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Creating a treadmill running video game with smartwatch interaction

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Abstract

In recent years, indoor or at-home sports have experienced significant growth. However, monotony is a common challenge in these static physical activities. Exergames, a genre of video games that combines physical activity and entertainment, have emerged as an attractive solution. Nevertheless, running on a treadmill and engaging in other activities simultaneously presents additional challenges. The balance and concentration required during running while interacting with a video game demand a special focus on the design of the Exergame. This paper presents a mobile Exergame designed specifically for treadmill running, utilizing interaction with a smartwatch. The game offers natural environments where, through smartwatch technology, it interprets the player's movements, transforming them into running speed and interactive actions by detecting gestures within the game. The main objective is to provide users with a satisfying gaming experience tailored to the characteristics of treadmill running. Particular emphasis has been placed on prioritizing the playful component of this Exergame, recognizing its relevance in the context of treadmill running. To evaluate the achievement of objectives and the proposed hypothesis, a comparative study was conducted between the proposed Exergame and a treadmill running simulator. Participants experienced both experiences and subsequently completed the Game Experience Questionnaire (GEQ), specifically the In-game GEQ version. The results obtained indicate that participants had a better gaming experience in the Exergame than in the simulator. These findings highlight the importance of prioritizing the playful component in Exergames and provide guidelines for future improvements and developments in the field.

Keywords Treadmill · Running · Exergame · Smartwatch · Interaction · Mobile · Cadence · Gestures

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1 Introduction

In recent years, there has been significant growth in indoor or at-home sports. Currently, there is high demand for products such as rollers, ellipticals, or treadmills, which can make them difficult to obtain due to stock shortages [5, 44]. However, indoor sports present a challenge related to monotony, as the static environment lacks the variety of changing stimuli found outdoors [2]. Some users may cope with this monotony, while others turn to different sources of entertainment to accompany their activity. In gyms, it is common to see people using stationary bikes, ellipticals, or treadmills while enjoying music, podcasts, movies, or other content. Additionally, video games have emerged as an entertainment option during sports activities, and the choice of games depends on the method of interaction and how well they adapt to the specific physical activity. For instance, playing a platform video game while using a treadmill would be challenging.

Exergames are video games specifically designed to incorporate physical activity as an essential part of the gaming experience. These games require specific body movements to handle mechanics and progress through the narrative [40]. Typically, player movements are controlled through motion-sensing devices, such as the Wii controller or Kinect sensor [53]. Examples of Exergames include dance games, boxing, or racing as the primary gameplay mechanics. Furthermore, it is crucial to design video games specifically tailored to treadmill running, as opposed to existing running simulators. While running simulators offer a realistic and effective training experience, their primary focus lies in accurately replicating outdoor running conditions. Besides that, Exergames can combine physical exercise with playful elements, providing a more enjoyable and motivating experience for users [14, 20].

In this context, prior studies have shown that the gaming experience in a running simulator was inferior to that provided by a video game [31]. Even considering that this video game was not specifically designed to be used on a treadmill, as another study prior to this one analyzed the differences between its use on the ground and its use on a treadmill [32] and demonstrated that it was possible to play effectively on the treadmill, adding additional challenges compared to its use on the ground, which is what it is designed for. Based on these findings, the decision has been made to develop an Exergame designed for treadmill running that combines elements of a running simulator and a video game. Where users follow running routes while facing in-game challenges to complete and progress through levels. All of this is controlled through the interaction between a smartphone and a smartwatch. This initiative is based on the hypothesis that Exergames offer a superior gaming experience compared to running simulators, an aspect that has been underexplored in the existing literature. The primary goal of this Exergame is to provide users with an engaging gaming experience that can combat the monotony of indoor exercise and promote physical activity among sedentary user profiles. Commercial devices have been leveraged instead of specific hardware to facilitate accessibility. Furthermore, prioritizing the playful component when evaluating these video games has been considered crucial, ensuring that a satisfactory gaming experience is provided through the design of the Exergame. To verify the hypothesis and the achievement of objectives, a user study was conducted using the Game Experience Questionnaire (GEQ), specifically its In-game version (In-game GEQ) [19]. This study aims to gather and analyze information on how video games and physical activity relate in terms of gaming experience.

In summary, this paper is organized as follows. Section 2 provides a review of the current state of sports games and Exergames, highlighting their potential compared to the use of running simulators. Section 3 describes the design of the developed game. Next, Section 4 details the configuration used for this game and its usage. The results obtained from the analysis of the applied questionnaire are presented in Section 5. Finally, in Section 6, the conclusions of the article are presented, summarizing the findings and emphasizing the importance of designing video games that integrate physical activity as an effective tool for promoting physical activity in indoor environments.

2 State of the art

Although the positive effects of active video games on various segments of the population have been known for some time [14, 26], Exergames are games that integrate physical activity into the mechanics of a video game, providing a captivating and interactive exercise experience [31, 52]. Unlike running simulators or route planners, Exergames utilize active physical movement from players to progress in the game narrative and achieve specific objectives [6]. These games promote real-world physical activity and offer feedback through devices that track and analyze body movements [23]. Moreover, multiple studies suggest that playing Exergames improves well-being, inducing positive mood changes, maintaining happiness levels, and contributing to better physical and mental health, especially in older adults and individuals with neurocognitive disorders [11, 18, 22, 38, 45, 54].

In the case of video games and applications related to running, various devices play specific roles in enhancing the overall experience [16]. Execution platforms, such as smartwatches, smartphones, desktop computers, and gaming consoles, form the foundation on which they operate. Input devices, such as keyboards, mice, touchscreens, tracking devices, and voice interaction, allow users to interact with the system and provide data for analysis. Output devices, such as monitors, speakers, and projectors, present the processed information to the user. These devices provide visual, auditory, and tactile feedback to enrich the running experience. Furthermore, some works and applications incorporate other sources of information for analyzing actions on the treadmill. For example, through vision-based activity recognition [21, 29, 48] or providing information through wearable sensors [10] or proximity sensors [12], for instance, to offer insights on walking behavior [25]. Understanding the characteristics of these devices allows harnessing their capabilities to create immersive and motivating experiences for users. This involves using execution, input, and output devices effectively to enhance functionalities and the overall user experience.

Emphasis on running Exergames suggests that these video games require at least one type of goal based on the player's movement. Taking a reference from a game like Ring Fit Adventures (RFA), where the player must use two interaction devices, simply raising the knees or performing skipping movements on the floor suffices without requiring significant displacement. However, the action of running is not natural, and certain studies have tested its adaptation on a treadmill [31]. While some studies aimed to develop Exergames for treadmill running with interaction methods that required specific and uncommon devices among the general public [1, 39], other studies have developed interaction systems in different video games using more generic devices like activity trackers or smartwatches. For instance, a gesture-based interaction system to play Super Mario World [35]. Nevertheless, no studies have been published that utilize commercial smartwatches to control gesture-based active video games. Considering the data from 2021 published in Statista [13], which indicates that 3.8 million people worldwide own smartphones and the global market for activity tracking bracelets generated a total revenue of approximately 14.5 billion US dollars, it appears evident that this can be a promising exploration in terms of interaction.

At a research level, efforts are being made in the development of Exergames and treadmill running simulators, utilizing approaches such as gamification and Extended Reality (XR), which encompasses Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR). Some studies have highlighted the potential of Exergames and gamification in promoting physical activity [33], but have noted that the experience may vary based on individual factors [37]. Furthermore, the impact of VR and related technologies on the user experience and exercise has also been studied, as exemplified by the effectiveness demonstrated by the omnidirectional KatWalk in VR environments [9]. While VR has been found to offer greater immersion and enjoyment in games, it can also lead to cybersickness [49]. Additionally, applications of VR and AR have been explored to motivate individuals with obesity to engage in exercise [51] and to investigate differences in the feeling of disorientation and the fear of colliding with real objects [64]. Nevertheless, it is also suggested that striking a balance between personal training and mobile app-based VR solutions in fitness is important [55].

Current literature suggests that Exergames yield positive outcomes for users, such as enhanced exercise enjoyment and reduced sedentary behavior. In this regard, distinctions have been explored between running on a treadmill using an Exergame like RFA versus its intended ground use, with findings favoring treadmill use in terms of the gaming experience [32]. Other studies have identified mood and attention improvements when running in virtual environments compared to viewing neutral stimuli [37]. Moreover, therapeutic applications of Exergames within XR have been investigated, enhancing the experience, rehabilitation, and monitoring of individuals with limited mobility [65]. A study focusing on treadmill games in VR revealed heightened flow and enjoyment compared to traditional desktop computer gaming but also reported elevated cybersickness levels [49]. Furthermore, investigations have delved into how natural settings can provide more enriching exercise experiences than indoor environments [2]. Despite these advancements, technological and safety challenges persist, with research primarily concentrating on specific populations and medical objectives [30]. Hence, further research is warranted to enhance the user experience and address issues such as stability and dizziness [9, 27].

Regarding VR devices with omnidirectional treadmills, a study [49] evaluated the use of The Elder Scrolls V: Skyrim under different experimental conditions. Three conditions were implemented: traditional desktop computer gaming, VR gaming using the HTC VIVE headset, and gaming in an omnidirectional treadmill environment. The results showed that VR gaming generated higher levels of flow and enjoyment but also induced greater cybersickness compared to traditional gaming. However, the use of the omnidirectional treadmill did not significantly improve the gaming experience or reduce cybersickness. In the realm of rehabilitation, a low-cost VR kit prototype has been developed, employing an omnidirectional treadmill to enable stroke survivors to walk in safe virtual environments and perform complex locomotor tasks [24]. Additionally, cybersickness has been evaluated in omnidirectional treadmills, emphasizing the importance of finding a balance between rapid movement and associated cybersickness [27]. While no specific studies on cyber sickness in the context of locomotion interface devices based on omnidirectional treadmills have been conducted [42], research in this area continues in pursuit of more efficient locomotion techniques that minimize negative effects.

Despite the growing evidence supporting the potential benefits of Exergames in promoting physical activity and health, a comprehensive understanding of their effects and the determination of optimal strategies for their implementation still require further in-depth research. In this context, the current study contributes to the existing literature by exploring the intrinsic characteristics of video games that can be effective in encouraging physical activity, an aspect that, to date, has received limited attention.

3 Description of the game

As mentioned previously, the video game presented in this work combines the playful element with physical training, specifically designed for use on a treadmill. Unlike existing running simulators and recreational video games, the objective of this game is to offer a fun experience while engaging in physical activity. Taking inspiration from the treadmill running simulator Zwift Run (ZWIFT), the aim is to create a smartphone game with the route planning and course design features of ZWIFT while also including in-game playful goals.

The designed game, named Fitoon, features a third-person runner who must traverse a predetermined route as quickly as possible while collecting coins along the way to increase their score. The defined courses take place in natural environments where coins are scattered, some of them partially hidden within the course surroundings. Upon capturing a coin, it approaches the runner, and a sound is played to indicate the successful action. Additionally, the game incorporates rhythmic background music to accompany the race. The game runs on a smartphone and is controlled using a smartwatch. This device enables the detection of the user's speed and converts it into the avatar's speed on the screen. Moreover, a specific arm movement gesture has been implemented for the smartwatch to collect the coins that appear during the game's progress.

A fundamental aspect aimed to be covered is to provide an immersive experience, meaning to deliver the subjective feeling of being in a different environment from the one physically occupied [57]. Building upon ZWIFT as an XR application [50, 56], where immersion, presence, and interactivity are considered core characteristics [58, 59], the video game strives to achieve these features by simulating the runner's movement, imitating the steps per minute rhythm displayed by the character through its animation based on the received information.

The development of Fitoon has relied on the Unity 3D game engine, specifically in its 2022.2.13b version. This game engine has served as the foundation for XR applications and video games that merge the digital and physical worlds, ranging from educational applications [60], those related to cultural heritage [61], commercial applications [62], to entertainment games like Pokémon GO, which blend virtual elements with the real environment [63]. Furthermore, a game development methodology based on multi-agent systems has been used to specify the game elements and their logic [28]. This methodology was selected due to its advantages in terms of flexible interaction, adaptability, artificial intelligence, and component reuse [43]. Fitoon was developed as an executable application for mobile devices, specifically on the Android platform. This choice does not exclude the possibility of adapting the application to other platforms like iOS in the future. The decision to initially develop on Android was based on its wide adoption and the flexibility it offers for connectivity with various devices. However, the most relevant aspect is the mobile nature of these operating systems. Mobile devices offer portability and the ability to interact with other devices features that align with Fitoon's goal of providing an accessible and versatile gaming experience. Additionally, development on mobile platforms allows for rapid iteration and testing, facilitating continuous improvement of the application. In Fig. 1, a screenshot of the game in full operation can be appreciated.

4 System description

Below is the system model designed for the creation of this game, including the necessary materials for its implementation, connectivity methods, user interaction, and integration for the proper execution of the video game.

4.1 Materials used, structure, and connectivity

Due to the specific requirements of the gaming experience, the execution of this video game requires multiple devices to cover four aspects: input, output, running surface, and runtime platform. Physical activity in this work is performed on a treadmill. Initially, it is not necessary to specify requirements for the type or model of treadmill, but it is recommended to have a medium to high width, as slight lateral displacements may occur, which could bring strides closer to the edges of the treadmill and cause minor stumbling. Specifically, this work has been developed using a BH-RC09 treadmill. This treadmill features a running surface of 155 × 55 cm and includes instant speed and incline keys for quick adjustments, as well as a 4.0/2.25 HP motor that provides speeds ranging from 1 to 16 km/h.

During the development process, priority was given to creating a game that is accessible and compatible with any treadmill, regardless of its specific characteristics. In this regard, there was a need to use a device for tracking gestures and the runner's speed. The solution found was to leverage devices that treadmill users typically have at hand, such as smartwatches. These devices are equipped with accelerometers that allow inferring the runner's speed and detecting gestures, facilitating interaction between the game and users. This decision makes the game universally compatible, irrespective of the specific treadmill features, such as Bluetooth connectivity, which can vary from one model to another. The system designed for this project consists of three main components: a smartwatch, a smartphone, and a smart TV, whose arrangement in the context of the game can be seen in Fig. 2.

Fig. 1 Screenshot of the game

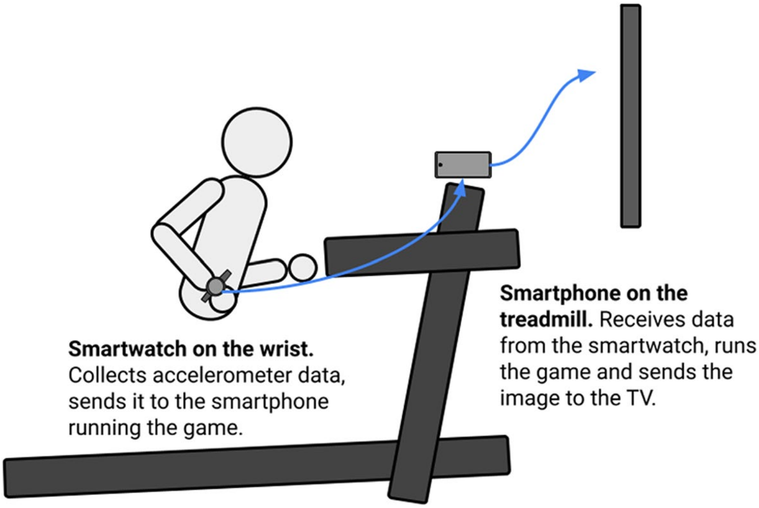

Fig. 2 Diagram of the layout and communication between the different configurations of system elements

The smartwatch used in this setup is the Samsung Galaxy Watch 4, operating on Android Wear 3. This device runs an application specifically designed to collect, interpret, and communicate user interaction data with the game. While previous versions of Android Wear allowed direct access to their API from Unity [4], the current Android Wear 3 does not permit it. However, a solution has been found by exporting the game as a library [46] and running it natively in an application generated using Android Studio, which acts as a bridge between both systems.

Figure 3 presents a diagram illustrating the general operation of the system and the interactions among its modules. To begin with, data from the smartwatch's linear accelerometer sensor are recorded through an Android Wear application installed on the smartwatch and are transmitted to the paired smartphone via Bluetooth using a communication service. On the smartphone, a service-receiving instance is running, which directly conveys this data to the Unity application. Once within Unity, the game processes the accelerometer data and converts it into information regarding the player's actions. Furthermore, the game can be

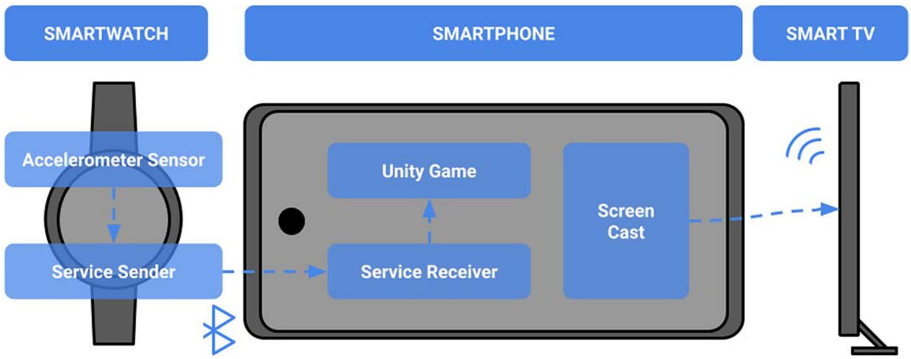

Fig. 3 Diagram of the communication architecture and information transfer between system modules

mirrored on a smart TV connected to the same WiFi network to enhance the game's visual experience.

As for the display, a smart TV is used, specifically an LG UHD-70–81003-LA with a 70-inch screen in this case. Although the game can be played on the smartphone's screen, the smart TV offers a larger size and convenience for the runner. Therefore, the smartphone's screen is sent to the smart TV for display at a higher resolution.

4.2 User interaction

In any video game, user interaction methods play a fundamental role in providing a satisfying gaming experience. Specifically, in an Exergame like this one, the interaction through obtaining the user's running speed and gestures must be robust.

In an ideal scenario, the player's running speed would be directly obtained from the treadmill's speed. However, due to technological limitations during the development of this work, direct access to this information was not possible. Obtaining the treadmill's speed would have been beneficial for more accurate estimation, but its difficult accessibility and the lack of Bluetooth connectivity in some treadmills would have limited the game's usability. Additionally, an additional device would have been required to detect gestures. For the sake of generality and safety, the automatic adjustment of parameters such as incline was discarded, as this could pose safety issues since the treadmill is controlled by the player.

To enhance the game's accessibility, efforts have been made to reduce the number of necessary hardware devices. A smartwatch placed on one of the runner's wrists is used, with its accelerometers providing approximately six samples per second in a three-dimensional vector format (x, y, z), along with a timestamp.

From these raw accelerometer data from the smartwatch, operations are performed to transform them into usable information for the game. The first operation involves calculating the magnitude of the vector for each sample and then taking the differentiation with the immediately preceding sample. Using these differential values, the process of estimation and detection begins to convert the user's movements into actions within the video game.

4.2.1 Estimation of running speed

The estimation of running speed on the treadmill is directly dependent on two parameters: cadence or the number of strides the runner takes per minute, and the length of those strides. By combining these two parameters, an estimation of the running speed can be obtained. To obtain them, and based on the differential values between the magnitudes of the accelerometer samples, it is necessary to make an approximate estimation of both parameters at stable intervals. Results from other studies suggest that wearable activity monitors such as smartwatches provide an acceptable measure of real-time cadence and offer the potential to improve the prescription of physical activity based on intensity [15].

For cadence estimation, the first step is to detect changes in the signal obtained, specifically the instants when the signal transitions from positive to negative or vice versa. These instants indicate the occurrence of a step or stride. With this data, the next step is to accumulate all the detected steps within one-second intervals and then multiply that value by 60 to obtain an estimated cadence value for the step frequency recorded in that interval. Finally, to filter noise and outliers, a data smoothing process is applied using a low-pass filter for noisy signals [7].

Regarding stride length estimation, there is a fundamental problem since the devices cannot directly measure the displacement on a treadmill. In the case of outdoor running, commercial devices obtain stride length from the relationship between the number of steps and the displacement measured by GPS over a time interval. However, in the literature, studies have explored multiple parameters related to running, such as stride frequency, stride length, running speed, and energy expenditure [8, 17, 47]. There are even studies comparing these parameters between outdoor and indoor treadmill running [3]. To address this issue, and based on the information from these articles, an interpolation curve was approximated to estimate stride length using cadence through a rational function. The interpolation aims to predict stride lengths for cadence values. For this purpose, a rational function was fitted based on data obtained from the literature, and then its inverse was used to estimate stride lengths for different cadence values. The rational function used for interpolation is defined as follows:

$$y = (a/(b + cx)) + d$$

In the provided equation, x represents the cadence variable (steps per minute), while y represents the stride length variable (meters). The parameters a, b, c, and d are utilized as coefficients for adjusting the function to fit the measured data and ensure an appropriate adaptation of the curve. Figure 4 depicts a graphical representation of this curve.

Finally, with the obtained values of cadence and stride length, the next step to determine the speed is to multiply both parameters for each interval and then convert the units to obtain the speed in kilometers per hour for each interval. Figure 5 illustrates an example of this process based on the cadence and stride length curves.

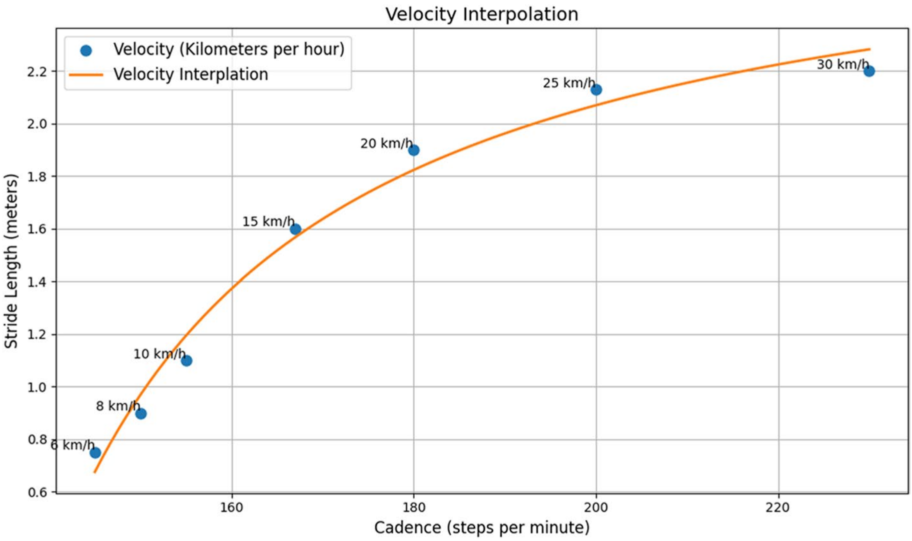

Fig. 4 Estimation of Stride Length through Cadence

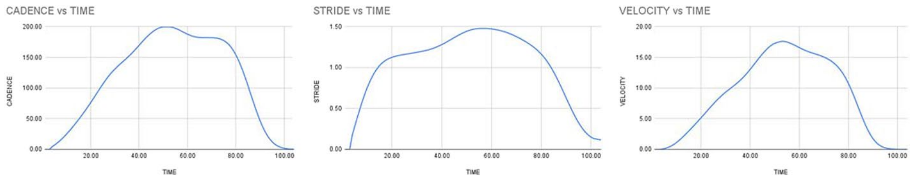

Fig. 5 Cadence Curve (left), Stride Length Curve (center), and Velocity Curve (right)

4.2.2 Gesture detection

Gesture recognition using sensors is a vast and diverse topic in the literature with multiple applications in various fields [36]. Upon reviewing the catalog of articles published in the last five years on this subject, it is evident that a significant majority utilize machine learning techniques. However, considering the characteristics of the gestures designed for this video game, a simpler recognition alternative has been considered in this case, while also contemplating the application of machine learning techniques as a future extension of this method.

The intended gesture to be detected is a cross-cutting gesture, similar to the motion one would make with a sword, axe, or hammer. By observing the accelerometer capture data, a significant peak in magnitude is observed during the moments when the gesture occurs, resembling a Dirac delta distribution. Figure 6 illustrates an example of a signal obtained from calculating the magnitude of the accelerometers, where the registered peaks after the gestures can be observed.

Regarding the gesture detection, it involves an analysis of the magnitude data obtained from the acceleration sensors, running in parallel with the speed analysis, where peaks or short-duration high-amplitude magnitude distributions are sought. To achieve this, a detection interval is utilized based on a threshold value.

4.3 Limitations

At the system level, a technical limitation was encountered due to the use of a smartwatch with the Android Wear 3 operating system, which was not directly integrated with the Unity game engine's API. However, a successful integration process was achieved, ensuring a robust and error-free solution in the studied cases. It is worth noting that the system has not been tested with other devices such as iOS, and therefore these specific problems cannot be extended to those devices. In future steps of this project, the aim is to explore extending the system to include iOS devices.

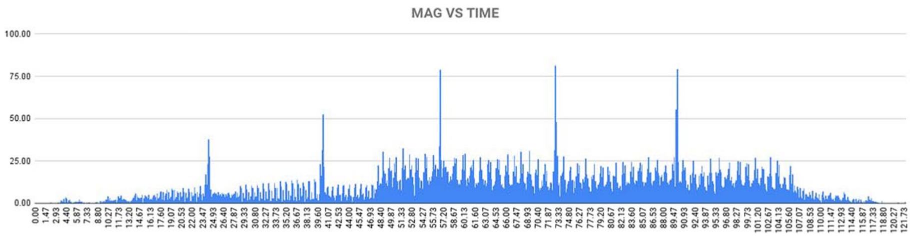

Fig. 6 Example of magnitude signal from an activity on the treadmill

Regarding the game itself, one of the main limitations was related to the accuracy of estimating the user's running speed. Unlike outdoor running where GPS-enabled devices are commonly used, estimating speed on a treadmill, where GPS is not applicable, required considering biometric and biomechanical factors, such as height, to carry out this estimation. By leveraging scientific literature in sports and physical activity, a method based on logarithmic curves was developed, which provided a stable and accurate estimation of running speed [8, 17, 47].

The results obtained so far have demonstrated that the implemented solution is robust and does not exhibit failures in the tested scenarios. Its functionality and performance have been validated through various tests, and the data provided by the smartwatch allow for a reliable estimation of running speed on the treadmill. However, further research and exploration of additional techniques to enhance the determination of stride length, speed, and gestures are considered valuable to improve the system's overall performance.

5 Experimentation and gameplay experience

One of the objectives of the design and development of this work is to create a video game that combines moderate physical activity with a satisfying gameplay experience that motivates users to repeat and turn it into a habit. To achieve this, a study has been conducted to evaluate the gameplay experience using both a running simulator and the Exergame presented in this work.

This evaluation aims to observe and analyze user feedback to determine which methods offer the best combination of enjoyment and difficulty. For this purpose, the In-game GEQ [19] was used, following the approach proposed by Pallavicini & Pepe [41]. Key aspects such as immersion level, fluency, positive or negative emotions, challenge, competition, and tension/anxiety were analyzed. Additionally, information about players' prior experience with video games, treadmill use, and running practice was collected.

Regarding the experiment design, both ZWIFT (running simulator) users and Fitoon (Exergame) users were positioned in front of a 70-inch screen and a BH-RC09 treadmill with a running surface of 155 × 55 cm. ZWIFT was chosen due to its significant differences from other simulators, allowing physical interactions between users and promoting interaction and socialization through group races in shared virtual spaces online. This application uses motion sensors to transfer users' actions into the virtual world in real-time, displaying landscapes and other users. The avatar's speed and actions in the virtual world reflect the athlete's physical activity and actions in the real world [50].

For the study, the "May Field" route within the Watopia environment in ZWIFT was selected, with a length of 0.4 km, although participants could stay on it as long as they wished. To simulate the same distance used in Fitoon, a route of 0.45 km length was chosen, with an approximate duration of 2 min, although this duration varied depending on the speed chosen by the participant. During the game, the runner had to move their arm to collect as many coins as possible while their virtual avatar progressed along the course. Participants using ZWIFT running wore a Zwift RUNPOD pedometer on their shoes, while Fitoon players used a properly positioned smartwatch. Figure 7 shows the arrangement of these two devices on two participants in the experience. IBM SPSS Statistics 28.0.0.0 was used as the software for statistical analysis.

Fig. 7 Pedometer used for ZWIFT (left) and smartwatch used for Fitoon (right)

5.1 Experiments

Exergames have proliferated nowadays due to their unique characteristics of immersion and interactivity. These video games are used for physical activity, but also as a form of entertainment. Although a previous study validated the use of Exergames compared to treadmill simulators in terms of immersion [31], the chosen Exergame platform is not designed to be used on treadmills. Thus, there is no scientific evidence justifying the use of Exergames for treadmill running compared to route simulators on treadmills. Therefore, a study is proposed to assess the player's experience and evaluate which technology may be more useful in the context of applications developed for treadmill running. In this regard, the In-game GEQ [19], will be used for comparison.

Depending on the study's goals, key aspects such as immersion level, flow, positive or negative emotions, challenge, competition, and tension will be analyzed. Additionally, participants will be asked whether they are runners, treadmill users, and video game players. The main hypotheses of this study are as follows:

- H1. Better flow is presented by Fitoon than ZWIFT.
- H2. Users feel more competent while playing Fitoon.
- H3. Fitoon generates less tension than ZWIFT.

The experiment was conducted with the participation of 74 individuals, comprising 27 females and 47 males, with an average age of 28.4 years (Standard Deviation = 9.3; minimum age: 18 years, maximum age: 54 years). Of the total, 67.6% had no previous experience in using treadmills, while 32.4% had prior experience. Participants were recruited through advertisements at our educational institution, and their involvement was individually scheduled in 20-min intervals. In an ideal scenario, participants would have tested both applications; however, logistical constraints, such as the availability of only one treadmill and the sluggishness of the transition and calibration process between applications, led to prioritizing the provision of a system prepared for their testing, avoiding constant changes. The allocation of the experience was random, with 32 users in the ZWIFT group and 42 in Fitoon. In both cases, users were given a few minutes to acquaint themselves with the application environment and unfamiliar interaction mechanisms. The study received approval from the Ethics Committee of the University Jaume I of Castellón. All participants reported no physical limitations that could hinder treadmill use and had some level of experience in both physical exercise and mobile games.

The study participants, all of whom were physically fit, engaged in a run either in Fitoon or in ZWIFT. After the experience, they completed the In-game GEQ questionnaire to evaluate their gaming experience. This questionnaire consists of 14 items that assess components such as Competence, Sensory and Imaginative Immersion, Flow, Tension, Challenge, Negative Affect, and Positive Affect. Table 1 shows the statements of the questions associated with each component.

Participants rated each item on a five-point Likert scale, where a value of 0 indicated complete disagreement and a value of 4 indicated complete agreement. The components of the In-game GEQ are grouped in pairs of items classified as follows: Competence (items 2 and 9), Sensory and Imaginative Immersion (items 1 and 4), Flow (items 5 and 10), Tension (items 6 and 8), Challenge (items 12 and 13), Negative Affect (items 3 and 7), and Positive Affect (items 11 and 14). It is noteworthy that participants did not receive any incentives to take part in the study.

5.2 Results

The results obtained are presented below after data collection and questionnaire analysis. Given the ordinal qualitative nature of the investigated variables, a non-parametric analysis was conducted to determine if there were significant differences between the measured variables. Due to the independence of the samples, the Mann–Whitney U test was employed to compare the medians [34].

Table 2 shows statistically significant differences ($p < 0.05$) for the components Competence ($U = 425.5$, $p = 0.005$) and Flow ($U = 384$, $p = 0.001$). Overall, both experiences presented very low levels of tension and negative affect, with slightly higher levels observed in ZWIFT. The median and mode indicate high to very high levels of both competence and perceived positive affect in both cases. Specifically, the statistical results reveal significant differences in competence, favoring Fitoon.

Perceived levels of challenge were moderate for both applications, while moderate to high levels of game flow were observed. Significant differences were found, indicating higher ratings for Fitoon. Immersion levels were high for both experiences, with Fitoon slightly surpassing ZWIFT in this aspect. These findings suggest that Fitoon outperforms

Table 1 In-game GEQ Questionnaire

Competence	Item 2. I felt successful Item 9. I felt skilled
Sensory and Imaginative Immersion	Item 1. I found the game plot interesting Item 4. I found it impressive
Flow	Item 5. I forgot about everything around me Item 10. I felt completely absorbed
Tension	Item 6. I felt frustrated Item 8. I felt irritable
Challenge	Item 12. I felt challenged Item 13. I had to put in a lot of effort
Negative Affect	Item 3. I felt bored Item 7. I found it heavy
Positive Affect	Item 11. I felt satisfied Item 14. I felt good

Table 2 Test results

		Median	Mann–Whitney U	Bil. A. Sig. (p value) z
Competence	ZWIFT	3	425,5	0,005
	FITOON	3		
Immersion	ZWIFT	3	618,5	0,549
	FITOON	2,75		
Flow	ZWIFT	2,25	384	0,001
	FITOON	3		
Tension	ZWIFT	0	541,5	0,104
	FITOON	0,25		
Challenge	ZWIFT	2	596	0,397
	FITOON	2		
Negative Affect	ZWIFT	0,5	502,5	0,051
	FITOON	0,5		
Positive Affect	ZWIFT	3,25	630	0,636
	FITOON	3,25		

ZWIFT in terms of competence and flow, providing users with a more engaging and enjoyable gaming experience. Additionally, both applications exhibited low levels of tension and negative affect, while competence, positive affect, challenge, game flow, and immersion were rated overall as high in both applications.

Significant differences between the groups were revealed for the following items:

- In terms of perceived success (item 2), Fitoon users rated themselves higher than ZWIFT users ($U = 489$, $p = 0.031$).
- Regarding boredom (item 3), Fitoon users experienced significantly lower levels compared to ZWIFT users ($U = 511$, $p = 0.044$).
- About the ability to forget about everything around them (item 5), Fitoon users showed higher agreement with this statement, while responses from ZWIFT users were more dispersed ($U = 360$, $p < 0.001$).
- In the perception of skill (item 9), Fitoon users felt more skilled than ZWIFT users ($U = 413.5$, $p = 0.002$).
- Finally, in relation to the effort required (item 13), Fitoon users perceived that they had to exert less effort compared to ZWIFT users ($U = 440$, $p = 0.007$).

Additionally, the following trends were observed:

- Regarding interest in the game's storyline (item 1), both groups showed a high level of agreement. However, Fitoon users exhibited slightly higher interest, with 25% of them completely agreeing, compared to 20% in ZWIFT.
- About perceived success (item 2), both experiences were similar, although Fitoon showed a more concentrated distribution of responses, with nearly half of the users feeling very successful.
- Boredom (item 3) was low in both experiences, although ZWIFT users displayed greater variation in their responses.

- There were no significant differences in the impression of the game (item 4) between both experiences.
- Frustration (item 6) was low in both experiences, although Fitoon users reported slightly more frustration, possibly due to the challenge of coordinating the run with arm gestures.
- Regarding the perception of the game's heaviness (item 7), ratings were low in both experiences.
- Both user groups strongly disagreed with feeling irritable (item 8).
- Fitoon users perceived themselves as more skilled than ZWIFT users (item 9).
- In terms of perceived absorption (item 10), Fitoon users had slightly higher ratings, although the differences were not statistically significant.
- The level of satisfaction (item 11) was high in both experiences, with no significant differences.
- Regarding perceived challenge (item 12), ZWIFT displayed a more evenly distributed set of ratings, but both experiences had high levels of perceived challenge.
- In relation to effort (item 13), both experiences received predominantly low ratings, but Fitoon users perceived less effort compared to ZWIFT users.
- Finally, in terms of well-being (item 14), both experiences received high ratings, with no significant differences between Fitoon and ZWIFT.

In addition to responding to the questionnaire items shown in Table 1, participants also rated their level of experience in three activities: playing video games, running, and using a treadmill. On a common scale, the mean results of these evaluations were 2.69, 2.00, and 1.14, respectively.

5.3 Comparative discussion

The three hypotheses on which this experimentation is based are related to flow, competence, and tension. The obtained results provide information about the differences between these two applications and their impact on user perception.

Hypothesis H1 was confirmed, as it was found that Fitoon exhibited higher levels of flow compared to ZWIFT. The results support this claim, showing that Fitoon outperformed ZWIFT in terms of perceived flow. These findings suggest that Fitoon provides a more immersive and engaging gaming experience, allowing users to fully immerse themselves in the activity. The combination of running on a treadmill and using the smartwatch as an interaction device likely contributed to the improved flow experienced by users. The natural movements enabled by the treadmill and the ability to control running speed according to individual preferences may have contributed to a smoother and more enjoyable gaming experience. It is important to note that while Fitoon showed advantages in terms of flow, there was a slight increase in tension due to the challenges of collecting coins. This may have influenced the flow experience to some extent, but it did not significantly compromise the overall improvement experienced compared to ZWIFT.

Hypothesis H2 proposed that users would feel more competent when playing Fitoon. The results confirmed this hypothesis, indicating that Fitoon users reported higher levels of competence compared to ZWIFT users. The unique features of Fitoon, such as the ability to use the smartwatch as an interaction device for gaming, may have contributed to users feeling more confident and skilled in their gameplay. Additionally, the game environment provided by Fitoon likely enhanced users' sense of competence, ultimately leading to a more positive user experience.

Hypothesis H3 suggested that Fitoon would generate less tension than ZWIFT. However, the statistical results do not support this hypothesis, as there were no significant differences between the medians of both groups. It is important to note that in both experiences, the majority of users indicated a negligible level of tension. The combination of engaging gameplay mechanics and the use of a smartwatch as an interaction device likely contributed to a user experience that was more stress-free and enjoyable in Fitoon.

Overall, the findings of this study indicate that Fitoon offers a more engaging and enjoyable user experience in terms of flow and competence compared to ZWIFT. The combination of running on a treadmill and interacting with a smartwatch in Fitoon creates a unique and immersive gaming experience that enhances user engagement and feelings of competence. These insights contribute to the growing body of research on Exergames and provide valuable information for developers and researchers in the design and evaluation of interactive fitness applications.

5.4 Fitoon discussion

Focusing on the data collected from the usability tests exclusively on the game designed in this work, the results in terms of usability were promising. The individual analysis of the game revealed high levels of competence and moderately high immersion, which motivates comparison with other existing treadmill running applications.

The analysis axes were evaluated as indicated by the questionnaire, averaging the two items involved in each category. Given the scalar quantitative nature of the variables and the number of users, both the mean and the median were taken into account for the analysis, along with the mode. A summary of the results obtained can be observed in Table 3. Additionally, to complement the analysis, the results were also studied on an individual item basis and the justifications provided by the users were qualitatively analyzed, highlighting comments, critiques, and valuable suggestions for improvements in the game's design.

From the results obtained in this study and presented in Table 3, several relevant insights can be extracted for each item:

- **Competence**: Participants generally felt skillful and successful during the game. The mean value of 3.2 and a median of 3 on the Likert scale suggest that players strongly

Table 3 Results obtained from the experimentation with Fitoon only

	Competence	Immersion	Tension	Challenge	Negative Affect	Positive Affect	Flow
Mean	3.226	2.786	0.429	1.869	0.417	3.321	3.000
Median	3.000	2.750	0.250	2.000	0.500	3.250	3.000
Mode	3.000	2.500	0.000	1.500	0.000	3.000	3.000
Skewness	-0.208	-0.120	1.170	-0.016	0.870	0.038	0.183
Kurtosis	-0.024	-0.143	0.663	-0.148	-0.290	-1.135	-0.721
Percentil25	3.000	2.500	0.000	1.500	0.000	3.000	2.500
Percentil50	3.000	2.750	0.250	2.000	0.500	3.250	3.000
Percentil75	3.500	3.000	0.625	2.500	0.625	4.000	3.500

agreed or completely agreed with feeling competent, indicating a high level of competence during the game.
- **Immersion**: The results showed a medium–high level of immersion. Most users indicated they strongly agreed that the game's plot was interesting. However, some users expressed confusion about what was meant by "plot" in the game.
- **Tension**: Users' responses indicated low levels of tension during the game, with the majority reporting a tension level of zero. Some users mentioned difficulties with gesture detection, which may have contributed to a certain level of frustration.
- **Challenge**: The perceived level of challenge was moderate. Although users felt challenged, they did not necessarily feel that they had to exert a lot of effort. This suggests that the game provides an appropriate balance of challenge.
- **Positive Affects**: Users reported high levels of satisfaction and well-being during the game. Nearly 90% of users indicated that they strongly to strongly agreed with feeling good during the game.
- **Negative Affects**: Users reported low levels of negative affects, with mean and median values not exceeding 0.5. Most users did not feel bored or find the game heavy.
- **Flow**: Users reported a high level of flow in the game, indicating they felt immersed and focused on the game.

Overall, the results show that users had a positive experience with the Exergame, with high levels of competence, positive affects, and flow. Although the challenge level was moderate, responses varied across items, which could suggest different interpretations of what constitutes a challenge in this context.

Regarding participants' suggestions for improving the proposal, they mentioned the possibility of varying the scenario and adding more incentives besides collecting coins. Some users had difficulties with gesture recognition from the smartwatch. Despite this, users felt enthusiastic and engaged with the game, although some mentioned the short duration of the experience as a limitation. These findings provide a solid basis for future improvements and developments of the Exergame.

6 Conclusions and future work

This paper presents an Exergame specifically designed for treadmill running, controlled through interaction between a smartphone and a smartwatch. The main objectives are to provide users with a video game that adapts to the characteristics and peculiarities of treadmill running, using generic devices instead of specific hardware, and to create a satisfying gaming experience that combats indoor monotony and promotes physical activity for sedentary user profiles.

Furthermore, the initial hypotheses in this study assert that to validate Exergames in the context of treadmill running, it is crucial to prioritize the ludic component over the physical activity component. In other words, to validate the purpose of the video game, it is necessary to evaluate if its design provides a satisfying gaming experience. To verify the degree of achievement of the objectives and hypothesis, a comparative user study was conducted where Fitoon was pitted against the ZWIFT treadmill running simulator. The assessment of the gaming experience was carried out using the In-game GEQ.

The study results suggest that Fitoon may provide a more appealing user experience compared to ZWIFT, particularly in terms of flow and competence. However, it is important to acknowledge the limitations of this study, including the relatively small sample size, which may restrict the generalization of the findings. Therefore, further research with larger and diverse samples is needed to validate and further expand these results. Additionally, while this study focused on users' subjective experiences, future research should consider the incorporation of objective measures of physical activity and fitness outcomes. This provides a more comprehensive understanding of the effects of Exergames on physical health and performance.

Overall, the study results support the usability of the proposed game and user satisfaction. However, some areas for improvement were highlighted, such as variation in the plot and the detection of gestures by the smartwatch. Furthermore, the limited duration of the experience was mentioned as a limitation of the study. Study participants showed enthusiasm and commitment to the game, expressing their desire to continue playing to improve. These findings support the idea that Fitoon has the potential to be an effective tool for promoting physical activity in sedentary user profiles.

In conclusion, this study contributes to the growing body of research on Exergames and highlights the potential of utilizing smartwatch interaction and treadmill running to create immersive and enjoyable fitness experiences. The findings have implications for developers, who can leverage this knowledge to design more engaging Exergames, as well as for researchers, who can continue investigating the impact of Exergames on physical activity adherence and health outcomes. By addressing limitations and exploring new research avenues, we can continue advancing the field and promoting the adoption of Exergames as a viable means of fostering physical activity and well-being.

In the future, the primary goal is to enhance the gaming experience on a treadmill. For instance, working with treadmills with interactive connectivity could be an interesting option. Although finding a standard method for multiple treadmill models appears challenging, in fact, the treadmill used in the study theoretically has Bluetooth connectivity, but the available functionalities did not allow real-time interaction with the game. On the other hand, improving the accuracy of stride length estimation and, consequently, participants' speed, either through additional sensors or advanced algorithms, is also intended. Additionally, the inclusion of more interactive gestures is contemplated to expand the possibilities of interaction in the game. Moreover, as a direction for future work, it would be valuable to explore alternative interaction methods, such as heart rate fluctuation monitoring or using a smartphone's camera. This approach could enable gesture recognition or facial expression tracking, opening new possibilities for enhancing user engagement and immersion in Exergames. By researching different interaction modalities, researchers and developers can continue innovating and improving the design of interactive fitness applications.

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Data availability Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

Declarations

Competing interests All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

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