



# Dynamic Difficulty Adjustment in Video Games for Encouraging Physical Exercise: A Review and Theoretical Framework

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**Abstract.** The goal of this literature survey is to evaluate whether Dynamic Difficulty Adjustment (DDA) holds promise as a tool for encouraging greater amounts and higher quality forms of physical exercise in the context of video exergames. DDA is an algorithm that tracks player performance and modifies gameplay difficulty accordingly. Reviewing relevant research contributions, we analyse how well these techniques can foster increased physical activity levels, improve responses to sedentary behaviours, and enhance long-term adherence rates among exercisers. Lastly, we provide insight into how health-related campaigns might benefit from integrating such strategies. The effectiveness of DDA in promoting physical activity is then discussed. The conclusion is that DDA has the capacity to enhance levels of physical activity, motivation and enjoyment of exercise, as well as reduce sedentary behaviour. However, challenges remain in standardising DDA algorithms and balancing optimal difficulty challenges. Therefore, this review highlights the great potential of incorporating DDA in video games as a means to encourage physical activity and offers ideas and directions for future research in this area.

**Keywords:** Dynamic, Difficulty, Adjustment, Encourage, Exergame, Physical, Activity.

## 1 Introduction

Video games have become an increasingly popular leisure activity in the lives of many and are increasingly being explored as a way to promote physical activity. Much research has been done concerning the utilisation of Dynamic Difficulty Adjustment (DDA) within the context of video games, which refers to real-time adjustment of the game difficulty level based on the player's performance. This ensures that the challenges presented align with the player's abilities, providing an optimal and engaging gaming experience while promoting physical activity through a gamified approach. The objective of this survey is to assess and examine the existing research on the application of Dynamic Difficulty Adjustment (DDA) in video games as a means to encourage and enhance physical activity levels. Specifically, this paper aims to synthesise the empirical evidence on the influence of DDA on physical activity levels, motivation, enjoyment, sedentary behaviour, and exercise adherence. This paper also describes three theoretical frameworks for the influence of DDA on physical exercise and to help people increase physical exercise via video exergames.

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### 1.1 Definition of Dynamic difficulty adjustment (DDA)

Dynamic Difficulty Adjustment (DDA) refers to an approach that automatically adapts various in-game features, scenarios, and behaviour in real time according to the player's level of play, so that players do not get bored playing the game. This is because, if a game is too easy, it can lead to boredom, while if it is too difficult, it can result in a loss of confidence.

The aim of DDA is to allow players to stick with the game until the end, rather than giving up in the middle, and to provide a challenging experience based on each player's skill level [1].

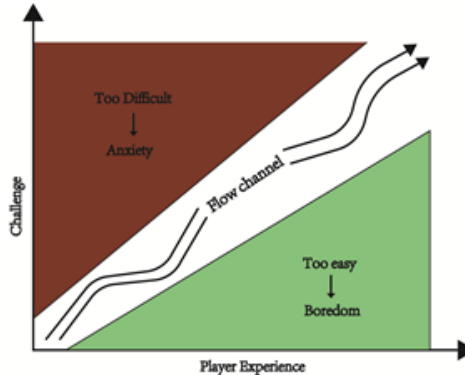


Fig. 1. Flow channel for DDA

Csikszentmihalyi proposed the Flow channel for DDA, which illustrates the optimal level of difficulty in a game (shown in Figure 1). It suggests that individuals are most engaged and experience a state of flow when the challenges presented by the game align with their skill level [2].

Since DDA adjusts the difficulty level as the player plays, it keeps the gamer interested throughout the game, customising the difficulty of the game for different players [3].

Darzi et al., (2021) divided 50 participants (N=50) into 5 groups, which corresponds to 5 DDA methods. By comparing all the data from the 5 DDA methods and reporting the players' gaming experience using a questionnaire, the results show that DDA improved the players' gaming experience [4].

VR exergames have been proven to motivate players when performing physical activity by generating levels that fit the player's ability using DDA, thus increasing the length of play [5].

Eishita & Stanley, (2018) developed an AR exergame that experimentally predicts the structure of the experience, taking into account the player experience (PX) and immersion. The results of this DDA system show that it makes the player feel a higher sense of confidence [6].

## 2 Literature review

This section reviews studies that have examined the impact DDA on physical exercise. The studies were chosen for their importance to the topic and their scientific rigour and this review summarizes the effects of DDA on physical activity levels, motivation, enjoyment, sedentary behaviour, and exercise adherence.

The paper also delves into the theoretical models that have been employed to elucidate the influence of Dynamic Difficulty Adjustment (DDA) on physical exercise.

Li et al. (2016) conducted a study examining the potential impact of exergames incorporating Dynamic Difficulty Adjustment (DDA). The findings indicated that games with DDA had a significantly more pronounced effect on player's gaming experience compared to those lacking this feature [7].

In their analysis of factors contributing to engagement in digital entertainment games, Boyle et al. (2012) identified DDA as an important factor associated with higher levels of player engagement [8], while Lyons et al. (2016) conducted a randomised controlled trial aimed to compare energy expenditure and enjoyment between exergames with and without DDA. The study concluded that games with this feature resulted in higher energy expenditure and enjoyment than their non-DDA counterparts [9].

Sinclair et al. (2007) offers useful considerations for designing successful exergames, including the integration of DDA. According to the authors, DDA may be used to adapt the gaming experience to each unique player, resulting in a considerable improvement in their engagement and motivation levels [10].

Jiang et al. (2022) proposed that when it comes to the impact of exergaming on physical fitness in adults, the results of the study showed that games with dynamic difficulty adjustment (DDA) outperformed games without it [11].

Peng et al. (2012) conducted a systematic review investigating the utilisation of video games for promoting physical exercise. The review highlights the prevalence of dynamic difficulty adjustment (DDA) as a common feature in active video games and identifies its positive contribution to improved levels of physical exercise [12].

In a systematic review conducted by Gao & Xiang (2014), the influence of exergames on the physical activity levels and intrinsic motivation of children were examined. The study revealed that exergames incorporating dynamic difficulty adjustment (DDA) were related to higher levels of physical exercise and intrinsic motivation compared to exergames without DDA [13].

Tscholl et al. (2015) investigated several exergame interfaces used in rehabilitation programs or research settings, including choices with dynamic difficulty modification. Exergames with DDA, according to the study, might be effective in rehabilitation programs since they can be tailored to specific patients' capacities. Furthermore, the participatory aspect of these games gives patients an interesting and encouraging experience during their recuperation [14].

The association between exercise and depression was investigated in a thorough evaluation of studies undertaken by Daley et al. (2014). The review found that exergames with dynamic difficulty adjustment (DDA) can be an effective technique for increasing physical activity and reducing depressive symptoms [15].

Lubans et al. (2016) conducted a comprehensive review in their study to investigate the processes by which physical exercise benefits adolescent cognitive and mental health. The review's findings revealed that exergames with dynamic difficulty adjustment (DDA) can be highly effective in increasing physical activity levels while also positively influencing cognitive function and mental health outcomes [16].

Pezzerà & Borghese, (2020) proposed a flexible Dynamic Difficulty Adjustment (DDA) system that can collect patients' historical data and real-time game performance. This system effectively adjusts the game difficulty based on the analysis of integrated data and patient performance [17].

**Tab 1.** Literature review organize and summarize

Author	Method	Description	Benefits
Li et al. (2016)	Experimental study	Examined the impact of exergames with DDA on depression	Significantly reduced symptoms compared to games without DDA

Boyle et al. (2012)	Analysis of factors contributing to engagement	Identified DDA as a factor associated with higher player engagement	DDA increases player engagement
Lyons et al. (2016)	Randomised controlled trial	Compared energy expenditure and enjoyment between exergames with and without DDA	Higher energy expenditure and enjoyment in games with DDA
Sinclair et al. (2007)	Systematic review	Provided considerations for designing successful exergames, including integration of DDA	Improved engagement and motivation levels with DDA
Jiang et al. (2022)	Study on impact of exergaming on physical fitness	Showed that games with DDA outperformed games without in terms of physical fitness	DDA improves players' will to exercise
Peng et al. (2012)	Systematic review	Highlighted prevalence of DDA in active video games and its positive contribution to physical exercise	Increased levels of physical exercise with DDA
Gao & Xiang (2014)	Systematic review	Exergames with DDA related to higher levels of physical activity and intrinsic motivation	Increased physical activity and intrinsic motivation with DDA
Tscholl et al. (2015)	Investigation of exergame interfaces in rehabilitation	Exergames with DDA tailored to specific patients' capacities, providing an	Effective in rehabilitation programs, tailored experience

Daley et al. (2014)	Evaluation of exercise and depression studies	Exergames with DDA effective in increasing physical activity and reducing depressive symptoms	encouraging experience Effective technique for increasing physical activity and reducing depression
Lubans et al. (2016)	Comprehensive review on exercise and adolescent health	Exergames with DDA increase physical activity levels and positively impact cognitive function and mental health outcomes	Increased physical activity, positive cognitive and mental health outcomes
Pezzerà & Borghese, (2020)	A mixed approach	Designed a flexible DDA system that utilises multiple data sources to adapt game difficulty, empower therapists to optimise rehabilitation and enhance the patient experience.	All parameters can be fully controlled to ensure patient safety and rehabilitation effectiveness

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### 3 Methodology

This paper aims to scrutinise the existing research on using dynamic difficulty adjustment (DDA) in video games as a means of promoting physical activity. Our methodology is similar to that of Pato & Delgado-Mata (2013). We broke down our exploration into three parts. The first part involves an appraisal of studies investigating DDA within exercise gaming – exergames had a positive impact on health outcomes via increased physical exertion. Our second focus was on prior research examining DDA implementation in gaming itself, where we assessed how it affected both the enjoyment of playing and amount of active vs. sedentary behaviour. Finally, our evaluation incorporated relevant theoretical frameworks surrounding DDA-based exercise [18].

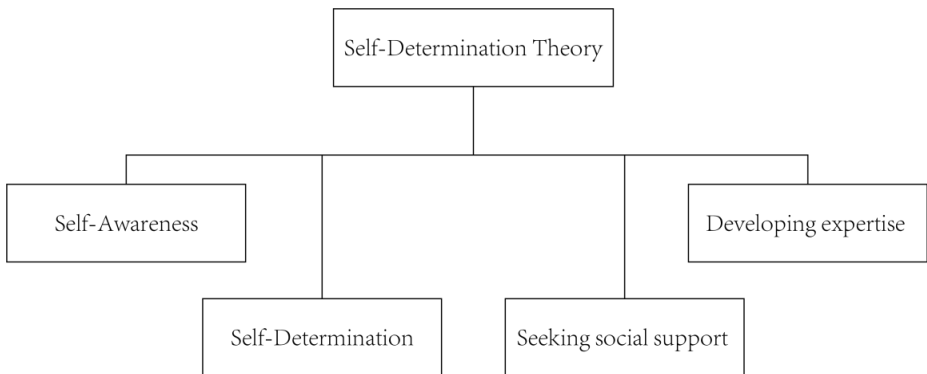
## 4 Theoretical framework for the effects of DDA on physical activity

### 4.1 Self-Determination Theory

The Self-Determination Theory has established three main characteristics necessary for encouraging successful involvement during activities, such as physical exercise: autonomous behaviour, feelings of competency, and a strong predisposition towards intrinsically gratifying tasks. Interestingly, Dynamic Difficulty Adjustment helps video games meet these standards. DDA's role is to adjust the game's difficulty based on the player's performance. This feature is critical since it allows gamers to feel autonomous and in control over their experience. Furthermore, the alignment between game demands and skill level fosters competence, which increased intrinsic motivation and engagement in physical activities.

**Fig. 2.** Cherry (2022) proposed four steps to improve one's own self-determination skills [19] their idea is worth a brief discussion here:

1. Self-awareness is one crucial measure to increase, which is necessary for making decisions that are in line with our aims and values. Activities like meditation or mindfulness techniques, actively seeking advice from others, or writing to record our thoughts and feelings, can help us develop this awareness.
2. To enhance one's self-determination, it is important to focus on developing one's self-regulation skills. This involves being more mindful of one's mental and physical well-being and practicing cognitive reframing techniques to better control one's emotional responses. By implementing these strategies, one can improve his/her ability to regulate himself/herself and ultimately strengthen his/her self-determination.
3. Seeking social support is important as strong social relationships can enhance motivation and overall well-being. Surround oneself with individuals who create an environment of acceptance and care, whether they are family members, friends, members of one's community, counsellors, or anyone who offers a sense of support and belonging.
4. Developing expertise in fields that hold significance to one may contribute to strengthening his/her feeling of self-determination. Regardless of whether one has a keen passion for a sport, hobby, area of study, or something else, dedicating oneself to learning and enhancing his/her skills can boost his/her sense.



**Fig. 2.** Self-Determination Theory

## 4.2 Flow Theory

Flow Theory, proposed by Csikszentmihalyi, posits that individuals are most engaged and satisfied when they experience a state of flow—a state of optimal challenge and immersion in an activity. DDA in video games can dynamically adjust the difficulty level to maintain the player's flow state, ensuring a balance between their skill level and the challenges presented. This balance contributes to increased enjoyment, prolonged engagement, and positive experiences during physical exercise.

## 4.3 Cognitive Load Theory (CLT)

Applying Cognitive Load Theory (CLT) can help explain the effects of Dynamic Difficulty Adjustment (DDA) on physical exercise. According to CLT, the cognitive load imposed on individuals during a task affects their learning and performance outcomes.

**Intrinsic Cognitive Load:** DDA in exercise games can dynamically adjust the difficulty level based on the individual's performance. By tailoring the challenge to the individual's abilities, it reduces the intrinsic cognitive load by providing an optimal level of challenge. This allows players to focus more on the exercise movements and techniques rather than struggling with overly difficult or too easy tasks [20].

**Extraneous Cognitive Load:** Poorly designed exercise games without DDA may impose extraneous cognitive load on individuals. They may struggle with complex controls, confusing instructions, or irrelevant information, which can distract from the exercise experience. DDA can help mitigate this extraneous cognitive load by providing a smoother and more intuitive gameplay experience.

**Germane Cognitive Load:** DDA in exercise games can optimise the germane cognitive load by promoting learning and skill development. By gradually increasing the difficulty as the player's performance improves, DDA encourages skill progression and mastery. This fosters the development of efficient movement patterns, motor skills, and cognitive strategies related to physical exercise.

By considering the cognitive load aspects of CLT, the implementation of DDA in exercise games can be better understood in terms of how it optimises the cognitive demands placed on individuals during physical exercise, leading to improved engagement, skill development, and overall effectiveness of the exercise experience.

Other relevant theoretical frameworks that have been applied include the Transtheoretical Model of Behaviour Change, which examines the stages individuals go through when adopting new behaviours. Additionally, the theoretical approach to planned behaviour explores subjective norms and how attitudes and perceptions of behaviour control impact the individual's intention to perform in behaviours. These frameworks can provide insights into how DDA in video games can facilitate behaviour change, encourage adherence to exercise routines, and promote healthy behaviours.

## 5 Conclusion

This conclusion section provides a summary of the value of Dynamic Difficulty Adjustment (DDA) in exergames for promoting healthy behaviour and exercise. The addition of DDA in exergames has a positive impact on encouraging physical exercises. Furthermore, we also discuss potential areas for further research.

The research on using DDA in video games as a motivator for people to engage in physical activity has been thoroughly examined. The findings suggest that employing DDA may increase individuals' level of exercise involvement while also boosting their motivation and enjoyment levels, reducing the

likelihood of idle time or giving up exercise altogether. Psychological theories, including self-determination, flow, and cognitive load theories, explain why using such tactics is advantageous to individuals' exercise efforts. However, striking an appropriate balance between algorithm standardisation and modifying difficulty settings remains a challenge. Therefore, additional research is required to refine the application of the DDA technique inside video games and make them more effective in promoting physical exercise.

## 6 Future work

After exploring the influence of DDA on physical activity and healthy lifestyle practices through different theoretical frameworks used to examine these outcomes, attention is drawn to specific limitations present in the related research articles reviewed. In addition to suggesting potential future avenues for the study of DDA in video games, it is proposed that this technology can enhance motivation and enjoyment levels throughout an individual's fitness journey while simultaneously reducing sedentary behaviours and mitigating exercise dropout rates. Overall, however, it has been observed that an effective calibration strategy using standardised algorithms is required to maintain a proper balance of difficulty levels.

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