11, no. 4, pp. 864–870, 2014.

[4] K. Ijaz, N. Ahmadpour, Y. Wang, and R. A. Calvo, "Player experience of needs satisfaction (pens) in an immersive virtual reality exercise platform describes motivation and enjoyment," *International Journal of Human–Computer Interaction*, vol. 36, no. 13, pp. 1195–1204, 2020.

[5] A. Matallaoui, J. Koivisto, J. Hamari, and R. Zarnekow, "How effective is "exergamification"? a systematic review on the effectiveness of gamification features in exergames," 2017.

[6] T. Kari, "Can exergaming promote physical fitness and physical activity?: A systematic review of systematic reviews," *International Journal of Gaming and Computer-Mediated Simulations (IJGCMS)*, vol. 6, pp. 59–77, Oct. 2014. DOI: 10.4018/ijgcms.2014100105.

[7] G. Osorio, D. C. Moffat, and J. Sykes, "Exergaming, exercise, and gaming: Sharing motivations," *Games for health: research, development, and clinical applications*, vol. 1, no. 3, pp. 205–210, 2012.

[8] J. Polechoński, M. Dębska, and P. G. Dębski, "Exergaming can be a health-related aerobic physical activity," *BioMed Research International*, vol. 2019, no. 1, p. 1 890 527, 2019.

[9] A. Denisova, C. Guckelsberger, and D. Zendle, "Challenge in digital games: Towards developing a measurement tool," in *Proceedings of the 2017 chi conference extended abstracts on human factors in computing systems*, 2017, pp. 2511–2519.

[10] S. Petralito, F. Brühlmann, G. Iten, E. D. Mekler, and K. Opwis, "A good reason to die: How avatar death and high challenges enable positive experiences," in *Proceedings of the 2017 CHI conference on human factors in computing systems*, 2017, pp. 5087–5097.

[11] C. Foch and B. Kirman, ""slow down and look": Desirable aspects of failure in video games, from the perspective of players.," in *Proceedings of the 16th International Conference on the Foundations of Digital Games*, 2021, pp. 1–10.

[12] W. Van den Hoogen, K. Poels, W. IJsselsteijn, and Y. De Kort, "Between challenge and defeat: Repeated player-death and game enjoyment," *Media Psychology*, vol. 15, no. 4, pp. 443–459, 2012.

[13] M. Csikszentmihalyi, M. Csikszentmihalyi, S. Abuhamdeh, and J. Nakamura, "Flow," *Flow and the foundations of positive psychology: The collected works of Mihaly Csikszentmihalyi*, pp. 227–238, 2014.

[14] S. A. Jackson and M. Csikszentmihalyi, *Flow in sports*. Human Kinetics, 1999.

[15] A. Denisova, P. Cairns, C. Guckelsberger, and D. Zendle, "Measuring perceived challenge in digital games: Development & validation of the challenge originating from recent gameplay interaction scale (corgis)," *International Journal of Human-Computer Studies*, vol. 137, p. 102 383, 2020.

[16] R. M. Ryan, C. S. Rigby, and A. Przybylski, "The motivational pull of video games: A self-determination theory approach," *Motivation and emotion*, vol. 30, pp. 344–360, 2006.

[17] B. Cowley, D. Charles, M. Black, and R. Hickey, "Toward an understanding of flow in video games," *Computers in Entertainment (CIE)*, vol. 6, no. 2, pp. 1–27, 2008.

[18] M. Ketcheson, L. Walker, and T. N. Graham, "Thighrim and calf-life: A study of the conversion of off-the-shelf video games into exergames," in *Proceedings of the 2016 chi conference on human factors in computing systems*, 2016, pp. 2681–2692.

[19] J. Sinclair, P. Hingston, and M. Masek, "Considerations for the design of exergames," in *Proceedings of the 5th international conference on Computer graphics and interactive techniques in Australia and Southeast Asia*, 2007, pp. 289–295.

[20] B. Soderman, *Against flow: Video games and the flowing subject*. MIT press, 2021.

[21] D. Ang and A. Mitchell, "Comparing effects of dynamic difficulty adjustment systems on video game experience," in *proceedings of the annual symposium on computer-human interaction in play*, 2017, pp. 317–327.

[22] J. D. Smeddinck, R. L. Mandryk, M. V. Birk, K. M. Gerling, D. Barsilowski, and R. Malaka, "How to present game difficulty choices? exploring the impact on player experience," in *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*, 2016, pp. 5595–5607.

[23] A. L. Martin-Niedecken, K. Rogers, L. Turmo Vidal, E. D. Mekler, and E. Márquez Segura, "Exercube vs. personal trainer: Evaluating a holistic, immersive, and adaptive fitness game setup," in *Proceedings of the 2019 CHI conference on human factors in computing systems*, 2019, pp. 1–15.

[24] A. L. Martin-Niedecken and U. Götz, "Go with the dual flow: Evaluating the psychophysiological adaptive fitness game environment "plunder planet"," in *Serious Games: Third Joint International Conference, JCSG 2017, Valencia, Spain, November 23-24, 2017, Proceedings 3*, Springer, 2017, pp. 32–43.

[25] Q. Mi and T. Gao, "Adaptive rubber-banding system of dynamic difficulty adjustment in racing games," *ICGA Journal*, vol. 44, no. 1, pp. 18–38, 2022.

[26] B. C. Wünsche, M. Abernethy, S. Hyniewska, *et al.*, "Rift racers-effect of balancing and competition on exertion, enjoyment, and motivation in an immersive exergame," in *2021 36th International Conference on Image and Vision Computing New Zealand (IVCNZ)*, IEEE, 2021, pp. 1–6.

[27] O. S. Ajani and R. Mallipeddi, "Pareto-based dynamic difficulty adjustment of a competitive exergame for arm rehabilitation," *International Journal of Human-Computer Studies*, vol. 178, p. 103 100, 2023.

[28] A. Darzi, S. M. McCrea, D. Novak, *et al.*, "User experience with dynamic difficulty adjustment methods for an affective exergame: Comparative laboratory-based study," *JMIR Serious Games*, vol. 9, no. 2, e25771, 2021.

[29] J. Sinclair, P. Hingston, and M. Masek, "Exergame development using the dual flow model," in *Proceedings of the Sixth Australasian Conference on Interactive Entertainment*, 2009, pp. 1–7.

[30] H. Tanaka, K. D. Monahan, and D. R. Seals, "Age-predicted maximal heart rate revisited," *Journal of the american college of cardiology*, vol. 37, no. 1, pp. 153–156, 2001.

[31] J. E. Muñoz, M. Cameirão, S. Bermúdez i Badia, and E. R. Gouveia, "Closing the loop in exergaming-health benefits of biocybernetic adaptation in senior adults," in *Proceedings of the 2018 Annual Symposium on Computer-Human Interaction in Play*, 2018, pp. 329–339.

[32] S. Liu, X. Wang, Z. Wu, and Y. He, "Physiotreadmill: An auto-controlled treadmill featuring physiological-data-driven visual/audio feedback," in *2020 International Conference on Cyberworlds (CW)*, IEEE, 2020, pp. 219–226.

[33] A. Schwarz, G. Cardon, S. Chastin, *et al.*, "Does dynamic tailoring of a narrative-driven exergame result in higher user engagement among adolescents? results from a cluster-randomized controlled trial," *International Journal of Environmental Research and Public Health*, vol. 18, no. 14, p. 7444, 2021.

[34] H. She, J. Young, O. Wittenberg, *et al.*, "Hiitcopter: Analysis of the suitability of vr exergaming for high-intensity interval training," in *Proceedings of the 32nd Australian Conference on Human-Computer Interaction*, 2020, pp. 293–302.

[35] M. Ferreira, A. Pinha, M. Fonseca, and P. Lopes, "Behind the door: Exploring horror vr game interaction and its influence on anxiety," in *Proceedings of the 18th International Conference on the Foundations of Digital Games*, 2023, pp. 1–11.

[36] R. Hunicke, "The case for dynamic difficulty adjustment in games," in *Proceedings of the 2005 ACM SIGCHI International Conference on Advances in computer entertainment technology*, 2005, pp. 429–433.

[37] M. A. M. Cuerdo, A. Mahajan, J. Mao, and E. F. Melcer, "Try again?: A macro-level taxonomy of the challenge and failure process in games," in *2023 IEEE Conference on Games (CoG)*, IEEE, 2023, pp. 1–8.

[38] M. Goršič, A. Darzi, and D. Novak, "Comparison of two difficulty adaptation strategies for competitive arm rehabilitation exercises," in *2017 international conference on rehabilitation robotics (ICORR)*, IEEE, 2017, pp. 640–645.

[39] A. T. Bayrak, R. Kumar, J. Tan, *et al.*, "Balancing different fitness levels in competitive exergames based on heart rate and performance," in *Proceedings of the 29th Australian Conference on Computer-Human Interaction*, 2017, pp. 210–217.

[40] M. D. Finco and R. W. Maass, "The history of exergames: Promotion of exercise and active living through body interaction," in *2014 IEEE 3nd International Conference on Serious Games and Applications for Health (SeGAH)*, IEEE, 2014, pp. 1–6.

[41] E. A. Boyle, T. M. Connolly, T. Hainey, and J. M. Boyle, "Engagement in digital entertainment games: A systematic review," *Computers in human behavior*, vol. 28, no. 3, pp. 771–780, 2012.

[42] C. J. Caspersen, K. E. Powell, and G. M. Christenson, "Physical activity, exercise, and physical fitness: Definitions and distinctions for health-related research.," *Public health reports*, vol. 100, no. 2, p. 126, 1985.

[43] N. A. Dasso, "How is exercise different from physical activity? a concept analysis," in *Nursing forum*, Wiley Online Library, vol. 54, 2019, pp. 45–52.

[44] D. Sewell, P. Watkins, M. Griffin, and D. A. Sewell, *Sport and exercise science: An introduction*. Routledge, 2013.

[45] T. Moholdt, C. J. Lavie, and J. Nauman, "Sustained physical activity, not weight loss, associated with improved survival in coronary heart disease," *Journal of the American College of Cardiology*, vol. 71, no. 10, pp. 1094–1101, 2018.

[46] K. M. Diaz and D. Shimbo, "Physical activity and the prevention of hypertension," *Current hypertension reports*, vol. 15, pp. 659–668, 2013.

[47] J. Karvonen and T. Vuorimaa, "Heart rate and exercise intensity during sports activities: Practical application," *Sports medicine*, vol. 5, pp. 303–311, 1988.

[48] S. Muangsrinoon and P. Boonbrahm, "Burn in zone: Real time heart rate monitoring for physical activity," in *2017 14th International Joint Conference on Computer Science and Software Engineering (JCSSE)*, IEEE, 2017, pp. 1–6.

[49] A. L. Martin-Niedecken, T. Schwarz, and A. Schättin, "Comparing the impact of heart rate-based in-game adaptations in an exergame-based functional high-intensity interval training on training intensity and experience in healthy young adults," *Frontiers in Psychology*, vol. 12, p. 572 877, 2021.

[50] R. Oman and E. McAuley, "Intrinsic motivation and exercise behavior," *Journal of Health Education*, vol. 24, no. 4, pp. 232–238, 1993.

[51] C. M. Frederick, C. Morrison, and T. Manning, "Motivation to participate, exercise affect, and outcome behaviors toward physical activity," *Perceptual and Motor Skills*, vol. 82, no. 2, pp. 691–701, 1996.

[52] A. Ruffault, M. Bernier, N. Juge, and J. F. Fournier, "Mindfulness may moderate the relationship between intrinsic motivation and physical activity: A cross-sectional study," *Mindfulness*, vol. 7, pp. 445–452, 2016.

[53] D. H.-L. Goh and K. Razikin, "Is gamification effective in motivating exercise?" In *Human-Computer Interaction: Interaction Technologies: 17th International Conference, HCI International 2015, Los Angeles, CA, USA, August 2-7, 2015, Proceedings, Part II 17*, Springer, 2015, pp. 608–617.

[54] T. Park, U. Lee, S. MacKenzie, M. Moon, I. Hwang, and J. Song, "Human factors of speed-based exergame controllers," in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 2014, pp. 1865–1874.

[55] A. L. Martin-Niedecken, A. Mahrer, K. Rogers, E. D. de Bruin, and A. Schättin, ""hiit" the exercube: Comparing the effectiveness of functional high-intensity interval training in conventional vs. exergame-based training," *Frontiers in Computer Science*, vol. 2, p. 33, 2020.

[56] Y. Gao and R. Mandryk, "The acute cognitive benefits of casual exergame play," in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 2012, pp. 1863–1872.

[57] F. Mueller, D. Edge, F. Vetere, *et al.*, "Designing sports: A framework for exertion games," in *Proceedings of the sigchi conference on human factors in computing systems*, 2011, pp. 2651–2660.

[58] S. Hwang, A. L. J. Schneider, D. Clarke, *et al.*, "How game balancing affects play: Player adaptation in an exergame for children with cerebral palsy," in *Proceedings of the 2017 Conference on Designing Interactive Systems*, 2017, pp. 699–710.

[59] M. Ketcheson, Z. Ye, and T. N. Graham, "Designing for exertion: How heart-rate power-ups increase physical activity in exergames," in *Proceedings of the 2015 Annual Symposium on Computer-Human Interaction in Play*, 2015, pp. 79–89.

[60] S. Lee, W. Kim, T. Park, and W. Peng, "The psychological effects of playing exergames: A systematic review," *Cyberpsychology, Behavior, and Social Networking*, vol. 20, no. 9, pp. 513–532, 2017.

[61] K. Durmanova, "The effects of juicy game design on exergames," M.S. thesis, University of Waterloo, 2022.

[62] F. Mueller, M. R. Gibbs, and F. Vetere, "Taxonomy of exertion games," in *Proceedings of the 20th Australasian conference on computer-human interaction: designing for habitus and habitat*, 2008, pp. 263–266.

[63] E. Biddiss and J. Irwin, "Active video games to promote physical activity in children and youth: A systematic review," *Archives of pediatrics & adolescent medicine*, vol. 164, no. 7, pp. 664–672, 2010.

[64] Z. Gao, S. Chen, D. Pasco, and Z. Pope, "A meta-analysis of active video games on health outcomes among children and adolescents," *Obesity reviews*, vol. 16, no. 9, pp. 783–794, 2015.

[65] A. G. LeBlanc, J.-P. Chaput, A. McFarlane, *et al.*, "Active video games and health indicators in children and youth: A systematic review," *PloS one*, vol. 8, no. 6, e65351, 2013.

[66] Y. Oh and S. Yang, "Defining exergames & exergaming," *Proceedings of meaningful play*, vol. 2010, pp. 21–23, 2010.

[67] M. Pasch, N. Bianchi-Berthouze, B. van Dijk, and A. Nijholt, "Movement-based sports video games: Investigating motivation and gaming experience," *Entertainment computing*, vol. 1, no. 2, pp. 49–61, 2009.

[68] F. Mueller and K. Isbister, "Movement-based game guidelines," in *Proceedings of the sigchi conference on human factors in computing systems*, 2014, pp. 2191–2200.

[69] P. Hämäläinen, J. Marshall, R. Kajastila, R. Byrne, and F. F. Mueller, "Utilizing gravity in movement-based games and play," in *Proceedings of the 2015 Annual Symposium on Computer-Human Interaction in Play*, 2015, pp. 67–77.

[70] A. L. Martin-Niedecken and E. D. Mekler, "The exercube: Participatory design of an immersive fitness game environment," in *Joint international conference on serious games*, Springer, 2018, pp. 263–275.

[71] J. F. Pinto, H. R. Carvalho, G. R. Chambel, J. Ramiro, and A. Gonçalves, "Adaptive gameplay and difficulty adjustment in a gamified upper-limb rehabilitation," in *2018 IEEE 6th international conference on serious games and applications for health (SeGAH)*, IEEE, 2018, pp. 1–8.

[72] W. Peng, J. C. Crouse, and J.-H. Lin, "Using active video games for physical activity promotion: A systematic review of the current state of research," *Health education & behavior*, vol. 40, no. 2, pp. 171–192, 2013.

[73] T. W. Malone, "What makes things fun to learn? heuristics for designing instructional computer games," in *Proceedings of the 3rd ACM SIGSMALL symposium and the first SIGPC symposium on Small systems*, 1980, pp. 162–169.

[74] B. Bostan and S. Öğüt, "Game challenges and difficulty levels: Lessons learned from rpgs," in *International simulation and gaming association conference*, 2009, pp. 1–11.

[75] M. Brandse and K. Tomimatsu, "Empirical review of challenge design in video game design," in *HCI International 2013-Posters' Extended Abstracts: International Conference, HCI International 2013, Las Vegas, NV, USA, July 21-26, 2013, Proceedings, Part I 15*, Springer, 2013, pp. 398–406.

[76] T. Campbell, B. Ngo, and J. Fogarty, "Game design principles in everyday fitness applications," in *Proceedings of the 2008 ACM conference on Computer supported cooperative work*, 2008, pp. 249–252.

[77] J. Vahlo and V.-M. Karhulahti, "Challenge types in gaming validation of video game challenge inventory (cha)," *International Journal of Human-Computer Studies*, vol. 143, p. 102 473, 2020.

[78] R. Furze, "Challenge," in *The Routledge companion to video game studies*, Routledge, 2014, pp. 143–151.

[79] D. Dziedzic and W. Włodarczyk, "Approaches to measuring the difficulty of games in dynamic difficulty adjustment systems," *International Journal of Human–Computer Interaction*, vol. 34, no. 8, pp. 707–715, 2018.

[80] J. Schell, *The Art of Game Design: A book of lenses*. CRC press, 2008.

[81] C. Macklin and J. Sharp, *Games, Design and Play: A detailed approach to iterative game design*. Addison-Wesley Professional, 2016.

[82] C. G. Anderson, K. Campbell, and C. Steinkuehler, "Building persistence through failure: The role of challenge in video games," in *Proceedings of the 14th International Conference on the Foundations of Digital Games*, 2019, pp. 1–6.

[83] J. Frommel, M. Klarkowski, and R. L. Mandryk, "The struggle is spiel: On failure and success in games," in *Proceedings of the 16th International Conference on the Foundations of Digital Games*, 2021, pp. 1–12.

[84] J. Juul, *The art of failure: An essay on the pain of playing video games*. MIT press, 2013.

[85] J. Juul, "In search of lost time: On game goals and failure costs," in *Proceedings of the Fifth International Conference on the Foundations of Digital Games*, 2010, pp. 86–91.

[86] J. Juul, "Fear of failing? the many meanings of difficulty in video games," *The video game theory reader*, vol. 2, no. 237-252, 2009.

[87] B. Aytemiz and A. M. Smith, "A diagnostic taxonomy of failure in videogames," in *Proceedings of the 15th International Conference on the Foundations of Digital Games*, 2020, pp. 1–11.

[88] K. Waldenmeier, S. Poeller, M. J. Dechant, N. Baumann, and R. L. Mandryk, "Cheat codes as external support for players navigating fear of failure and self-regulation challenges in digital games," in *Proceedings of the CHI Conference on Human Factors in Computing Systems*, 2024, pp. 1–13.

[89] K. M. Gilleade and A. Dix, "Using frustration in the design of adaptive videogames," in *Proceedings of the 2004 ACM SIGCHI International Conference on Advances in computer entertainment technology*, 2004, pp. 228–232.

[90] F. Allison, M. Carter, and M. Gibbs, "Good frustrations: The paradoxical pleasure of fearing death in dayz," in *Proceedings of the Annual Meeting of the Australian Special Interest Group for Computer Human Interaction*, 2015, pp. 119–123.

[91] D. Haglind, *Coping with success and failure–a qualitative study on athletes and coaches in track and field*, 2003.

[92] J. M. Domingues, V. Filipe, A. Carita, and V. Carvalho, "Understanding the impact of perceived challenge on narrative immersion in video games: The role-playing game genre as a case study," *Information*, vol. 15, no. 6, p. 294, 2024.

[93] P. Vorderer, T. Hartmann, and C. Klimmt, "Explaining the enjoyment of playing video games: The role of competition," in *Proceedings of the second international conference on Entertainment computing*, 2003, pp. 1–9.

[94] M.-V. Aponte, G. Levieux, and S. Natkin, "Scaling the level of difficulty in single player video games," in *Entertainment Computing–ICEC 2009: 8th International Conference, Paris, France, September 3-5, 2009. Proceedings 8*, Springer, 2009, pp. 24–35.

[95] J. Chen, "Flow in games (and everything else)," *Communications of the ACM*, vol. 50, no. 4, pp. 31–34, 2007.

[96] P. Sweetser and P. Wyeth, "Gameflow: A model for evaluating player enjoyment in games," *Computers in Entertainment (CIE)*, vol. 3, no. 3, pp. 3–3, 2005.

[97] N. Falstein, "Understanding fun–the theory of natural funativity," *Introduction to game development*, pp. 71–98, 2005.

[98] P. Rodrigues, M. Fonseca, and P. Lopes, "Physiological-based difficulty assessment for virtual reality rehabilitation games," in *Proceedings of the 18th International Conference on the Foundations of Digital Games*, 2023, pp. 1–4.

[99] E. L. Deci and R. M. Ryan, "The" what" and" why" of goal pursuits: Human needs and the self-determination of behavior," *Psychological inquiry*, vol. 11, no. 4, pp. 227–268, 2000.

[100] E. D. Mekler, J. A. Bopp, A. N. Tuch, and K. Opwis, "A systematic review of quantitative studies on the enjoyment of digital entertainment games," in *Proceedings of the SIGCHI conference on human factors in computing systems*, 2014, pp. 927–936.

[101] Y. Qin, "Attractiveness of game elements, presence, and enjoyment of mobile augmented reality games: The case of pokémon go," *Telematics and Informatics*, vol. 62, p. 101 620, 2021.

[102] S. Abuhamdeh and M. Csikszentmihalyi, "The importance of challenge for the enjoyment of intrinsically motivated, goal-directed activities," *Personality and social psychology bulletin*, vol. 38, no. 3, pp. 317–330, 2012.

[103] S. Abuhamdeh, M. Csikszentmihalyi, and B. Jalal, "Enjoying the possibility of defeat: Outcome uncertainty, suspense, and intrinsic motivation," *Motivation and Emotion*, vol. 39, pp. 1–10, 2015.

[104] W. Rao Fernandes and G. Levieux, "Difficulty pacing impact on player motivation," in *International Conference on Entertainment Computing*, Springer, 2022, pp. 140–153.

[105] N. Sorenson, P. Pasquier, and S. DiPaola, "A generic approach to challenge modeling for the procedural creation of video game levels," *IEEE Transactions on Computational Intelligence and AI in Games*, vol. 3, no. 3, pp. 229–244, 2011.

[106] G. A. Borg and B. J. Noble, "Perceived exertion," *Exercise and sport sciences reviews*, vol. 2, no. 1, pp. 131–154, 1974.

[107] M. W. Kilpatrick, S. J. Greeley, and J. M. Ferron, "A comparison of the impacts of continuous and interval cycle exercise on perceived exertion," *European journal of sport science*, vol. 16, no. 2, pp. 221–228, 2016.

[108] M. M. Slawinska and P. A. Davis, "Recall of affective responses to exercise: Examining the influence of intensity and time," *Frontiers in Sports and Active Living*, vol. 2, p. 573 525, 2020.

[109] G. Andrade, G. Ramalho, A. Gomes, and V. Corruble, "Dynamic game balancing: An evaluation of user satisfaction," in *Proceedings of the AAAI Conference on Artificial Intelligence and Interactive Digital Entertainment*, vol. 2, 2006, pp. 3–8.

[110] N. Fisher and A. K. Kulshreshth, "Exploring dynamic difficulty adjustment methods for video games," in *Virtual Worlds*, MDPI, vol. 3, 2024, pp. 230–255.

[111] D. Ang and A. Mitchell, "Representation and frequency of player choice in player-oriented dynamic difficulty adjustment systems," in *Proceedings of the Annual Symposium on Computer-Human Interaction in Play*, 2019, pp. 589–600.

[112] R. Pagulayan, K. Keeker, D. Wixon, R. Romero, and T. Fuller, "User-centered design in games," *Human-Computer Interact. Handb*, pp. 883–906, Jan. 2003. DOI: 10.1201/b11963-39.

[113] M. Zohaib, "Dynamic difficulty adjustment (dda) in computer games: A review," *Advances in Human-Computer Interaction*, vol. 2018, pp. 1–12, Nov. 2018. DOI: 10.1155/2018/5681652.

[114] D. Dziedzic, "Dynamic difficulty adjustment systems for various game genres," *Homo Ludens*, vol. 9, no. 1, pp. 35–51, 2016.

[115] A. Denisova and P. Cairns, "Adaptation in digital games: The effect of challenge adjustment on player performance and experience," in *Proceedings of the 2015 Annual Symposium on Computer-Human Interaction in Play*, 2015, pp. 97–101.

[116] A. Streicher and J. D. Smeddinck, "Personalized and adaptive serious games," in *Entertainment Computing and Serious Games: International GI-Dagstuhl Seminar 15283, Dagstuhl Castle, Germany, July 5-10, 2015, Revised Selected Papers*, Springer, 2016, pp. 332–377.

[117] M. Danousis, C. Goumopoulos, and A. Fakis, "Exergames in the game2awe platform with dynamic difficulty adjustment," in *International Conference on Entertainment Computing*, Springer, 2022, pp. 214–223.

[118] J. C. Lopes and R. P. Lopes, "A review of dynamic difficulty adjustment methods for serious games," in *International Conference on Optimization, Learning Algorithms and Applications*, Springer, 2022, pp. 144–159.

[119] A. Li, I. Chai, and K.-W. Ng, "Dynamic difficulty adjustment in video games for encouraging physical exercise: A review and theoretical framework," in *3rd International Conference on Creative Multimedia 2023 (ICCM 2023)*, Atlantis Press, 2023, pp. 113–121.

[120] R. J. V. De Medeiros and T. F. V. De Medeiros, "Procedural level balancing in runner games," in *2014 Brazilian Symposium on Computer Games and Digital Entertainment*, IEEE, 2014, pp. 109–114.

[121] M. Zohaib, "Dynamic difficulty adjustment (dda) in computer games: A review," *Advances in Human-Computer Interaction*, vol. 2018, no. 1, p. 5 681 652, 2018.

[122] J. D. Smeddinck, "Human-computer interaction with adaptable & adaptive motion-based games for health," *arXiv preprint arXiv:2012.03309*, 2020.

[123] B. Magerko, "Adaptation in digital games," *Computer*, vol. 41, no. 6, pp. 87–89, 2008.

[124] A. Sarkar and S. Cooper, "Transforming game difficulty curves using function composition," in *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*, 2019, pp. 1–7.

[125] A. Seyderhelm and K. Blackmore, "Systematic review of dynamic difficulty adaption for serious games: The importance of diverse approaches," *Available at SSRN*, vol. 3982971, 2021.

[126] C. E. Erali and M. McCoy Jr, "Designing with the player experience in mind: Dynamic difficulty adjustment,"

[127] D. Ang, "Difficulty in video games: Understanding the effects of dynamic difficulty adjustment in video games on player experience," in *Proceedings of the 2017 ACM SIGCHI Conference on Creativity and Cognition*, 2017, pp. 544–550.

[128] P. Moschovitis and A. Denisova, "Keep calm and aim for the head: Biofeedback-controlled dynamic difficulty adjustment in a horror game," *IEEE Transactions on Games*, 2022.

[129] L. Climent, A. Longhi, A. Arbelaez, and M. Mancini, "A framework for designing reinforcement learning agents with dynamic difficulty adjustment in single-player action video games," *Entertainment Computing*, vol. 50, p. 100 686, 2024.

[130] D. Sharek and E. Wiebe, "Investigating real-time predictors of engagement: Implications for adaptive videogames and online training," *International Journal of Gaming and Computer-Mediated Simulations (IJGCMS)*, vol. 7, no. 1, pp. 20–37, 2015.

[131] A. Longhi, A. Arbelaez, M. Mancini, and L. Climent, "A framework for designing reinforcement learning agents with dynamic difficulty adjustment in single-player action video games," *Entertainment Computing*, p. 100 686, 2024.

[132] D. S. Lora-Ariza, A. A. Sánchez-Ruiz, P. A. González-Calero, and I. Camps-Ortueta, "Measuring control to dynamically induce flow in tetris," *IEEE Transactions on Games*, vol. 14, no. 4, pp. 579–588, 2022.

[133] N. Robb and B. Zhang, "Performance-based dynamic difficulty adjustment and player experience in a 2d digital game: A controlled experiment," *Acta Ludologica*, vol. 5, no. 1, pp. 4–22, 2022.

[134] F. Mortazavi, H. Moradi, and A.-H. Vahabie, "Dynamic difficulty adjustment approaches in video games: A systematic literature review," *Multimedia Tools and Applications*, pp. 1–48, 2024.

[135] C. Vang, "The impact of dynamic difficulty adjustment on player experience in video games," *Scholarly Horizons: University of Minnesota, Morris Undergraduate Journal*, vol. 9, no. 1, p. 7, 2022.

[136] J. Cutting, S. Deterding, S. Demediuk, and N. Sephton, "Difficulty-skill balance does not affect engagement and enjoyment: A pre-registered study using artificial intelligence-controlled difficulty," *Royal Society Open Science*, vol. 10, no. 2, p. 220 274, 2023.

[137] R. Hunicke and V. Chapman, "Ai for dynamic difficulty adjustment in games," *Challenges in game artificial intelligence AAAI workshop*, vol. 2, Jan. 2004.

[138] T. Félix, F. Mourato, and J. Morais, "Dungeon wipe: Exploring dynamic difficulty adjustment with power-up mechanics," in *International Conference on Entertainment Computing*, Springer, 2024, pp. 323–330.

[139] A. Karime, B. Hafidh, W. Gueaieb, and A. El Saddik, "A modular mobile exergaming system with an adaptive behavior," in *2015 IEEE International Symposium on Medical Measurements and Applications (MeMeA) Proceedings*, IEEE, 2015, pp. 531–536.

[140] T. Huber, S. Mertes, S. Rangelova, S. Flutura, and E. André, "Dynamic difficulty adjustment in virtual reality exergames through experience-driven procedural content generation," in *2021 IEEE Symposium Series on Computational Intelligence (SSCI)*, IEEE, 2021, pp. 1–8.

[141] S. Demediuk, M. Tamassia, W. L. Raffe, F. Zambetta, X. Li, and F. Mueller, "Monte carlo tree search based algorithms for dynamic difficulty adjustment," in *2017 IEEE conference on computational intelligence and games (CIG)*, IEEE, 2017, pp. 53–59.

[142] H.-Y. Sung, G.-J. Hwang, and Y.-F. Yen, "Development of a contextual decision-making game for improving students' learning performance in a health education course," *Computers & Education*, vol. 82, pp. 179–190, 2015.

[143] P. Cairns and A. L. Cox, *Research methods for human-computer interaction*. Cambridge University Press Cambridge, 2008, vol. 10.

[144] J. A. Kraft, W. D. Russell, T. A. Bowman, C. W. Selsor III, and G. D. Foster, "Heart rate and perceived exertion during self-selected intensities for exergaming compared to traditional exercise in college-age participants," *The Journal of Strength & Conditioning Research*, vol. 25, no. 6, pp. 1736–1742, 2011.

[145] M. Hoda, R. Alattas, and A. El Saddik, "Evaluating player experience in cycling exergames," in *2013 IEEE International Symposium on Multimedia*, IEEE, 2013, pp. 415–420.

[146] Center for self-determination theory (CSDT), *Intrinsic motivation inventory (imi) – selfdeterminationtheory.org*, `https://selfdeterminationtheory.org/intrinsic-motivation-inventory/`, (accessed Mar. 17, 2024).

[147] N. Ballou, A. Denisova, R. Ryan, C. S. Rigby, and S. Deterding, "The basic needs in games scale (bangs): A new tool for investigating positive and negative video game experiences," *International Journal of Human-Computer Studies*, vol. 188, p. 103 289, 2024.

[148] Self-Determination Theory, *Player experience of need satisfaction (pens)*, Accessed: 2025-01-03, 2024. [Online]. Available: `https://selfdeterminationtheory.org/player-experience-of-needs-satisfaction-pens/`.

[149] A. Azadvar and A. Canossa, "Upeq: Ubisoft perceived experience questionnaire: A self-determination evaluation tool for video games," in *Proceedings of the 13th international conference on the foundations of digital games*, 2018, pp. 1–7.

[150] D. Kendzierski and K. J. DeCarlo, "Physical activity enjoyment scale: Two validation studies," *Journal of sport and exercise psychology*, vol. 13, no. 1, pp. 50–64, 1991.

[151] A. Schättin, J. Pickles, D. Flagmeier, *et al.*, "Development of a novel home-based exergame with on-body feedback: Usability study," *JMIR Serious Games*, vol. 10, no. 4, e38703, 2022.

[152] Y.-C. Lai, S.-T. Wang, and J.-C. Yang, "An investigation of the exergames experience with flow state, enjoyment, and physical fitness," in *2012 IEEE 12th international conference on advanced learning technologies*, IEEE, 2012, pp. 58–60.

[153] J. Berg, A. I. Wang, S. Lydersen, and T. Moholdt, "Can gaming get you fit?" *Frontiers in Physiology*, vol. 11, p. 1017, 2020.

[154] S. A. Jackson and H. W. Marsh, "Development and validation of a scale to measure optimal experience: The flow state scale," *Journal of sport and exercise psychology*, vol. 18, no. 1, pp. 17–35, 1996.

[155] M. Klarkowski, D. Johnson, P. Wyeth, S. Smith, and C. Phillips, "Operationalising and measuring flow in video games," in *Proceedings of the Annual Meeting of the Australian Special Interest Group for Computer Human Interaction*, 2015, pp. 114–118.

[156] S. Engeser and F. Rheinberg, "Flow, performance and moderators of challenge-skill balance," *Motivation and emotion*, vol. 32, pp. 158–172, 2008.

[157] T. A. Kyriazos, A. Stalikas, K. Prassa, V. Chatzilia, M. Galanakis, and K. Flora, "The flow short scale (fss) dimensionality and what mimic shows on heterogeneity and invariance," 2018.

[158] W. A. IJsselsteijn, Y. A. De Kort, and K. Poels, "The game experience questionnaire," 2013.

[159] Y. Gao and R. L. Mandryk, "Grabapple: The design of a casual exergame," in *International Conference on Entertainment Computing*, Springer, 2011, pp. 35–46.

[160] M. F. Montoya, J. E. Muñoz, and O. A. Henao, "Enhancing virtual rehabilitation in upper limbs with biocybernetic adaptation: The effects of virtual reality on perceived muscle fatigue, game performance and user experience," *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, vol. 28, no. 3, pp. 740–747, 2020.

[161] S. Yoo, M. Carter, and J. Kay, "Vrmove: Design framework for balancing enjoyment, movement and exertion in vr games," in *Proceedings of the 2018 Annual Symposium on Computer-Human Interaction in Play Companion Extended Abstracts*, 2018, pp. 295–307.

[162] D. T.-P. Fong, K.-Y. Yam, V. W.-S. Chu, R. T.-H. Cheung, and K.-M. Chan, "Upper limb muscle fatigue during prolonged boccia games with underarm throwing technique," *Sports biomechanics*, vol. 11, no. 4, pp. 441–451, 2012.

[163] M. Y. Martin, C. Marín-Lora, and M. Chover, "A comparative analysis of game experience in treadmill running applications," *Entertainment Computing*, vol. 52, p. 100 888, 2025.

[164] S. Yoo and J. Kay, "Vrun: Running-in-place virtual reality exergame," in *Proceedings of the 28th Australian Conference on Computer-Human Interaction*, 2016, pp. 562–566.

[165] M. Ahn, S. Kwon, B. Park, *et al.*, "Running or gaming," in *Proceedings of the international conference on advances in computer entertainment technology*, 2009, pp. 345–348.

[166] S. Finkelstein, A. Nickel, Z. Lipps, T. Barnes, Z. Wartell, and E. A. Suma, "Astrojumper: Motivating exercise with an immersive virtual reality exergame," *Presence: Teleoperators and Virtual Environments*, vol. 20, no. 1, pp. 78–92, 2011.

[167] C. Khundam and F. Nöel, "A study of physical fitness and enjoyment on virtual running for exergames," *International Journal of Computer Games Technology*, vol. 2021, no. 1, p. 6 668 280, 2021.

[168] A. L. Martin-Niedecken and U. Götz, "Design and evaluation of a dynamically adaptive fitness game environment for children and young adolescents," in *Proceedings of the 2016 Annual Symposium on Computer-Human Interaction in Play Companion Extended Abstracts*, 2016, pp. 205–212.

[169] S. Yoo, C. Parker, and J. Kay, "Designing a personalized vr exergame," in *Adjunct Publication of the 25th Conference on User Modeling, Adaptation and Personalization*, 2017, pp. 431–435.

[170] S. N. Zealand, *Fundamental movement: Running*, Accessed: 2025-01-08, n.d. [Online]. Available: `https://sportnz.org.nz/media/2050/fundamental-movement-running.pdf`.

[171] M. A. Nystoriak and A. Bhatnagar, "Cardiovascular effects and benefits of exercise," *Frontiers in cardiovascular medicine*, vol. 5, p. 408 204, 2018.

[172] D. Dack, *The Total Beginner's Guide to Running*. Runner's Blueprint, 2018, Accessed: Jan. 7, 2025. [Online]. Available: `https://www.runnersblueprint.com/wp-content/uploads/2018/11/RunnersBluePrint-E-Book.pdf`.

[173] J. D. Bartlett, G. L. Close, D. P. MacLaren, W. Gregson, B. Drust, and J. P. Morton, "High-intensity interval running is perceived to be more enjoyable than moderate-intensity continuous exercise: Implications for exercise adherence," *Journal of sports sciences*, vol. 29, no. 6, pp. 547–553, 2011.

[174] P. Sweetser, D. Johnson, P. Wyeth, A. Anwar, Y. Meng, and A. Ozdowska, "Gameflow in different game genres and platforms," *Computers in Entertainment (CIE)*, vol. 15, no. 3, pp. 1–24, 2017.

[175] P. Sweetser, "Gameflow 2020: 15 years of a model of player enjoyment," in *Proceedings of the 32nd Australian Conference on Human-Computer Interaction*, 2020, pp. 705–711.

[176] A. Keesing, M. Ooi, O. Wu, X. Ye, L. Shaw, and B. C. Wünsche, "Hiit with hits: Using music and gameplay to induce hiit in exergames," in *Proceedings of the Australasian Computer Science Week Multiconference*, 2019, pp. 1–10.

[177] P. M. Fitts, "Perceptual-motor skill learning," in *Categories of human learning*, Elsevier, 1964, pp. 243–285.

[178] J. R. Anderson, "Acquisition of cognitive skill.," *Psychological review*, vol. 89, no. 4, p. 369, 1982.

[179] H. K. Kim, J. Park, Y. Choi, and M. Choe, "Virtual reality sickness questionnaire (vrsq): Motion sickness measurement index in a virtual reality environment," *Applied ergonomics*, vol. 69, pp. 66–73, 2018.

[180] U. A. Chattha, U. I. Janjua, F. Anwar, T. M. Madni, M. F. Cheema, and S. I. Janjua, "Motion sickness in virtual reality: An empirical evaluation," *IEEE Access*, vol. 8, pp. 130 486–130 499, 2020.

[181] C. Marín-Lora, M. Chover, M. Y. Martín, and L. García-Rytman, "Creating a treadmill running video game with smartwatch interaction," *Multimedia Tools and Applications*, vol. 83, no. 19, pp. 57 709–57 729, 2024.

[182] A. Touati and Y. Baek, "What leads to player's enjoyment and achievement in a mobile learning game?" *Journal of Educational Computing Research*, vol. 56, no. 3, pp. 344–368, 2018.

[183] P. Lopes and M. Fonseca, "Towards effectively adapting games: What needs to be conquered to achieve adaptation," *Eurosis Game-On*, 2021.

[184] R. Avram, G. H. Tison, K. Aschbacher, *et al.*, "Real-world heart rate norms in the health eheart study," *NPJ digital medicine*, vol. 2, no. 1, p. 58, 2019.

[185] N. Williams, "The borg rating of perceived exertion (rpe) scale," *Occupational medicine*, vol. 67, no. 5, pp. 404–405, 2017.

[186] P. Ekkekakis, "Pleasure and displeasure from the body: Perspectives from exercise," *Cognition and emotion*, vol. 17, no. 2, pp. 213–239, 2003.

[187] J. G. Moulard, M. Kroff, K. Pounders, and C. Ditt, "The role of suspense in gaming: Inducing consumers' game enjoyment," *Journal of Interactive Advertising*, vol. 19, no. 3, pp. 219–235, 2019.

[188] O. M. Giggins, U. M. Persson, and B. Caulfield, "Biofeedback in rehabilitation," *Journal of neuroengineering and rehabilitation*, vol. 10, pp. 1–11, 2013.

[189] A. Macvean and J. Robertson, "Understanding exergame users' physical activity, motivation and behavior over time," in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 2013, pp. 1251–1260.

[190] B. Marcus and L. Forsyth, *Motivating people to be physically active* (Physical activity intervention series), eng. Champaign, Ill. ; Human Kinetics, 2003, ISBN: 0736040641.

[191] F. Mueller, F. Vetere, M. Gibbs, *et al.*, "Balancing exertion experiences," in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 2012, pp. 1853–1862.

[192] J. Tremblay, *A new approach to dynamic difficulty adjustment in video games*. Université du Québec à Chicoutimi, 2011.

[193] J. Knorr and C. Vaz de Carvalho, "Using dynamic difficulty adjustment to improve the experience and train fps gamers," in *Ninth International Conference on Technological Ecosystems for Enhancing Multiculturality (TEEM'21)*, 2021, pp. 195–200.

[194] C. Graf, "The relevance of graphics and sound for the manipulation of a video game difficulty using feature-based dynamic difficulty adjustment," Ph.D. dissertation, Otto-von-Guericke University, 2012.

[195] G. Borg, *Borg's perceived exertion and pain scales*. Human kinetics, 1998.

[196] Z. Guo, R. Thawonmas, and X. Ren, "Rethinking dynamic difficulty adjustment for video game design," *Entertainment Computing*, p. 100 663, 2024.

[197] S. Deterding, M. M. Andersen, J. Kiverstein, and M. Miller, "Mastering uncertainty: A predictive processing account of enjoying uncertain success in video game play," *Frontiers in psychology*, vol. 13, p. 924 953, 2022.

[198] S. Nebel, M. Beege, S. Schneider, and G. D. Rey, "Competitive agents and adaptive difficulty within educational video games," in *Frontiers in education*, Frontiers Media SA, vol. 5, 2020, p. 129.

[199] J. E. Cechanowicz, C. Gutwin, S. Bateman, R. Mandryk, and I. Stavness, "Improving player balancing in racing games," in *Proceedings of the first ACM SIGCHI annual symposium on Computer-human interaction in play*, 2014, pp. 47–56.

[200] E. D. Van Der Spek, "Towards designing for competence and engagement in serious games," in *Serious Games Development and Applications: Third International Conference, SGDA 2012, Bremen, Germany, September 26-29, 2012. Proceedings 3*, Springer, 2012, pp. 98–109.

[201] R. Vicencio-Moreira, R. L. Mandryk, and C. Gutwin, "Now you can compete with anyone: Balancing players of different skill levels in a first-person shooter game," in *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, 2015, pp. 2255–2264.

[202] J. S. Thum, G. Parsons, T. Whittle, and T. A. Astorino, "High-intensity interval training elicits higher enjoyment than moderate intensity continuous exercise," *PloS one*, vol. 12, no. 1, e0166299, 2017.

[203] A. Darzi, M. Goršič, and D. Novak, "Difficulty adaptation in a competitive arm rehabilitation game using real-time control of arm electromyogram and respiration," in *2017 International Conference on Rehabilitation Robotics (ICORR)*, IEEE, 2017, pp. 857–862.

[204] S. Thomas, J. Reading, and R. J. Shephard, "Revision of the physical activity readiness questionnaire (par-q).," *Canadian journal of sport sciences= Journal canadien des sciences du sport*, vol. 17, no. 4, pp. 338–345, 1992.

Appendix A

The Approval of Ethics Application

The documents on the following pages present the ethical grants for the Pilot Study, Experiment 1, Experiment 2, and Experiment 3 consecutively.

Physical Sciences Ethics Committee

Date: November 10, 2022

To: Sittikrai Chorrojprasert

Subject: Ethics Approval

PSEC Application Ref: Chorrojprasert20221021

Dear Sittikrai,

Thank you for your recent application to the Physical Sciences Ethics Committee for the project entitled "A pilot study of a running exergame: flow, intrinsic motivation, and exercise intensity evaluation and game feedback". I am pleased to inform you that the committee has reviewed your application and supporting documents and we approve the research to be conducted on the basis described on the application form.

Please note the committee must be informed of any amendments to the protocol and/or participant information/informed consent prior to the research taking place. Please follow the amendments procedures using the reference above in any correspondence concerning this project in the future.

It is also your responsibility to ensure continuing conformance to the University of York's ethical policy over the life-time of the project.

Yours Sincerely,

Burak Merdenyan

On behalf of the Physical Sciences Ethics Committee

Physical Sciences Ethics Committee

Date: April 26, 2023
To: Sittikrai Chorrojprasert
Subject: Ethics Approval
PSEC Application Ref: Chorrojprasert20230412

Dear Sittikrai,

Thank you for your recent application to the Physical Sciences Ethics Committee for the project titled "A study of the effect of an exergame on player experience". I am pleased to inform you that the committee has reviewed your application and supporting documents and we approve the research to be conducted on the basis described on the application form.

Please note the committee must be informed of any amendments to the protocol, participant information, or informed consent prior to the research taking place. Please follow the amendments procedures using the reference above in any correspondence concerning this project in the future.

It is also your responsibility to ensure continuing conformance to the University of York's ethical policy over the lifetime of the project.

Yours sincerely,

Siamak F. Shahandashti
Ethics Coordinator, Dept. Computer Science

On behalf of the Physical Sciences Ethics Committee

Physical Sciences Ethics Committee

Date: September 29, 2023

To: Sittikrai Chorrojprasert

Subject: Ethics Approval

PSEC Application Ref: Chorrojprasert20230923

Dear Sittikrai,

Thank you for your recent application to the Physical Sciences Ethics Committee for the project entitled "The effects of performance-based dynamic difficulty adjustment in exergames on player experiences and exercise intensity". I am pleased to inform you that the committee has reviewed your application and supporting documents and we approve the research to be conducted on the basis described on the application form.

Please note the committee must be informed of any amendments to the protocol and/or participant information/informed consent prior to the research taking place. Please follow the amendments procedures using the reference above in any correspondence concerning this project in the future.

It is also your responsibility to ensure continuing conformance to the University of York's ethical policy over the life-time of the project.

Yours Sincerely,

Burak Merdenyan

On behalf of the Physical Sciences Ethics Committee

Physical Sciences Ethics Committee

Date: May 24, 2024

To: Sittikrai Chorrojprasert

Subject: Ethics Approval

PSEC Application Ref: Chorrojprasert20240513

Dear Sittikrai,

Thank you for your recent application to the Physical Sciences Ethics Committee for the project entitled "The effects of different dynamic difficulty adjustment in exergames on player experience.". I am pleased to inform you that the committee has reviewed your application and supporting documents and we approve the research to be conducted on the basis described on the application form.

Please note the committee must be informed of any amendments to the protocol and/or participant information/informed consent prior to the research taking place. Please follow the amendments procedures using the reference above in any correspondence concerning this project in the future.

It is also your responsibility to ensure continuing conformance to the University of York's ethical policy over the life-time of the project.

Yours Sincerely,

Burak Merdenyan

On behalf of the Physical Sciences Ethics Committee

Appendix B

Information Sheets

The messages in the grey area below show the details of the Information Sheet provided to participants in Experiment 1.

The Participant Information Sheet
Title: A study of the effect of an exergame on player experiences

1. Purpose of the study

This study aims to investigate player experience when playing an exergame (i.e. a video game that a player must exert themselves to interact with the game).

2. Participation

Participation in this study is completely voluntary. As a reward for taking part and completing the study, you will receive a £20 Amazon.co.uk eGift voucher after completing the debriefing stage.

3. Participation eligibility

- Age: 18 and above.
- Do not consider yourself to have a limitation in physical activity (i.e. walking, running, punching, and stretching arms out). The exercise intensity found in this study can range from light to vigorous intensity.
- This study uses the Samsung Galaxy Watch 4 to measure heart rates and collect movement data. Those who have a pacemaker implanted or other devices that might be interfered with by the watch are not allowed to take part in this study.
- All questions in the Physical Activity Readiness questionnaire are answered as "NO". This questionnaire can be found in Appendix 1.

4. Participant's involvement

This study is divided into 3 sessions, and you are required to attend all sessions. You can arrange the time to take part in each session with the investigator. Each session takes approx. 40 minutes, so the whole study takes approx. 120 minutes to be completed.

In each part, you will be asked to play the running exergame for around 12 minutes. It is a casual video game without any exercise machines or equipment where you control the game by walking in place, running in place, punching, and stretching your arms out. And this game might induce light to vigorous exercise intensity. Your physiological and biomechanical data will be collected and fed into the game using 3 sensors (i.e. the Samsung Galaxy Watch 4) that will be attached to your body which are explained in Section 5 in detail. After the playtime session ends, you will be asked to complete questionnaires to evaluate player experiences in the game. Overall, the goal of this study is to examine how the exergame affects the player experience.

Full instructions on how to complete each task will be provided to you on the day of the experiment. If you are uncomfortable with having physical activity, wearing the sensors, or for other reasons (e.g. time availability), please do not take part in this study.

5. Sensors used in this study

The investigator will prepare the sensors for you. In this study, you will be asked to wear 3 sensors (i.e. the Samsung Galaxy Watch 4). These sensors are used for collecting heart rates or acceleration data. The first one will be attached to your right wrist. The second one will be attached to your left wrist. And the last one will be attached to your right ankle or left ankle. The investigator will help or explain how to affix the sensors to you.

6. Observation and note-taking

You might be observed by the investigator in this study. Also, any conversations or data from observations related to the study might be taken notes to ensure no data is missed. This data will be used for assessing this experimental design or improving the design for future experiments.

7. Photos taken in the study

You might be taken a photo if you give a consent to the investigator to do so. If there is your face in the photo, it will be blurred. The photo can be included in the investigator's thesis and potentially in relevant publications.

8. Participant's right to stop the playtime session

While you are playing the exergame, you can stop the session at any point.

9. Participant's right to withdraw from the study

You have an absolute right to withdraw from the study without any negative consequences and without giving any reasons on the day of the study. You can also request your data to be withdrawn up to two weeks after the study completion. Your collected data will not be processed and reported, and all relevant data will be disposed of. You will be given an ID that you can use to give to the investigator to request your data to be withdrawn. If you would like to withdraw from the study, please contact the investigator using the information in Section 13 below.

10. Participant confidentiality

Your participation in this study will not be disclosed to anyone and you will not be identified or identifiable from the collected data.

11. Data usage, protection, and a retention period

The data collected from the study will be anonymous. We will use a randomly generated participant ID to link your data in case you wish to withdraw it. This ID will not be used for any other purposes. Any hard copies produced in this study will be kept strictly in locked drawers. Also, any soft copies will be secured by passwords and stored in online repositories or computers provided by the University of York. The collected data can be accessed by the investigator and his supervisors only, and the data will be managed by the investigator. Your collected data will be used for research purposes and will be retained by following the university's policy (the default period for research data retention is 10 years from the date of last requested access). If you give us your email address, it will be recorded and used for making any appointments. Also, a voucher for completing the study will be sent to you via this email. The email record will not be used for linking other data. It might be kept if you give a consent to the investigator to use this email to inform you about any recruitment calls for future studies. Otherwise, it will be disposed of after the voucher is sent to you.

The investigator will comply with the UK General Data Protection Regulation (GDPR) and Data Protection Act 2018. And if you have any data protection questions, comments, or complaints, please contact the Data Protection Officer by sending an email to `dataprotection@york.ac.uk`.

12. Location and instructions

The experiment will take place at the University of York, Campus East. You will be informed by the investigator about the venue, date, and time after the appointment is arranged.

You are advised to wear breathable and flexible clothes, socks, and trainers (or any other footwear you are comfortable with for physical activity). We advise you to have enough sleep the night before the day of the experiment.

13. Contact for further information

If you have any questions related to this study, please feel free to contact the investigator.

Mr SITTIKRAI CHORROJPRASERT

Room 214, Department of Computer Science, University of York, Deramore Lane, Heslington, York, YO10 5GH, United Kingdom

Email: `sittikrai.chorrojprasert@york.ac.uk`

His supervisors' information

Dr Alena Denisova

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Email: `alena.denisova@york.ac.uk`

Dr Ben Kirman

School of Arts and Creative Technologies, University of York

Email: `ben.kirman@york.ac.uk`

14. Complaints about the study

If you are unhappy or have a complaint about this study, you can contact the investigator or his supervisors. You can also contact his department:

Department of Computer Science, University of York, Deramore Lane, Heslington, York YO10 5GH, United Kingdom Email: cs-reception@york.ac.uk Tel: +44 (0)1904 325501

Appendix 1: The Physical Activity Readiness Questionnaire

You can access the questionnaire by this link: `https://docs.google.com/document/d/1Kdfa5yS90xFcp_zQPu1ugobMHiomn8JavDmr1UG2lZg/edit?usp=sharing`

This study is granted by the Physical Science Ethics Committee of the University of York.

The messages in the grey area below show the details of the Information Sheet provided to participants in Experiment 2.

The participant information sheet

Title: a study of the effects of an exergame on player experiences

(Study No. 2)

1. Purpose of the study

This study aims to investigate player experience after playing an exergame (i.e. a video game that a player must exert themselves to interact with the game).

2. Participation

Participation in this study is completely voluntary. As a reward for taking part and completing the study, you will receive a £10 Amazon.co.uk eGift voucher after completing the debriefing stage*.

*A voucher will be sent to your given email address. After that, the email address kept by the investigator will be disposed of. However, any related data or records of payment will be kept by the investigator's department and may be shared in case of an audit by HMRC

3. Participation eligibility

- Age: 18 and above.
- Do not consider yourself to have a limitation in physical activity (i.e. walking, running, punching, and stretching arms out). The exercise intensity found in this study can range from light to vigorous intensity.
- This study uses the Samsung Galaxy Watch 4 to measure heart rates and related data. Those who have a pacemaker implanted or other devices that might be interfered with by the watch are not allowed to take part in this study.
- All questions in the Physical Activity Readiness questionnaire are answered as "NO". This questionnaire can be found in Appendix 1.

To ensure the physical safety of participants, people who do not meet these criteria will not be eligible to participate in the study. If you do wish to participate in this study and do meet the eligibility criteria, you will be asked to read and sign a consent form on the day of the experiment.

4. Participant's involvement

This study is divided into 2 sessions, and you are required to attend all sessions. The whole study takes approx. 60 minutes to be completed. In each session, you will be asked to play the running exergame for around 10 minutes. It is a casual video game without any exercise machines or equipment where you control the game by walking in place, running in place, punching, and stretching your arms out. And this game might induce light to vigorous exercise intensity. After the playtime session ends, you will be asked to complete questionnaires* to evaluate player experiences in the game. Overall, the goal of this study is to examine how the exergame affects the player experience. Full instructions on how to complete each task will be provided to you on the day of the experiment. If you are uncomfortable with having physical activity, wearing the sensors, or for other reasons (e.g. time availability), please do not take part in this study.

While you are playing the exergame, you can stop playing at any point.

*The questionnaires (Likert scales) are written in English, and there are 53 questions in total for each session.

5. Sensors used in this study

In this study, you will be asked to wear a Samsung Galaxy Watch 4 (prepared by the investigator). It will be used for collecting your heart rates and related data. The investigator will help or explain how to affix the sensors to you.

6. Observation and note-taking

You might be observed by the investigator in this study. Also, any conversations or data from observations related to the study might be taken notes to ensure no data is missed. This data will be used for data analysis, assessing this experimental design, and improving the design for future experiments. There will be no private information or identifiable data noted.

7. Photos taken in the study

You might be taken a photo if you give a consent to the investigator to do so. If there is your face in the photo, it will be blurred. The photo can be included in the investigator's thesis and potentially in relevant publications.

8. Video recording in the study

The investigator needs to collect your in-game performance data (e.g. your success rates to achieve tasks in the game) used for data analysis. Although the game system is developed to record this data, there might be system defects or human errors. Therefore, recording your interactions with the game and a game screen is essential for double-checking.

Any recordings will be strictly kept in encrypted folders in the university's devices secured with passwords. The recordings will be permanently disposed of within 3 months after the experiment completion, or after the data analysis is reviewed by the investigator's supervisors. The investigator will position a camera to avoid your faces as much as possible.

9. Participant's right to withdraw from the study

You have an absolute right to withdraw from the study without any negative consequences and without giving any reasons on the day of the study. You can also request your data to be withdrawn up to two weeks after the study completion. Your collected data will not be processed and reported, and all relevant data will be disposed of.

You will be given an ID that you can use to give to the investigator to request your data to be withdrawn. If you would like to withdraw from the study, please contact the investigator using the information in Section 13 below.

10. Participant confidentiality

Your participation in this study will not be disclosed to anyone, and research data will not be identifiable.

11. Data usage, protection, and a retention period

The data collected from the study will be anonymous. We will use a randomly generated participant ID to link your data in case you wish to withdraw it. This ID will not be used for any other purposes. Any hard copies produced in this study will be kept strictly in locked drawers. Also, any soft copies will be secured by passwords and stored in online repositories or devices provided by the University of York. The collected data (related to the research) can be accessed by the investigator and his supervisors, and the data will be managed by the investigator. However, anonymised research data might be shared with external parties.

Research data will be used for research purposes and will be retained by following the university's policy (the default period for research data retention is 10 years from the date of last requested access). The investigator will comply with the UK General Data Protection Regulation (GDPR) and Data Protection Act 2018. And if you have any data protection questions, comments, or complaints, please contact the Data Protection Officer by sending an email to dataprotection@york.ac.uk.

12. Location and instructions

The experiment will take place at the University of York, Campus East. You will be informed by the investigator about the venue, date, and time after the appointment is arranged. You are advised to wear breathable and flexible clothes, socks, and trainers (or any other footwear you are comfortable with for physical activity). We advise you to have enough sleep the night before the day of the experiment.

13. Contact for further information

If you have any questions related to this study, please feel free to contact the investigator.

Mr SITTIKRAI CHORROJPRASERT

Room 214, Department of Computer Science, University of York, Deramore Lane, Heslington, York, YO10 5GH, United Kingdom

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Dr Ben Kirman

School of Arts and Creative Technologies, University of York

Email: ben.kirman@york.ac.uk

14. Complaints about the study

If you are unhappy or have a complaint about this study, you can contact the investigator or his supervisors. You can also contact his department:

Department of Computer Science, University of York, Deramore Lane, Heslington, York YO10 5GH, United Kingdom Email: cs-reception@york.ac.uk Tel: +44 (0)1904 325501

Appendix 1: The Physical Activity Readiness Questionnaire

You can access the questionnaire by this link:

`https://drive.google.com/file/d/1ZlhooW7NHa1EpVaV1pUp2AelAOhroOrT/view?usp=drive_link`

This study is granted by the Physical Science Ethics Committee of the University of York.

The messages in the grey area below show the details of the Information Sheet provided to participants in Experiment 3.

The participant information sheet Title: a study of the effects of an exergame on player experiences (Study No. 3)

1. Purpose of the study

This study aims to investigate player experience after playing an exergame (i.e. a video game that requires physical exertion to interact with the game).

2. Participation

Participation is voluntary and compensated with a £12 Amazon.co.uk eGift voucher upon study completion.

*A voucher will be sent to your given email address. After that, the email address kept by the investigator will be deleted. However, any related data or records of payment will be kept by the investigator's department and may be shared in case of an audit by HMRC

3. Participation eligibility

- Age: 18 and older.
- Able to perform physical activities like walking, running, stretching, and punching motions. The exercise intensity in the study will range from light to vigorous.
- This study uses a Samsung Galaxy Watch 4 to monitor heart rate. If you have a pacemaker or any other medical implant that might interfere with the watch, you won't be able to participate.
- To ensure your safety, all questions in the Physical Activity Readiness questionnaire must be answered as "NO". This questionnaire can be found in Appendix 1.

If you meet all the criteria and wish to participate, you will be asked to read and sign a consent form on the day of the experiment.

4. Participant's involvement

This study is divided into 2 sessions, and you are required to attend all sessions. The whole study takes approx. 60 minutes to be completed. In each session, you will be asked to play the running exergame for around 10 minutes. It is a casual video game without any exercise machines or equipment where you control the game by walking in place, running in place, punching, and stretching your arms out. And this game might induce light to vigorous exercise intensity. After the playtime session ends, you will be asked to complete questionnaires to evaluate your experience of playing the game.

Full instructions on how to complete each task will be provided to you on the day of the experiment. If you are uncomfortable with having physical activity, wearing the sensors, or for other reasons (e.g. time availability), please do not take part in this study. While you are playing the exergame, you can stop playing at any point.

5. Sensors used in this study

During the study, you'll wear a Samsung Galaxy Watch 4 (provided) to monitor your heart rate. The investigator will assist with setup. Your movements will be recorded by a camera solely for game control and then discarded.

6. Observation and note-taking

During the study, the investigator may observe your gameplay and take anonymous notes for analysis and future design improvement. No personal information will be recorded.

7. Optional photo consent

With your consent, a photo may be taken for the investigator's thesis and potential publications. Your face will be blurred to ensure anonymity.

8. Confidentiality and withdrawal right

Your participation in this study will not be disclosed to anyone, and research data will not be identifiable.

You can withdraw from the study anytime, with no explanation needed. This applies even on the day of the study. Up to two weeks after completion, you can also request your data to be withdrawn by providing the investigator with an anonymous ID. In this case, your data won't be used and will be deleted.

If you wish to withdraw, please contact the investigator using the information in Section 11.

9. Data usage, protection, and a retention period

Your participation will be completely anonymous. To allow for potential data withdrawal if you choose, we will assign you an anonymous ID that has no connection to your identity. All data, both physical copies kept in locked drawers and electronic copies secured with passwords on online repositories or devices provided by the University of York, will be strictly protected. Only the investigator, their supervisors, and authorised personnel will have access to the data for research purposes. Anonymised research findings, however, may be shared with external parties.

Research data will be used for research purposes and will be retained by following the university's policy (the default period for research data retention is 10 years from the date of last requested access). The investigator will comply with the UK General Data Protection Regulation (GDPR) and Data Protection Act 2018. And if you have any data protection questions, comments, or complaints, please contact the Data Protection Officer by sending an email to dataprotection@york.ac.uk.

10. Location and instructions

The experiment will be held at the University of York, Campus East. We will confirm the specific venue, date, and time with you once an appointment is scheduled.

For your comfort during the experiment, we recommend wearing breathable and flexible clothing, socks, and trainers (or any footwear suitable for physical activity). Getting a good night's sleep before the experiment is also advisable. 11. Contact for further information

If you have any questions related to this study, please feel free to contact the investigator.

Mr SITTIKRAI CHORROJPRASERT

Room 214, Department of Computer Science, University of York, Deramore Lane, Heslington, York, YO10 5GH, United Kingdom

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His supervisors' information

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Department of Computer Science, University of York

Email: alena.denisova@york.ac.uk

Dr Ben Kirman

School of Arts and Creative Technologies, University of York

Email: ben.kirman@york.ac.uk

12. Complaints about the study

If you have any concerns or complaints about this study, you can contact the investigator or their supervisors. You can also reach out to the investigator's department.

Appendix 1: The Physical Activity Readiness Questionnaire

You can access the questionnaire by this link: `https://drive.google.com/file/d/1ZlhooW7NHa1EpVaV1pUp2AelAOhroOrT/view?usp=drive_link`

This study is granted by the Physical Science Ethics Committee of the University of York.

Appendix C

Consent Forms

The following documents, shown on the subsequent pages, present the consent forms for Experiment 1, Experiment 2, and Experiment 3 consecutively.

A CONSENT FORM

Please complete the whole of this sheet

	Actions Please tick circles
1. I confirm that I am aged 18 or over.	○
2. I confirm that I can do physical activity in this study.	○
3. I confirm that I have no physical limitations on using or wearing the sensors (i.e. the Samsung Galaxy Watch 4).	○
4. I confirm that I have completed the Physical Activity Readiness questionnaire, and all questions are answered as "NO".	○
5. I confirm that my participation is voluntary, and I understand that I have a right to withdraw from the study without giving any reasons on the day of the study.	○
6. I agree to be observed and I confirm that any conversations or data from observations related to the study can be taken notes.	○
7. I confirm that my given data can be used and managed by the investigator for research purposes. Also, I understand that I can request the investigator to withdraw my collected data up to two weeks after the study completion by providing them with the generated participant ID. The research data will be kept by following the university's policy (the default period for research data retention is 10 years from the date of last requested access.).	○
8. I confirm that the investigator allowed me to ask questions related to the study, and my questions were thoroughly answered satisfactorily.	○
9. I confirm that I have read and understood the participant information sheet of this study.	○

Optional additional consent

	Actions	
	Yes	No
I give my consent to the investigator to take a photo of me while I am taking part in the study. If there is my face in the photo, it must be blurred. The photo can be included in the investigator's thesis and potentially in relevant publications.	○	●
I give my consent to the investigator to keep my email address so that the investigator can inform me about any recruitment calls for future studies.	○	●

I give my consent to participate in this study

○ Yes
○ No

A CONSENT FORM

Please complete the whole of this sheet

	Actions Please tick circles
1. I confirm that I am aged 18 or over.	○
2. I confirm that I can do physical activity in this study.	○
3. I confirm that I have no physical limitations on using or wearing the sensors (i.e. the Samsung Galaxy Watch 4).	○
4. I confirm that I have completed the Physical Activity Readiness questionnaire, and all questions are answered as "NO".	○
5. I confirm that my participation is voluntary. Also, I understand that I am eligible to receive a voucher for completing the study; however, records of payment will be kept by the investigator's department and may be shared in case of an audit by HMRC.	○
6. I agree to be video recorded in this study.	○
7. I agree to be observed, and I confirm that any conversations or data from observations related to the study can be taken notes.	○
8. I confirm that my given data can be used and managed by the investigator for research purposes. Also, I understand that I can request the investigator to withdraw my collected data up to two weeks after the study completion by providing them with the generated participant ID. The research data will be kept by following the university's policy (the default period for research data retention is 10 years from the date of last requested access.).	○
9. I confirm that the investigator allowed me to ask questions related to the study, and my questions were thoroughly answered satisfactorily. Also, I understand that I have a right to withdraw from the study without giving any reasons on the day of the study.	○
10. I confirm that I have read and understood the participant information sheet of this study.	○

Optional additional consent

	Actions Yes	No
I give my consent to the investigator to take a photo of me while I am taking part in the study. If there is my face in the photo, it must be blurred. The photo can be included in the investigator's thesis and potentially in relevant publications.	○	●

I give my consent to participate in this study

○ Yes

○ No

A CONSENT FORM

Please complete the whole of this sheet

	Actions Please tick circles
1. I confirm that I am aged 18 or over.	○
2. I confirm that I can do physical activity in this study.	○
3. I confirm that I have no physical limitations on using the sensors (i.e. the Samsung Galaxy Watch 4).	○
4. I understand that my participation in this study is voluntary and that I have the right to withdraw at any time without giving any reasons on the day of the study.	○
5. I consent to being observed and the recording of conversations and observational data for this study.	○
6. I consent to the investigator using my data for research. I understand I can withdraw my data within two weeks after the study by providing my participant ID. The data will be retained following university policy (the default period for research data retention is 10 years from the date of last requested access.).	○
7. I confirm that the investigator allowed me to ask questions related to the study, and my questions were thoroughly answered satisfactorily.	○
8. I confirm that I have read and understood the participant information sheet of this study.	○

Optional additional consent

	Actions	
	Yes	No
I consent to the investigator taking a photo of me during the study, with my face blurred if identifiable. This photo may be included in the investigator's thesis and potentially in relevant publications.	○	◉

I give my consent to participate in this study

○ Yes

○ No

Appendix D

Research Ethics Debrief Form

A research ethics debrief form used across experiments is shown in the grey area below.

Research Ethics Debrief Form The study title: A study of the effect of an exergame on player experiences

Your participant ID is

Your collaboration is essential to this study, and we would like to say thank you so much for your participation. You provided us with useful data. Your collected data will be anonymised and strictly kept confidential. You will not be identified or identifiable in any works or reports or publications. Your collected data will remain by following the university policy and be under the investigator's management. Nevertheless, you have a right to withdraw your data from the study within 2 weeks after the study completion. If you would like to do so, please contact the investigator and provide him with your participant ID above. Hence, please do not lose the ID.

You can ask any questions related to the study that you have done, and we are willing to answer your questions. Or if you have any questions or complaints regarding this study after this, please feel free to contact the investigator or his supervisors. And we do apologise for any convenience caused. Finally, If you have any severe physical injury from this study, please immediately contact 111 to ask for help.

Thank you again for taking part in this study.

This study is undertaken by Mr Sittikrai Chorrojprasert, Email: sittikrai.chorrojprasert@york.ac.uk Room 214, Department of Computer Science, University of York, Deramore Lane, Heslington, York, YO10 5GH, United Kingdom

His supervisors' information

Dr Alena Denisova, Department of Computer Science, University of York Email: alena.denisova@york.ac.uk

Dr Ben Kirman, School of Arts and Creative Technologies, University of York Email: ben.kirman@york.ac.uk

Appendix E

Physical Activity Readiness Questionnaire

The Physical Activity Readiness Questionnaire (shown in the following page), adapted from [204], was used to screen participants for their ability to safely participate in each experiment, which involved physical activities ranging from light to vigorous intensity. To mitigate potential health or safety risks, participants who answered "Yes" to any of the questionnaire items were excluded from the experiments.

The Physical Activity Readiness Questionnaire (PAR-Q)

If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you participate in this experiment. If you are over 69 years of age and are not used to being very active, check with your doctor.

Please read each question carefully and answer honestly by indicating **YES** or **NO**.

QUESTIONS	YES	NO
1. Has your doctor ever said you have a heart condition and that you should only do physical activity recommended by a doctor?		
2. Do you feel pain in your chest when you do physical activity?		
3. In the past month, have you had chest pain when you were not doing physical activity?		
4. Do you lose balance because of dizziness or do you ever lose consciousness?		
5. Do you have a bone or joint problem (e.g. back, knee or hip) that could be made worse by a change in your physical activity?		
6. Is your doctor currently prescribing medication for your blood pressure or heart condition?		
7. Do you know of **any other reason** (e.g. pregnancy) why you should not take part in physical activity?		

If you answered **YES** to one or more questions: You should consult with your doctor to clarify that it is safe for you to become physically active at this current time and in your current state of health.
If you answered **NO** to all questions: It is reasonably safe for you to participate in physical activity, gradually building up from your current ability level. A fitness appraisal can help determine your ability levels.

Appendix F

Safety Checklist for Venues and Experiments

As recommended by the Physical Sciences Ethics Committee, the checklist (shown in the following page) that investigators must review to ensure that the room, first-aid toolkit, safety measures, participants, and experimental equipment are ready before starting the experiment.

A safety checklist for the venue and experiment

Please make sure that the following requirements are met before running each experiment.

Instructions: Tick boxes if the below requirements are met.	
Participant's physical readiness	
	The participants complete the Physical Activity Readiness questionnaire, and all questions are answered as "NO".
	The participants confirm that they are ready to have physical activity.
Equipment	
	The sensors are cleaned.
	The phone holder is cleaned.
Room	
	Windows are open, or related electric appliances (i.e. fans) are turned on to allow sufficient air space and airflow.
	There is enough room to move and exercise safely.
	The exercise area is kept clear. There are no spills or other objects that might cause any harm. If there are any chairs, desks, or tables in the room, they must be moved away from the area to allow more space for physical activity.
	Unauthorized people are not allowed into the room to prevent any disturbance or collision with the research participants.
	There is enough light in the room.
	There are no objects blocking the exit or fire doors.
	There is a space for relaxation.
First aids	
	A first-aid kit is prepared and ready to be used.
	In case of any emergency, one of the following telephone numbers will be dialed: • ***3333 (from a university extension)*** or • 01904323333 or • 111
	The investigator will be around so that the participants can ask for any helps.
	Drinking water is prepared for the participants.

Participant ID: _____

Date-time: _____

Appendix G

Challenge Originating from Recent Gameplay Interaction Scale

This appendix shows a sample of the Challenge Originating from Recent Gameplay Interaction Scale (CORGIS) used in this research.

The challenge originating from recent gameplay interaction scale (CORGIS)

- Performative challenge

Please indicate to what extent you agree/disagree with each of the statements below after you finished playing the game on the following scale:

I had to react quickly when playing the game.						
Strongly Disagree 1	Disagree 2	Slightly Disagree 3	Neither Agree Nor Disagree 4	Slightly Agree 5	Agree 6	Strongly Agree 7

I had to act quickly when playing the game.						
Strongly Disagree 1	Disagree 2	Slightly Disagree 3	Neither Agree Nor Disagree 4	Slightly Agree 5	Agree 6	Strongly Agree 7

Thinking fast was an important part of the game.						
Strongly Disagree 1	Disagree 2	Slightly Disagree 3	Neither Agree Nor Disagree 4	Slightly Agree 5	Agree 6	Strongly Agree 7

Quickly responding to things that I saw was an important part of the game.						
Strongly Disagree 1	Disagree 2	Slightly Disagree 3	Neither Agree Nor Disagree 4	Slightly Agree 5	Agree 6	Strongly Agree 7

I had to make snap decisions when playing the game.						
Strongly Disagree 1	Disagree 2	Slightly Disagree 3	Neither Agree Nor Disagree 4	Slightly Agree 5	Agree 6	Strongly Agree 7

Appendix H

The Borg's Rating of Perceived Exertion Scale

A sample of Borg's Rating of Perceived Exertion shown in the grey area below.

The Borg's scale: Rating of Perceived Exertion (RPE)

Look at the rating scale below. Please rate **how hard you feel like your body was working** while you were engaging in the physical activity in the game. It ranges from 6 to 20, where 6 means "no exertion at all" and 20 means "maximal exertion".

Choose the number from below that best describes your level of exertion.

- 6 No exertion at all
- 7 Extremely light
- 8
- 9 Very light
- 10
- 11 Light
- 12
- 13 Somewhat hard
- 14
- 15 Hard (heavy)
- 16
- 17 Very hard
- 18
- 19 Extremely hard
- 20 Maximal exertion

Appendix I

Flow State Scale

This appendix presents the full version of the Flow State Scale [154], followed by the challenge-skill balance.

Flow State Scale

Please answer the following questions in relation to your experience in the event you have just completed. These questions relate to the thoughts and feelings you may have experienced during the event. There are no right or wrong answers. **Think about how you felt during the event and answer the questions using the rating scale below.** Select the number that best matches your experience from the options to the bottom of each questions.

I was challenged, but I believed my skills would allow me to meet the challenge.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

I made the correct movements without thinking about trying to do so.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

I knew clearly what I wanted to do.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

It was really clear to me that I was doing well.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

My attention was focused entirely on what I was doing.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

I felt in total control of what I was doing.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

I was not concerned with what others may have been thinking of me.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

Time seemed to alter (either slowed down or speeded up).						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

I really enjoyed the experience.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

My abilities matched the high challenge of the situation.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

Things just seemed to be happening automatically.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

I had a strong sense of what I wanted to do.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

I was aware of how well I was performing.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

It was no effort to keep my mind on what was happening.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

I felt like I could control what I was doing.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

I was not worried about my performance during the event.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

The way time passed seemed to be different from normal.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

I loved the feeling of that performance and want to capture it again.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

I felt I was competent enough to meet the high demands of the situation.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

I performed automatically.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

I knew what I wanted to achieve.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

I had a good idea while I was performing about how well I was doing.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

I had total concentration.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

I had a feeling of total control.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

I was not concerned with how I was presenting myself.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

It felt like time stopped while I was performing.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

The experience left me feeling great.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

The challenge and my skills were at an equally high level.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

I did things spontaneously and automatically without having to think.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

My goals were clearly defined.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

I could tell by the way I was performing how well I was doing.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

I was completely focused on the task at hand.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

I felt in total control of my body.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

I was not worried about what others may have been thinking of me.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

At times, it almost seemed like things were happening in slow motion.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

I found the experience extremely rewarding.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

Flow State Scale (FSS): Challenge-skill balance

Please answer the following questions in relation to your experience in the event you have just completed. These questions relate to the thoughts and feelings you may have experienced during the event. There are no right or wrong answers. **Think about how you felt during the event and answer the questions using the rating scale below.** Select the number that best matches your experience from the options to the bottom of each questions.

I was challenged, but I believed my skills would allow me to meet the challenge.						
Strongly disagree 1	2	3	Neither agree or disagree 4	5	6	Strongly agree 7

My abilities matched the high challenge of the situation.						
Strongly disagree 1	2	3	Neither agree or disagree 4	5	6	Strongly agree 7

I felt I was competent enough to meet the high demands of the situation.						
Strongly disagree 1	2	3	Neither agree or disagree 4	5	6	Strongly agree 7

The challenge and my skills were at an equally high level.						
Strongly disagree 1	2	3	Neither agree or disagree 4	5	6	Strongly agree 7

Appendix J

Flow Short Scale

This appendix shows the Flow Short Scale [156] used in this research.

Flow Short Scale (short version)

Please answer the following questions in relation to your experience in the event you have just completed. These questions relate to the thoughts and feelings you may have experienced during the event. There are no right or wrong answers. Think about how you felt during the event and answer the questions using the rating scale below. Select the number that best matches your experience from the options to the bottom of each questions.

I feel just the right amount of challenge.						
not at all 1	2	3	Partly 4	5	6	Very much 7

My thoughts/activities run fluidly and smoothly.						
not at all 1	2	3	Partly 4	5	6	Very much 7

I don't notice time passing.						
not at all 1	2	3	Partly 4	5	6	Very much 7

I have no difficulty concentrating.						
not at all 1	2	3	Partly 4	5	6	Very much 7

My mind is completely clear.						
not at all 1	2	3	Partly 4	5	6	Very much 7

I am totally absorbed in what I am doing.						
not at all 1	2	3	Partly 4	5	6	Very much 7

The right thoughts/movements occur of their own accord.						
not at all 1	2	3	Partly 4	5	6	Very much 7

I know what I have to do each step of the way.						
not at all 1	2	3	Partly 4	5	6	Very much 7

I feel that I have everything under control.						
not at all 1	2	3	Partly 4	5	6	Very much 7

I am completely lost in thought.						
not at all 1	2	3	Partly 4	5	6	Very much 7

Appendix K

Intrinsic Motivation Inventory

The following paragraphs show the Intrinsic Motivation Inventory: Interest/ Enjoyment [146].

The Intrinsic Motivation Inventory (IMI)

Interest/ Enjoyment

For each of the following statements, please indicate how true it is for you, using the following scale:

I enjoyed playing this game very much.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

Playing this game was fun to do.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

I thought playing this game was a boring activity.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

Playing this game did not hold my attention at all.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

I would describe playing this game as very interesting.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

I thought playing this game was quite enjoyable.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

While I was playing this game, I was thinking about how much I enjoyed it.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

The following paragraphs show the Intrinsic Motivation Inventory: Perceived Competence [146].

The Intrinsic Motivation Inventory (IMI)

Perceived Competence

For each of the following statements, please indicate how true it is for you, using the following scale:

I think I am pretty good at this activity.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

I think I did pretty well at this activity, compared to other participants.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

After working at this activity for awhile, I felt pretty competent.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

I am satisfied with my performance at this task.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

I was pretty skilled at this activity.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

This was an activity that I could not do very well.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

The following paragraphs show the Intrinsic Motivation Inventory: Effort/ Importance [146].

The Intrinsic Motivation Inventory (IMI)

Effort/ Importance

For each of the following statements, please indicate how true it is for you, using the following scale:

I put a lot of effort into playing this game.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

I did not try very hard to do well at playing this game.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

I tried very hard on playing this game.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

It was important to me to do well at playing this game.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

I did not put much energy into playing this game.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

The following paragraphs show the Intrinsic Motivation Inventory: Pressure/ Tension [146].

The Intrinsic Motivation Inventory (IMI)

Pressure/ Tension

For each of the following statements, please indicate how true it is for you, using the following scale:

I did not feel nervous at all while playing this game.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

I felt very tense while playing this game.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

I was very relaxed while playing this game.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

I was anxious while playing this game.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

I felt pressured while playing this game.						
Not at all true 1	2	3	Somewhat true 4	5	6	Very true 7

Appendix L

Basic Needs in Games Scale

This appendix shows the Basic Needs in Games Scale [147] used in this research.

The Basic Needs in Games Scale (BANGS): Competence

Please consider your experience playing the exergame and answer the following questions

I felt I was getting better at playing this exergame.						
Strongly disagree 1	2	3	Neither agree nor disagree 4	5	6	Strongly agree 7

I felt that I made progress while playing this exergame.						
Strongly disagree 1	2	3	Neither agree nor disagree 4	5	6	Strongly agree 7

I felt a sense of achievement while playing this exergame.						
Strongly disagree 1	2	3	Neither agree nor disagree 4	5	6	Strongly agree 7

I often felt that I lacked the skills necessary for this exergame.						
Strongly disagree 1	2	3	Neither agree nor disagree 4	5	6	Strongly agree 7

I kept failing to accomplish what I wanted to while playing this exergame.						
Strongly disagree 1	2	3	Neither agree nor disagree 4	5	6	Strongly agree 7

I felt disappointed with my performance in this exergame.						
Strongly disagree 1	2	3	Neither agree nor disagree 4	5	6	Strongly agree 7

Appendix M

Project Links

The source code of the ExerWitch game can be accessed via the link below:

- **Game Software, ExerWitch:** See: GitHub Repository

All game assets, such as images, sounds, models, and others, were credited and included in the repository.