Staying Fit in the Metaverse: Evaluating Diegetic GUIs for Representing Exertion Data in a VR Exergame

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Virtual reality (VR) exergames are becoming a popular exercise method, enabling players to have fun in a fully immersive environment where their physical interactions can be exerting enough to provide beneficial levels of physical activity. However, players cannot easily keep track of their level of exertion while immersed in the VR environment which could lead to over-exertion. Therefore, this paper presents the design and evaluation of three in-game diegetic graphical user interfaces for representing exertion data in VR exergames. We conducted an empirical study to test and evaluate the user experience of the GUI designs in a custom prototype VR exergame, Snowballz. Our key contribution is design recommendations for diegetic GUIs representing real-time exertion data in VR exergames, covering integration, orientation, calibration and learning process. We also outlined opportunities for future research in this area.

CCS Concepts: • **Human-centered computing → Virtual reality**; • **Computing methodologies → Virtual reality**.

Additional Key Words and Phrases: virtual reality, exergame, graphical user interface, diegetic, metaverse, data visualisation

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1 INTRODUCTION

Fully-immersive virtual reality (VR) exercise games using a head-mounted display (HMD) are becoming more accessible than ever before through consumer HMD devices like the Oculus Quest[1]. VR exergames can lead to increased motivation and enjoyment of workouts [6, 10, 41] while also having the ability to provide beneficial levels of physical activity [53]. Previous work has demonstrated that exercise in VR can enhance both exercise capability and concentration of the user compared with exercising in a non-VR environment [30]. Furthermore, players can perceive less exertion than their actual exertion while playing VR games [45, 51], suggesting VR exergames can distract players from the exertion experienced during physical activity through immersive content.

Despite VR games becoming a new way to gain beneficial exercise, it can be difficult for players to keep track of their exertion during gameplay. It has been widely acknowledged that monitoring intensity during exercise is important for obtaining optimal exercise effects and avoiding overexertion [25, 52]. Significant health risks can be produced from overexertion or inappropriate exercise [21], such as coronary [14] and cardiac events [17]. However, the lower perceived exertion level in VR games [45] makes it easy for players to underestimate their actual exertion, increasing the risk of overexertion. Furthermore, in VR gaming sessions, the player is in a fully immersive environment, making it difficult for them to check their exercise monitoring devices in reality, such as a fitness band or a smartwatch.

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[1] https://www.oculus.com/quest/refurbished/

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In response to the limitations, a graphical user interface (GUI) with exertion data like heart rate displayed in-game can help players keep track of their real-time exertion during gaming sessions. Some commercial systems such as Oculus Move[2] and PowerBeats VR[3] have applied head-up displays (HUDs) to display such information, but it has been suggested that the presence of those elements can compromise the player's game immersion - which is crucial to preserve in VR exergames [23, 42] - or even cause discomfort [38]. One way to overcome this limitation is to add "diegesis" to GUI elements, by integrating those elements within the game environment and narrative. Researchers have found such "diegetic GUI" can be perceived as more immersive by players [28] compared with non-diegetic GUIs. However, while there have been some design cases of diegetic GUI in VR games in both commercial (see Table 1) or academic areas [31, 43, 49], they may not fit for displaying real-time exertion data in VR exergames. The majority of those GUIs are designed to show in-game information such as the player's health or gun ammo, which needs to be constantly checked throughout the gameplay. But for exertion data, as the research of Yoo et al. [53] suggests, the player should still have the ability to immerse themselves in the game and refer to the information just when they need it, implying GUIs in this context may need to be designed differently in a more unobtrusive way.

To address this, this work aims to explore the design of such diegetic GUIs guided by the following **research question (RQ):** ***"How can diegetic GUIs be designed to integrate real-time exertion data in a VR exergame?"*** To answer this research question, we designed and evaluated three diegetic GUIs in a custom VR exergame prototype, Snowballz. Each of the GUIs is designed differently according to the parameters synthesised from existing design precedents. Based on the data collected from an empirical study, we discussed the impact of those different design choices. The key contribution of this research is a set of design guidelines for diegetic GUI representing real-time exertion data in VR exergames.

2 RELATED WORK

2.1 The Diegesis of Game GUIs in VR Environment

The concept of "diegesis" is frequently discussed in research about in-game GUIs. Based on the model categorising in-game GUI design proposed by Fagerholt and Lorentzon [15] and its later modification for VR games by Willemsen [49], the GUI for VR games can be summarised by four types: Non-diegetic, Meta, Geometric, and Diegetic, depending on their integration within the 3D world and game narrative. The "diegetic" GUI refers to GUI elements that exist in both the virtual environment and the game's narrative. Examples of diegetic GUI include a map held in the game character's hand, a watch on the character's wrist, or a virtual digital screen within the game world.

Previous work has shown this diegesis of GUI elements has the potential to improve the player's performance, immersion, and enjoyment [35, 43]. For non-VR games, there have been already a number of works evaluating it in different scenarios, such as in FPS games [28, 35, 39], role-playing games [42], or side-scroller games [40]. In terms of VR environment, there have been evaluations of a game configuration menu [43], VR fps games [31, 49] and a VR training simulation [13]. The consensus among these works is that diegetic GUIs provide a high level of immersion with players reporting an increased sense of presence and realism. However, while some studies found that diegetic integration has a positive effect on player's performance [35] or system usability [43], others found a diegetic GUI can require more effort to understand the data during gameplay and can be thus more difficult to use [13, 28, 31, 49]. We argue those different user experiences can be caused by the designs of those GUIs themselves, and their adherence to the needs of use scenarios, implying a need for design guidelines within this area.

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[2] https://support.oculus.com/move/

[3] https://www.powerbeatsvr.com/vr-fitness-game/supported-heart-rate-monitors/

Table 1. Diegetic GUI in commercial games

Name	Year	Is VR	GUI Form	Data	Representation Method
Metro 2033	2010	No	Virtual Smartwatch	Level of visibility	A LED Light
Crysis 2	2011	No	Virtual helmet	Player status	Number & Chart
The Forest	2014	No	Campfire	Remaining burn time	Fire size
Keep Talking and Nobody Explodes	2015	Yes	Room Ambient	Bomb countdown	Flashing alarm light
Minecraft (Switch)	2017	No	Outdoor Environment	Time	Skybox and Light
Pinball FX2	2018	Yes	Virtual screen	Leader board	Text
Half-life Alyx	2020	Yes	Digital glove	Player Status	Number & Icon
Halo Infinite	2021	No	On-weapon screen	Ammo	Number
Dakar Desert Rally	2022	No	In-car cockpit	driver information	Number & Chart
Racket: Nx	2022	Yes	Virtual screen	level progression	Chart

As we identified limited precedents of diegetic GUI within academic research, we also conducted a review of the design of diegetic GUIs in commercial games, to better understand the state-of-art design of diegetic GUI. To further broaden the review scope, we chose to include both VR and non-VR first-person games, and both exercise and non-exercise games. The selection of games was based on the following resources:

- The Game UI Database [11]: A free resource offering over 50,000 screenshots from more than 1,000 games.
- Interface in Game [24]: A creative tool collecting interface designs from over 300 games.
- The TV Tropes [47]: A wiki that describes and collects examples of tropes in Media, with an entry focused on diegetic game interfaces.

We found a variety of designs of diegetic GUI in commercial systems. Table 1 summarises some representative samples according to the form of those GUIs, the types of data represented, and their methods of data representation. Those design precedents informs the prototype design in our study, which will be discussed in the following sessions.

2.2 Design Guidelines of VR GUIs

There have been some design guidelines for GUI in VR environments in either academic [7, 19, 32] or commercial [38, 48] areas. Alves et al. [3] collected some existing guidelines and then evaluated them based on the player's perception of them. The study identified some specific guidelines to be important considerations in VR GUI design, such as comfortable content distance", "use texts in UI that are easily read", and "provide visual feedback on interactive elements". Alger [2] discussed the areas for content disposal in VR, where the environment can be preliminarily divided into Content Zone, Peripheral Zone, Curiosity Zone, No-no Zone, and Background Zone, based on their distance and orientation from the user. They also pointed out a touch UI zone within the content zone where contents are comfortably reachable without causing eye strain [2].

While those guidelines have built a basis for GUI design in VR, they are not specifically refined for representing exertion data in VR exergames, resulting in some issues arising when adopting them directly. Firstly, many of the existing guidelines are prepared for the interactive elements in games, such as menus and buttons [48, 56], while the exertion data are usually non-interactive elements displaying information to players. Secondly, while existing guidelines have encouraged the adoption of diegetic elements by *integrating information into the environment* and *avoiding pinned GUIs in users' view* [38], there is a lack of further exploration about how those elements could be specifically designed. Finally, different from the data that needs to be constantly checked throughout the gameplay for a coherent gaming experience, exertion data in exergames, as suggested by previous research, may be shown in an unobtrusive way for users to check when needed [53], posing new requirements for its design.

2.3 Representing Exertion Data in VR Exergames

VR exergaming has been a widely explored topic in the HCI community during recent years, with studies investigating its effectiveness [29, 30, 53] and many prototype exergames for different purposes designed [4, 5, 46]. However, limited work has paid attention to providing users with their exertion data while they are playing. One of the existing examples in the research area is the exergame designed by Keesing et al. [26], where the user's real-time heart rate is displayed by a colour of heart on the left bottom corner as a HUD. Another previous work [55] developed a platform to input and show heart-rate data within the game to avoid overexertion in two ways: a HUD displaying a number on the screen and a spatial GUI displaying a 3D heart in the game scene. There are also more recent empirical studies, where Grioui and Blascheck [18] evaluated different 2D visualisations of heart rate on a virtual smartwatch panel and compared the participants' performance while using those different visualisations. While these works have provided important concepts, the vast design space of diegetic GUIs and the impact of different design choices on the player's experience, such as immersion, still need further exploration and evaluation.

In summary, explorations of the design of diegetic GUI for VR exergames representing exertion data are limited. To tackle this gap in the literature, we designed and developed a VR game called Snowballz to explore how such a diegetic GUI should be designed in this context to enable the player to keep track of their exertion as well as promote an optimistic user experience.

3 SNOWBALLZ: VR GAME AND GUI DESIGN

We designed three different diegetic GUIs showing the player's real-time exertion data in a prototype VR exergame called Snowballz, which is modified from the prototype game used in our previous research [54]. The steps of the prototyping phase are summarised as follows, with details documented below:

1. Develop the prototype exergame game as the evaluation platform.
2. Identify design variables and ideate design concepts of the GUIs.
3. Construct the final design of the GUIs.

3.1 The Snowballz Game

Snowballz is a VR tower-defence prototype game, where the player's goal is to defend their igloo from waves of enemies by using snowballs to hit them (see Fig. 1). As the player would need to squat and pick up snowballs from the ground, and then stand up to throw them at the enemies, the exertion of both upper body and lower body are integrated. According to the measurement of exertion level proposed by Mesquita et al. [37] using the approximate maximum heart rate, we estimated this would be capable of providing a moderate to vigorous level of exertion for most of the players.

As the GUI evaluation platform, the Snowballz game incorporates the following attributes:

- It's a 360° stereoscopic VR exergame where players can rotate freely during gameplay, rather than just facing their front without the ability to turn around.
- The player can navigate across the scene using their joysticks, rather than being restrained to a relatively fixed position.

Fig. 1. The Snowballz game

Generally, the game provides players with relatively high flexibility in terms of rotation and movement. While this poses extra challenges to GUI design, it to some extent also ensures the GUI designed from this prototype has higher compatibility when adopted to other VR games.

3.2 Identifying Design Parameters

Our review in section 2.1 indicated there are a variety of ways when design diegetic GUIs. From those different design choices, we identified two prevalent parameters according to which those GUIs are different: position and data representation method.

3.2.1 GUI's Position. According to the relative position between the GUI and the player, the GUI can be divided into four categories: Diegetic HUD, On player, Around player and Ambient. The explanation of each category is as follows.

- *Diegetic HUD* refers to the HUD that is embedded diegetically within the player's FOV. This is usually accomplished by a specific game narrative, where the game character is wearing a smart device, such as AR glasses or a digital helmet. An example is the virtual helmet displaying HUD in *Crysis 2* [4]. However, HUD elements in a VR environment can be uncomfortable [38] and have the risk of being in the no-no zone [2] where persistent content can be inappropriate, so we chose not to include this category in our design and discussion.
- *On player* refers to GUIs displaying data on objects that are attached to the game character. Examples include the virtual Digital glove with player health in *Half-life Alyx* [5], the virtual smartwatch using an LED light indicating

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[4] https://www.gameuidatabase.com/gameData.php?id=1204

[5] https://www.gameuidatabase.com/gameData.php?id=1447

the player's visibility to the enemy in *Metro 2033* [6], and the virtual wristwatch in the research by Köhle et al. [31]. GUIs in this category are often within a touch UI zone [2], which enables players to check it with minimal physical movements.

- *Around player* refers to the GUIs that are at a certain distance from the player, usually in the form of external objects and interfaces that do not move with the player. Examples include the virtual screen showing score and level progression in *Racket: Nx* [7], and the Leader board in *Pinball FX2* [8]. We do not further subdivide those GUIs according to whether they are in front of or behind the player as in Alger [2]'s model, because in exergames including the Snowballz prototype, the player's FOV is constantly rotating during gameplay. This also means such GUI does not stay in the player's FOV all the time and they may need to rotate while deliberately checking it.
- *Ambient* refers to the GUIs embedded in the environment surrounding the player using background, light, weather effects, etc. For example, in *Keep Talking and Nobody Explodes* [9], as an indicator of the bomb countdown, a red alarm light in the room would flash during the last minute. This enables players to collect information inadvertently during gameplay with their peripheral view without intentional physical movement.

3.2.2 GUI's Data Representation Method.

Aside from the position, another distinct difference identified among the GUIs is their data representation method, which can be categorised as explicit and implicit.

According to our review, the majority of diegetic GUIs adopt **explicit** representations of data by providing precise numbers or standardised charts. This usually requires the game to have a "screen" in the environment to fit in the diegesis. Therefore, many games adopting this diegetic GUI have a modern or sci-fi background, such as the on-weapon screen showing gun ammo in *Halo Infinite* [10] and the digital in-car cockpit with driver information in *Dakar Desert Rally* [11].

At the same time, many games also employed the **implicit** data representation, focusing more on providing an intuitive comprehension of the data instead of precise numerical values. For example, in the game *The Forest* [12], while there is no clear indicator about the time of campfires before they burn out, the fire gradually fades as time passes for the player to intuitively understand the remaining time. In *Minecraft* [13], the player can roughly understand the time within a day by looking at the position of the sun or the moon in the sky or paying attention to the position, colour, or intensity of ambient light.

Notably, this implicit data representation has also been adopted beyond the area of diegetic GUIs. For example, in many first-person shooter games, there is a gradual visual transition to a blood-splattered screen as the player's health declines. Even outside the gaming field, this implicit way of data representation has been widely applied to visualise exercise data in fitness tracking systems, such as using the growth and activity of a fish [34], the bloom of flowers [12] or creative art patterns [16]. In those works, such elements have shown a potential to increase users' enjoyment and engagement [12] and offer an at-a-glance understanding [16] of the player's exercise state. Therefore, we propose this implicit way would also be an effective strategy for designing GUIs representing exertion data as a consistent but unobtrusive reminder of the player's exertion.

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[6] https://tvtropes.org/pmwiki/pmwiki.php/VideoGame/Metro2033
[7] https://www.gameuidatabase.com/gameData.php?id=1453
[8] https://www.gameuidatabase.com/gameData.php?id=1655
[9] https://www.gameuidatabase.com/gameData.php?id=648
[10] https://interfaceingame.com/games/halo-infinite/
[11] https://www.gameuidatabase.com/gameData.php?id=1677
[12] https://www.gameuidatabase.com/gameData.php?id=853
[13] https://www.gameuidatabase.com/gameData.php?id=1696

3.3 Prototype GUI Design

According to the discussion above, we designed three GUIs each allocated to a different position as the first design parameter: an "on player" GUI, an "around player" GUI, and an "ambient" GUI. A variety of data representation methods, as the second parameter, is applied within the three GUIs, ranging from relatively explicit elements, such as numbers and charts, to more implicit elements, such as colour gradients, object sizing, and ambient effects. We expect this design approach would enable us to investigate how different design choices of the two parameters would affect the player's holistic experience while engaging with the GUI during gameplay. The key differences between those three GUIs are outlined in Table 2.

Table 2. Difference of the three GUIs, based on Form, Position, and Data Representation method.

Form	Position	Data Representation Method
Smartwatch	On Player	Mostly Explicit
Fire and Ice	Around Player	Mostly Implicit
Weather Effects	Ambient	Mostly Implicit

The visual impact and data representation of the three GUIs are shown in Fig. 2. To comply with the requirement of being diegetic, we designed an "on player" GUI as a smartwatch, an "around player" GUI as a fire melting an ice crystal and an "ambient GUI" in the form of weather effects. The data representation of the "on player" GUI is mostly explicit corresponding to its more "digital" form as a smartwatch, while the other two are mostly implicit as being integrated into the surrounding landscape.

Fig. 2. Data representation in each of the GUIs, highlighting how each GUI represents heart-rate data and progression towards an exercise time goal.

The GUIs are designed to show exactly the same set of exertion data. First, the player's real-time heart rate is displayed with the corresponding exertion level: light, moderate, or vigorous, calculated out of the maximum heart rate

[37]. Secondly, the GUIs present the player's progress towards an exercise goal: maintaining a moderate or vigorous intensity level for two minutes, to promote moderate or vigorous intensity in accordance with the ACSM / AHA recommendations [20]. The time limit of two minutes is set considering the duration of the study session. Previous studies found instead of explicitly presenting the time, showing progress towards a goal can be more effective in preventing overexertion [54].

The exact designs choices of each GUI are explained further below:

(1) **"On player" GUI - Smartwatch**: This GUI is designed as a virtual smartwatch on the player's wrist in-game. The heart rate is shown by a number on the smartwatch panel, with its colour changes according to the player's exertion level: red during light exertion (as an alarm that the player is not receiving enough exertion according to the game narrative of staying warm), green during moderate exertion, and orange during vigorous exertion. As the player spends time in moderate or vigorous exertion, a progress bar will gradually fill the smartwatch panel from left to right, indicating the player's progression of the exercise goal. As the data representation here uses precise numbers and charts, this GUI is considered to use a more explicit form of data representation. This GUI is attached to the player's virtual hand in the game, so the player can check it by slightly raising their arms or lowering their heads.

(2) **"Around player" GUI - Fire melting ice crystal**: This GUI represents data as a fire burning a big ice crystal in front of the player's snow igloo. The fire will get bigger when the player's heart rate gets higher, with its colour indicating the exertion level, where the fire will turn green in light exertion, red in moderate exertion and blue in vigorous exertion, metaphorising a rising flame temperature as the player's exertion level increases. In moderate or vigorous exertion, the ice crystal will gradually melt and finally disappear showing the player's progression towards the goal. In this GUI design, the exertion data is represented by the colour and size of a tangible object instead of numeric or chart representations, to integrate better with the game landscape. Initially, we intended to place the GUI in the same direction as incoming enemies, but this was found to hinder players' vision when they were looking at enemies, so we placed it beside the snow igloo. This GUI occasionally requires the player to rotate while checking it.

(3) **"Ambient" GUI- Weather effects**: This GUI embeds the player's exertion data in the ambient Weather Effects. During gameplay, the sky gets brighter as the player's heart rate gets higher, and depending on the player's exertion level, the colour of the sky will change from a dark purple (light exertion), blue (moderate exertion), to orange (vigorous exertion), metaphorising a warmer environment as player's exertion increases. In the beginning, there are snows as ambient weather effects of the scene, which will gradually reduce and finally disappear as the player maintains moderate or vigorous exertion. Like the "around player" GUI, this GUI also adopts a more implicit way of data representation. This GUI uses the ambient effect on the virtual environment that surrounds the player, so it will not block any foreground objects, and the player can check it by simply paying attention to their peripheral vision without any physical movement. We expected that this design approach will ensure the convenience in checking the GUI, while enriching the gameplay itself with ambient effects.

We tried to minimise those GUIs' negative effects on game immersion in two ways: firstly, none of the GUIs would continuously stay in the player's field of view in order to be unobtrusive to the original gaming experience. Secondly, each GUI is designed to integrate well with the game environment and narrative, where the character is defending his snow igloo from enemies while keeping physical exertion to stay warm in a snowfield.

Although the three GUIs are different, we tried to keep logical consistency within their design. For example, in every GUI, the heart rate and progression are represented by two different in-game objects that are inherently linked with each other. We also tried to align every GUI with real-world scenarios: heart rate and progress indication are common functions of a fitness tracker watch; ice melts as a consequence of burning fire, and snowfall ceases gradually as sunlight gets intense. We expect this will further reduce the user's learning cost during study sessions.

4 STUDY DESIGN

Based on the prototype, a study was conducted following the ethical approval granted by the university of Sydney (ID 2016/089). This study enabled us to assess the user experience of the three different GUI designs and the effects of different design variables. While we were investigating the overall user experience, we mainly focused on two aspects: the GUIs' impact on game immersion and their effectiveness in helping participants keep track of their exertion.

4.1 Participant Recruitment

The study was set up inside a local library in China with prior approval from library staff. Participants were recruited via email and flyers in the library. The prerequisite for the recruitment of participants was that they should all be 18 years or older, be physically healthy, and fluent in Mandarin or English.

4.2 Study Setup

The study setup involves the VR headset, a computer running Unity 3D, a wristband for collecting the participants' heart rate data (Huawei band 4[14]) and a mobile phone for the researcher to check the heart-rate. During game sessions in which participants wore the VR headset and wristband, the researcher applied a "Wizard of Oz" prototyping method [36] by manually updating the heart rate shown on the mobile phone on the game system every five seconds. Although this manual input can cause slight errors, we do not collect quantitative results related to the exertion data themselves, so we expect that those errors would not significantly affect the study outcome. In addition, this approach minimises the possibility of connection issues between the wristband and the game program during study sessions.

4.3 Study Procedure

The study sessions took up to 40 minutes for each participant. In preparation for the study, participants received a participant information statement (PIS) and a participant consent form (PCF) to review and sign. If they agreed to participate, they would be asked to complete a demographic questionnaire including their gender, age, exercise routine, prior experience with VR, and habits and preferences in regard to monitoring exertion data. Then, the researcher used verbal instructions and a tutorial scene to instruct them about how to use the Oculus controller and play the Snowballz game. After the tutorial, the participants were instructed to wear the wristband.

As the main part of the study, the participants were asked to play three sessions of the game with each GUI. Before each session, considering the participants' unfamiliarity with the Snowballz game and using a diegetic GUI, we chose to verbally inform them about how their exercise data was presented in each GUI before the corresponding game round to minimise possible confusion. They were also reminded to check the GUI at least once during or after every wave of enemies before each session. The order of the three GUIs was arranged according to Latin Square to minimise biases from the order.

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[14] https://consumer.huawei.com/cn/wearables/band4/

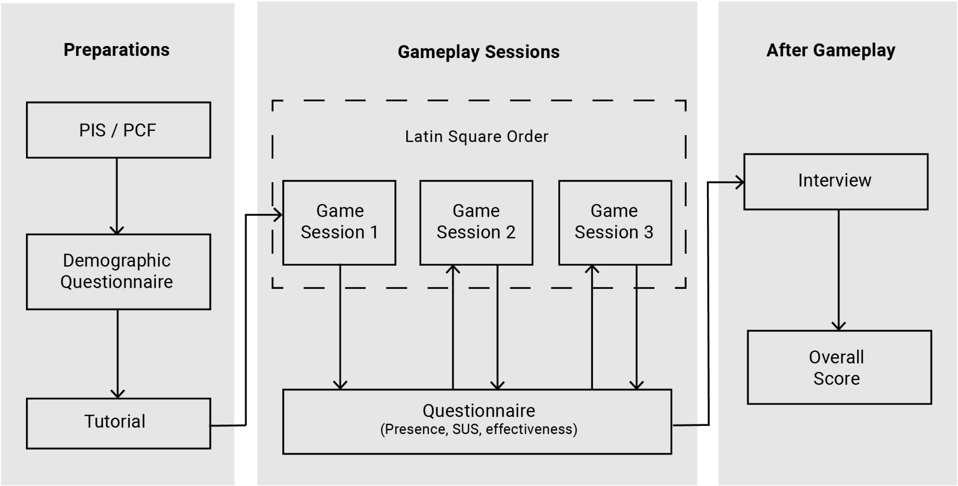

Fig. 3. Process of the study

After each session, the participants were asked to complete a questionnaire based on the previous session measuring the presence of the whole game environment, the GUI's usability, and the GUI's effectiveness in conveying exertion data. The questions for measuring presence were selected from the presence questionnaire (Version 2.0) by Witmer and Singer [50], with the aim to evaluate the GUI's impact on the exergame's immersion. Usability was measured with the System Usability Scale (SUS) [33]. Finally, some custom questions asked the participants to use the 5-point Likert Scale to state their agreement on statements such as if they were aware of their exertion data throughout the whole session, and if they found it convenient to access their exertion anytime during sessions.

After all three rounds of gameplay, semi-structured interviews were conducted. During the interview, the participants were asked to explain their responses in questionnaires and answer some open-ended questions about their likes, dislikes, and suggestions for GUI improvement. Finally, we asked each participant to give each GUI an overall rating on a 10-point scale (1 - very bad, 10 - very good) as a general examination of whether they liked the GUI design. A summary of the procedure is shown in Fig. 3.

5 RESULTS

There were 12 participants recruited for the study, 10 male and 2 female, with their ages ranging from 18 to 52. According to the demographics questionnaire, 9 of them did exercise at least once a week, and 4 of them had VR experience before. Most of the participants showed an interest in self-monitoring exertion during their workouts, with 10 expressing a desire to track their heart rate and 11 tracking their overall physical exertion.

A thematic analysis was performed on the interview data following the six phases by Braun and Clarke [8]. The researchers further reflected and validated the findings by contrasting the emerging themes with the questionnaire. The following themes were identified through the analysis.

5.1 Required Physical Movement

The design of the GUIs inherently influences the physical behaviour needed from the participants when they are trying to check the GUI. The majority of participants found the "on player" GUI convenient to use: *"The smartwatch is good because I can look at watch and snowman at the same time." (P9); "when I need my exercise data, I simply raise my arm to check it, which is very convenient" (P6).* Checking the smartwatch is also considered as a habitual behaviour by 5 participants: *"it is similar to my habit in reality to raise my arm and look at it." (P2).* In contrast, the physical movement required for the "around player" GUI was criticised by 8 participants who found it inconvenient, commenting *"when you turn around, sometimes you can't face the enemy at the same time." (P4)*; or *"it's an unnecessary movement that doesn't belong to the game itself. " (P9).* To improve it, two participants suggested adding some copies of the "around player" GUI in other angles so the player can easily check it all the time without the need to turn. For the "ambient" GUI, as expected, no participant considered it as inconvenient because it did not *"involve any physical interaction" (P8)* and they *"can just glance to see it" (P2).*

5.2 Understanding of Data Representation

As the three GUIs employed a variety of data representation methods from explicit to implicit, participants demonstrated various degrees of understanding of those data representation methods. Generally, most participants found it straightforward to understand the meaning of heart rate values shown on the watch panel in the "on player" GUI: *"[My] favourite thing about the watch is it tells the exact number of my heart rate, which gives me a clear understanding [of my exertion]."(P6)*; Another participant liked the mix of explicit elements like number and relatively implicit elements like colour, by commenting *"The colour changes make the data visually more intuitive." (P11)* Five participants showed difficulty in understanding the meaning of the progress bar which represents time: *"I noticed there was a green bar but I don't know what it represents." (P5).*

For the "around Player" GUI, 6 participants found the meaning of the fire and the ice crystal difficult to understand: *"this way of representing data is complex"(P9)* and *"it's relatively difficult to observe the changes of size"(P7).* However, another 6 participants managed to correctly understand their meanings, *"I can see the ice gradually getting smaller, so I can roughly understand the meaning of it: my exercise amount" (P6).* Despite the implicit nature of this representation, 2 participants preferred this GUI to the "on player" GUI for its at-a-glance readability: *"I can see if the ice crystal is gone indicating I have reached the goal instantly."(P5).*

For the "ambient" GUI, while one participant stated *"the weather was the most intuitive way"(P8)*, the majority of participants faced some difficulty while using it. They expressed that this GUI was *"difficult to read" (P1)* as they *"need to examine it carefully to understand the data"(P7).* Three participants pointed out that the changes in sky and snow in this GUI needed to be more obvious, such as by making it *"completely black or white" (P11)* when the exertion level is low or high. Only 3 participants successfully understood that the changes in sky brightness represented their heart rate, with the majority having difficulty understanding it: *"When I was playing, I can feel the weather is changing but I don't react to the specific meaning of it."(P6); "If it is brighter, my eyesight is clearer, but I did not think too much about its meaning, because my attention can be only paid to one thing at a time." (P4).*

5.3 Awareness of the GUI

While we reminded the participants to regularly check the GUI before each session, 11 of the participants indicated they frequently became unaware of the presence of at least one of the GUIs during the gameplay: 3 reported being unaware of the "on player" GUI, 5 for the "around player" GUI, and 5 for the "ambient" GUI. Compared with the other GUIs, lack of awareness was not as serious for the "on player" GUI, where 5 participants reported they always kept it in mind during the entire session, partially because of its *"alignment with a smartwatch in reality" (P11)*. Also, 6 participants commented becoming unaware of the GUI was a persistent experience during all sessions as they were focusing mostly on the gameplay, regardless of how the GUI was designed: *"I just played this game without thinking much about my exercise data" (P10); "I just threw the snowballs" (P3)*. Also, 2 participants attributed their ignorance to unfamiliarity with the game *"I will pay more attention to the data represented when playing the game next time" (P6)*.

Aside from being unaware of the GUI itself, participants reported ignoring some specific data representation elements within GUI, even if those elements have appeared in their FOV. All participants did not notice the changes in snow intensity in the "ambient" GUI. Most participants (9) mainly paid attention to the size of the fire in the "around player" GUI, completely ignoring its colour change.

Despite the unawareness reported, the participants provided a high mark on the effectiveness of the GUI in conveying exertion data. When asked if they find it convenient to access their exertion anytime during gaming sessions, the participants left a relatively high average rating of 4.6 (out of 5) for on player GUI, 3.9 for around player GUI, and 4 for ambient GUI. The rating dropped when asked if they kept aware of their exertion during the entire session, with an average rating of 3.3 for one player GUI, 3.1 for around player GUI, and 3.0 for ambient GUI. This can be interpreted by the participants being confident to access their exertion data through the GUIs but not willing to focus on them during the intense gameplay.

5.4 Impact on Game Immersion

Most participants did not consider the GUIs as interfering during their game immersion. They commented *"it just depends on what you are focusing on" (P8); or "it did not affect my gaming experience because I didn't need to pay much attention to it while doing exercise" (P5)*. This is supported by the quantitative data (see table 3), where the presence questionnaire generally indicates an overall high level of presence. Some participants reported their appreciation of the "around player" or "ambient" GUI about their flawless integration within the game scene, with 4 participants mentioning this is an advantage of the "around player" GUI, and 2 participants mentioning that the 'ambient' GUI also enhance immersion by influencing their mood during gameplay, where they would wish to make the sky brighter when it is darker with lower heart-rate.

However, it has been pointed out that a break of game immersion can happen when the participants were checking the GUI and trying to understand the data represented. Participants pointed out that after checking the "around player" GUI, they have to *"turn back to face the enemies" (P8)*. Similarly, the "ambient" GUI required some participants to *"deliberately focus on it" (P12)*, and when they focused on the weather, they were *unable to remain as concentrated on throwing the snowball at the same time" (P11)*, which means they can be distracted from the game while checking the GUI.

5.5 Quantitative Results

While our research primarily focuses on qualitative data, we also collected quantitative data to increase the objectivity and provide another layer of the results. Table 3 provides an overview of the quantitative data, including scores from the Presence Questionnaire (out of 60), SUS (out of 100) and the overall rating (out of 10). The results show that all GUIs have high scores in terms of Presence Score and SUS, suggesting all three GUI designs do not significantly impact the game immersion and generally have good usability. The good usability can be also supported by participants' comments

Table 3. Quantitative Results

GUI	Presence	SUS	Overall Rating
On player GUI	54.6	90	8.75
Around player GUI	53.4	85	7.08
Ambient GUI	53.1	84	7.25
P Value	0.77	0.35	**0.03**

in the interview: *"Simple assistance is enough for me to understand how to use [the GUIs]. " (P5)*; *"[The usability] of the three GUIs are similar - all fluent to use." (P4)*. The probability value (P-value) indicates that GUI designs do not lead to any statistically significant changes in presence and usability. As for the overall rating, with the P-value of this data set indicating its statistical significance, the "on player" GUI is most preferred, followed by the "Ambient" GUI, and then the "around player" GUI.

Gathering both qualitative and quantitative results, it can be summarised that the "on player" GUI is generally preferred by the participants due to its comprehensive performance in protecting the game immersion, minimising body movement, being easily understandable, and maintaining the player's awareness. For the other two GUIs, the major issues are the "around player" GUI needs for physical rotation, and the "ambient" GUI can be difficult to understand. Those two GUIs are also not as good at maintaining the player's awareness of their exertion compared with the "on player" GUI. However, the strength of those two GUIs is being integrated well within the game and representing data in an implicit but intuitive way.

6 DISCUSSION

As articulated by our research question, this research aims to gain insights into designing diegetic GUIs for VR exergames to track real-time exertion data. While each of the three GUIs showed some strengths and weaknesses, our focus is to go beyond the GUIs themselves and reflect on the mechanism that led to those different user experiences. Therefore, this section will refer back to the design of those GUIs discussed in part 3 and contrast them with the actual user experience from the study session, to extract implications for future diegetic GUI design.

6.1 Workload of Keeping Track of Exertion

One way that the two key design parameters (namely, position and data representation method) impacted user experience was by affecting the workload involved while the player was tracking their exertion. This aligns with findings from previous work that evaluated diegetic GUIs [31, 49], where an increased perceived workload during game GUI usage can decrease user engagement and the overall experience [13]. To further understand the origin of those extra workloads, we break the workload observed in our study into locating the GUI and understanding the data representation.

6.1.1 Locating the GUI. A diegetic GUI is usually different from a HUD that always stays in the player's FOV. In our prototype, to check the GUI, the player needs to find and bring the GUI into their FOV, and then return to the gameplay after they finished checking it. When we were designing the three GUIs, we expected all behaviours required in the locating process to be subtle and easily manageable. However, it turned out that while the locating process of the "on player" GUI, where the player simply raises their arm or lowers their head, and "ambient" GUI, where no changes of FOV are necessary, was considered convenient, the "around player" GUI, which involves the player rotating, was considered inconvenient to use.

Participants' comments revealed that they could get confused with directions when checking the "around player" GUI. After checking the GUI, it would also require them to spend a few seconds to find and focus back on enemies. This disorientation in a VR environment is also reported in previous studies, often from a lack of self-motion cues such as when using teleport systems [1, 27]. While our prototype doesn't implement a teleportation system, the discrete rotation system that is usually used by VR joysticks by default (for reducing motion sickness) and the vast snowfield environment can result in a lack of self-motion cues as well. Thus, checking the GUI with rotating behaviours can lead to a significantly increased workload because it involves spatial reorientation, which can be challenging in a VR environment. This extra workload is not required in either the "on player" or the "ambient" GUI, which allows the player to focus back on gameplay almost simultaneously.

6.1.2 Understanding the Data Representation. The understanding process of a data representation always involves some cognitive workload. In this study, the explicit representation of data on the "on player" GUI, was found to be the easiest to understand. According to participants' feedback, the reason is partially their familiarity with a smartwatch interface and this data representation method. In contrast, the implicit data representation method, especially in the "ambient" GUI, can result in transient breaks of immersion by requiring the player to pay extra cognitive effort and attention in interpreting the data.

However, some participants still reported they favour the implicit ways in the "around player" and "ambient" GUIs as well for their good integration in the landscape and intuitiveness. One reason that they are not performing as well as the explicit data representation method is the absence of calibration. For example, although the participants understand the ice crystal will get smaller as they exercise, they can forget the original size of it during the intense gameplay. In that case, the meaning of size becomes ambiguous, because they can no longer correlate it with the time that has passed. One solution we propose is adding a reference object as calibration, for example, a pole beside the ice crystal marking the crystal's initial size. In previous studies that apply those implicit data representation methods, such elements are usually used to represent binary states such as whether a goal has been achieved or not [12, 34] with an object's presence. This aligns with the participants' comment that they could easily realise if the ice crystal was gone. To represent more quantitative data with those elements, calibration is needed to enable players to instinctively understand the data represented at a glance.

Another issue of implicit data representation methods as in "around player" and "ambient" GUIs is the learning cost faced by the participants due to unfamiliarity. Although we explained the data representation method before the game sessions, participants did not have enough time to reflect on the interface's meaning during intense gameplay. To address this issue, some participants proposed making GUI changes in a more noticeable or obvious way aligned with changes in the player's exertion data, which would enable the player to contrast their heart rate and the GUI more easily and thus understand its meaning naturally.

6.2 Unobtrusive Design

As discussed in section 3, we attempted to maintain the original gaming experience's immersion by creating unobtrusive GUIs, which are available at players' discretion rather than always staying their FOV. As expected, participants reported high levels of immersion, with no obvious perceived disruptions caused by three different GUIs.

However, we found the unobtrusiveness of these GUIs resulted in ignorance toward them, negatively affecting their effectiveness in conveying exertion data and avoiding overexertion. One reason is the participants generally felt the GUIs were disconnected from the core game task of defending the igloo by throwing snowballs, and were thus not willing to frequently check them. They commented that they may get more interested in checking their exertion data after becoming more familiar with the game or having the opportunity to play it another time. This aligns with findings in previous research [23, 35] where the player's expertise also has an impact on the effectiveness of GUI. This suggests that the intense gameplay, especially for new players, can distract from paying sufficient attention to their physical exertion data in VR exergaming contexts.

While the GUIs are designed to be unobtrusive, it's also important to ensure regular GUI checks to protect the player from overexertion. One approach we suggest is to motivate the player by linking the data displayed more closely with the game task. For example, we could make the snowballs larger as the player's heart rate increases. At the same time, the larger snowball also makes it easier to hit the enemies, which can lower the physical exertion required to control the exertion to a safer level. This would allow players to remain focused on the game while naturally raising their awareness towards their physical exertion. Furthermore, the motivation of checking the GUI may also in turn influence the workload as discussed in the previous session, because the user could gain more proficiency in using the GUI by getting motivated to rapidly check it. In this way, the cognitive workload engaged in the learning process of the GUI would decrease further.

6.3 Limitation

As an exploration into the emerging area of diegetic GUIs for VR exergames, this study inevitably has several limitations. Firstly, while we tried to cover a variety of design possibilities of diegetic elements according to parameters synthesised from design precedents, there is still space for the creation and imagination of new design approaches. Secondly, the smartwatch that the players wear in reality during the study session may strengthen the participants' awareness of the "on player" GUI, potentially resulting in some biases. However, we tried to minimise the participants' perception that they were wearing a real wristband by using a wristband that is light and comfortable to wear. Thirdly, while some participants commented they may be able to get more motivated to check the GUI while they get more familiar with the game, we did not manage to recruit those participants again for a further study to check the impact of player expertise. Finally, while the number of participants (n=12) can be considered sufficient in reaching data saturation in qualitative research [22], which is also the focus of our study, a larger sample size can improve the validity of quantitative results. Despite those limitations, we believe our study has successfully obtained insights into the design of diegetic GUI in this scenario.

7 DESIGN RECOMMENDATIONS

As the key contribution of this research, we synthesised the following design recommendations for diegetic GUIs representing exertion data in VR exergames:

(1) **Strengthen the link between exertion data and the game.** Intense gameplay during exergaming sessions can deter players from actively engaging with the GUI. Linking the exertion data displayed to the game task more directly could motivate the player to check it, even if they are completely immersed in the game. For example, an overly high heart rate may strengthen the player's weapon, which also has the potential to "nudge" the players to control their exertion level [44] to maximise health benefits. Recent research has proposed some "adaptive" exergames [9, 54] which can be a good basis for exploring this concept.

(2) **Avoid spatial reorientation.** Players in a VR environment can easily lose track of their orientation when they are using specific movement methods, especially teleportation and rotating. The reorientation process can be

slow and cognitively heavy. Therefore, the process of checking the GUI should not involve these tasks, which can be a source of distraction from the gameplay. Subtle physical movements like the behaviour of checking their watch do not require a reorientation and are thus regarded as largely not distracting.

(3) **Make the calibration visible.** Implicit ways of representing data, such as using the colour and size of some game objects, can be perceived as intuitive and well-integrated in the game scenario. However, for the data represented in this way, a visible calibration or reference object is needed for the player to understand the meaning of its representation. This does not apply to data representation methods that are inherently calibrated, for example, numbers or standardised charts.

(4) **Provide support in the learning process.** Diegetic GUIs can be relatively unfamiliar to the players which usually requires a learning process. However, during the intense exergame session, the player can struggle to pay sufficient attention to become proficient in using and understanding a GUI. Therefore, designers should either ensure the learning process is sufficiently supported, such as adding an internal tutorial, establishing a natural but strong correlation between the exertion data and visual representation, or designing a GUI with pre-existing familiarities, such as adopting a smartwatch panel similar to the panel of that in reality.

8 CONCLUSION AND FUTURE WORK

This paper presented an exploratory study about how diegetic GUIs showing exertion data in VR exergames should be designed. From background research, we identified the design of diegetic GUIs representing exertion data in VR exergames as a knowledge gap. As the design precedents of diegetic GUI displaying exertion data are still limited in commercial and academic areas, we designed three distinctively different diegetic GUIs providing their exertion data in a custom VR exergame and then took them into a study evaluating their effect on user experience. The study highlighted the importance of considering the perceived workload and the player's motivation to engage with the GUI. Four design guidelines have been formulated as a synthesis of user feedback. We hope the result of the study will be also beneficial for the consideration of diegetic GUI in other VR environments, outside the realm of exergames.

Aside from design recommendations, some future research directions were identified. Firstly, while this study explored the space of a "GUI", future work could open up space for integrating multi-modal feedback, such as sounds or vibrations, which can act as reminders or alerts for players to check their exertion data. This may further strengthen the effect of preventing over-exertion. Secondly, future work could also dive deeper into the details of each design choice, such as which colour is the most suitable for representing each exertion level, or the size of visual elements in each GUI. Finally, aside from providing real-time exertion data during game sessions, another potential direction might be providing a summary of exertion data periodically, or at the end of each session. Future work can make comparisons between the effectiveness and user experience of those different approaches.

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