VRmove: Design Framework for Balancing Enjoyment, Movement and Exertion in VR Games

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Abstract
Since the release of the HTC Vive and Oculus Rift tracking has improved, leading to virtual reality (VR) games that allow players to stand and physically move around virtual environments. Consequently, these VR games can provide players with beneficial levels of exercise. In this paper we provide a design framework for using activity sensor data within VR games called VRmove. This framework was derived from an analyses of data from studies of 18 players over 4 diverse commercial VR games to identify key elements for exertion and enjoyment: actual and perceived exertion – being key for representing the gain from the fun disguising the effort and the multi-factorial element of movement involved. The rationale of this work is to demonstrate the use of the VRmove framework to inform the design of a new game. This work's core contribution is the VRmove framework, which informs the design of future VR games so they are exerting while still being enjoyable.

Author Keywords
Virtual Reality; Exergame; Design Framework; Exercise; HMD-VR; Exertion; Enjoyment

CCS Concepts
• **Human-centered computing → Virtual reality;**

Introduction
Sedentary activities are on the rise as society and modern lifestyles become increasingly digitised [23]. It is recommended that people take regular breaks from sedentary activities to prevent health problems [15]. Regular exercise can also help break up sedentary routines and can provide many health benefits, both physical and cognitive. Previous research has shown that even getting 10 minutes of daily exercise can improve people's physical and cognitive abilities [11], potentially improving work performance [19]. However, for many people, there are barriers to getting regular exercise [16, 6], such as lack of time and motivation.

Virtual reality (VR) games may offer a promising way to harness the motivation that drives people to play games for exercise. As the cost of high quality VR hardware, such as the HTC Vive[1] head mounted display (HMD), are falling, VR games provide an increasingly *accessible* platform. Compared with conventional games on console or PC, which are sedentary, in VR games players move around and interact in the virtual space using their whole body as they play. This avoids the need for specialised and limited function devices, such as exercycles and rowing machines [1]. Recent research has also demonstrated that VR games can provide moderate and vigorous levels of exercise [33, 34]; that is similar to going for a run or playing certain sports.

Beyond the attraction of playing games, VR games can encourage the player to work harder by immersing them within the virtual world [1, 35], thus distracting them from the actual exertion experienced [33]. Despite the demonstrated effectiveness of VR games providing beneficial levels of exertion, there is currently little in the way of guidelines or principles for the design of VR games that promote stand-alone cardio exercises.

In this paper, we contribute a design framework informed by previous work and our own review of existing commercial VR games. We validate this framework by demonstrating its application to the design of a VR exergame we developed. After reflecting on this analysis, we present 4 design guidelines for future work on VR exergames.

Related Work
This section reviews work on using VR games for exercise and how exertion can be detected.

Virtual Reality Games for Exercise
Exergaming is a term that is defined as a combination of video games and physical interaction to ultimately achieve some form of exercise. Exergames usually require some form of external device to capture the player's movement [26, 7], such as depth sensing cameras, dance mats, exercycles and hand-held controllers [24, 21, 9, 18, 20].

An emerging area of exergame research is VR exergames. They have the advantage of being fully-immersive, allowing players to engage with the content facing any direction. Much of the previous work on VR exergames has focused on exercycles [27, 32]. One example used the combination of the VR HMD and exercycle to simulate newspaper delivery [1]. This had less focus on the actual exercise and more on the game elements. Another interesting interaction is the use of a trampoline [30] in a virtual jump game called Jump 'N' Run for the Samsung Gear VR.

Another example use breathing as an interaction to control the growth of a tree by practicing pursed-lip breathing [25]. Similarly, Astrojumper [10] is a stereoscopic virtual reality exergame to engage the players in immersive and full-body

[1] https://www.vive.com

exercise. The game is set in space, with the aim to dodge incoming virtual objects by jumping, ducking and swerving. This study found that exergames have strong potential to motivate physical activity.

One of the problem with the previous examples is that they may be too cumbersome for most people and would require a lot of space. However, VR exergames do not necessarily need to use large and expensive equipment. Research by Tregillus and Folmer [31] demonstrated that sensing steps using an accelerometer can bring the cost down for VR experiences while enabling portability. Another study by Yoo and Kay [35] explored a prototype running-in-place VR exergame made for the Google Cardboard, specifically focusing on its potential as a portable VR exergame experience. What these examples all have in common is that the player can perform physical movement in VR without the need of other external equipment to interact, like exercycles. While these games were designed specifically for exercise, recent work [33, 36] has found that some VR games, which have not necessarily been designed for exercise, can provide high amounts of incidental exertion.

Measuring Exertion
Exertion in exergames can be measured through two aspects: perceived and actual.

Perceived
Perceived exertion in an exergame [12, 33] is commonly measured using the Borg Rating of Perceived Exertion (RPE) scale [2, 3], where users rate how hard exercise was on a 15 level scale (6 to 20). This scale can be mapped (Table 1) to a description of the intensity, along with an estimated heart-rate, by multiplying the level by 10 (for example: 7 * 10 = 70 beats per minute) [3]. Another method is to get users to subjectively rate their workout intensity

Intensity	Max HR (%)	Borg score (RPE)
No exertion	20-39	6-7
Very light	40-59	8-10
Light	60-69	11-12
Moderate	70-79	13-14
Heavy	80-89	15-16
Very heavy	90-99	17-18
Maximum	100	19-20

Table 1: Mapping exercise intensity, heart-rate, Borg intensity, and heart-rate

using a Likert scale, with a score range of 1 - 7 (1 = "not at all intense" to 7 = "extremely intense" [10]).

Actual
Actual physical exertion is commonly measured with wearable heart-rate sensors [11, 14], such as chest or wrist worn devices. The gold standard measurement of exertion is VO^2 max [13, 22, 29]. However, as the player is already wearing a HMD, it may prove to be too cumbersome to wear, affecting their performance, immersion and enjoyment of the game. Consumer devices also give adequate and useful measurements already, making the level of accuracy provided by the VO^2 max measure unnecessary for those simply looking to track their progress.

Study 1 - Commercial VR Games
We conducted studies on four popular commercial VR games from Steam[2] for the HTC Vive head mounted display (HMD). The focus of that work was to explore whether

[2]http://store.steampowered.com

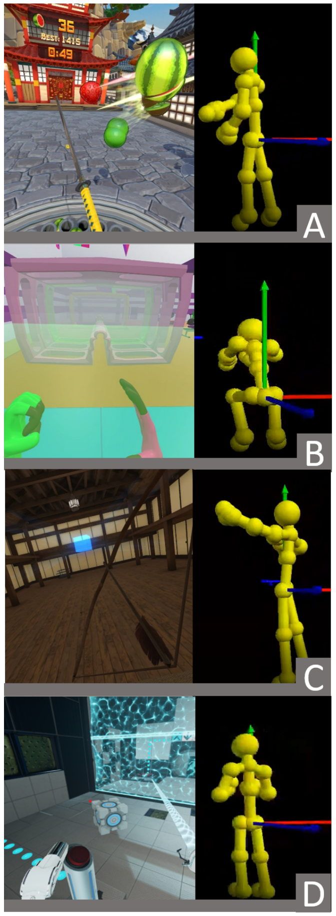

Figure 1: Screen shots and characterisation of the body movement for the 4 games (A) Fruit Ninja - uses arms (B) Hot Squat - squats (C) Holopoint - mainly arms and some ducking and weaving and (D) Portal stories: VR - a baseline of very low movement

players gained significant levels of exertion in these games, which were not explicitly designed as exergames, and to interrogate the fun and playful experience of them.

Game	Arms	Legs	Steps
Holopoint	✓✓	✓✓	✓✓
Fruit Ninja	✓✓✓	✓	
Hot Squat		✓✓✓	
Portal Stories: VR		✓	

Table 2: Physical movement. ✓= Light use; ✓✓= Moderate use; ✓✓✓= Heavy use.

The four commercial VR games were: Fruit Ninja, Hot Squat, Holopoint, and Portal Stories: VR. The VR games were selected based on their popularity and to represent three main body parts being utilised for the interactions: arms, legs, and steps (Table 2). Figure 1 shows screen-shots and indications of the body movement for the selected VR games. Importantly, while these games were not designed as exergames, they are designed so that players need to stand and physically move around during gameplay – making VR games very different from traditional sedentary games. At the very least, the player is standing and this has significant cardiovascular benefits [15, 23, 8].

In this study (ethics approval ID 2016/089) we tested four VR games with 18 participants (female: 5, male: 13), aged between 18 and 36 (mean: 27) in a single session. Three participants had prior experience with VR gaming. Participants were asked to play each VR game for 10 minutes, however they could stop earlier if needed. While playing the VR games, participants were asked to wear a Polar chest heart-rate monitor to measure their actual exertion. After completing each game, the researcher would ask participants to rate their perceived exertion using the Borg scale [3, 2] and enjoyment of the game (Likert scale, from 1, very boring to 7, high enjoyment). Only seven participants played all the games for 10 minutes.

We used the heart-rate measure for two key reasons:

1. It is adequate for a broad classification of exertion, as moderate or vigorous [4].
2. It is widely used on gym equipment and personal tracking by runners assessing their exertion (ie wearables like Fitbit, Pebble, and Polar), fitting our broader goals of sharing exertion measures with users.

Fruit Ninja (Figure 1A) This game involves a lot of ***arm movement*** and is played ***standing in one spot***. The player holds a virtual samurai sword in each hand. Fruit is thrown into the air in front of the player, who must slice as much fruit as possible for around one minute; this is repeated for 10 minutes. For the trials with this game, we used the *arcade* mode to ensure all participants played the game at the same difficulty.

Hot Squat (Figure 1B) Players need to ***stand in one spot*** and duck under incoming barriers by ***squatting*** and ***standing back up*** in between each barrier. As the game progresses, the barriers move faster and the distance between them decreases, gradually forcing players to squat at a faster rate.

Holopoint (Figure 1C) This game involves ***arm movements*** as well as sudden physical whole body movements, like ***ducking or moving fast***, to avoid being hit by an enemy projectile. The player holds a virtual bow in one hand while the other hand draws arrows from behind the player's head. Enemies appear all around the player, making it necessary to continuously turn around to check for enemies behind. The enemies must be shot with the bow and arrow and upon being hit will launch a projectile at the player, which the player must either side-step or duck under to avoid being hit and killed. The enemies appear in waves, which become progressively faster and harder. The goal of the game is to get to the highest wave possible.

Portal Stories: VR (Figure 1D) This is a puzzle game, requiring ***very little physical movement*** as players can teleport to move around the virtual world. The player moves through different rooms, each with their own puzzle. In one hand, the player holds a virtual device which allows them to teleport to any horizontal surface in their line of sight. In the other they hold a device which acts as a 'tractor beam', allowing the player to pull certain objects towards them.

Finding a Factor with Enjoyment

Table 3 shows the summary of each VR game. For each game the dimensions of the analysis were the name of the game, interaction method to play, movement in virtual space, actual and perceived exertion (described in Table 1), enjoyment with standard deviation, and the degrees of view in the virtual space. Now, we will discuss details on what factors could affect the game enjoyment.

Interaction, Movement and Play Angle

We now report on what the analysis revealed about the the interaction types and actual movement by players. All but *Hot Squat* involved at least two different types of movement. While Fruit Ninja ostensibly is about arm movement alone, in practice, the study indicates that people actually stepped back and forth. *Portal stories: VR* was designed to use teleportation to move around the virtual environment. However, most participants (13 of the 18) preferred to walk instead. Interview comments indicate they found walking more natural. This indicated that stand on spot and use teleporting as a interaction methods or single repeated movement might lead to the game enjoyment.

The last column indicates the range of play in terms of player orientation in the virtual space. Fruit Ninja and Hot squat used 180 degrees – easily seen without actually walking or spinning around. By contrast, *Holopoint* and *Portal Stories: VR* used the full 360 degrees. This is important because, the study used a tethered HTC Vive HMD with a *cable*. For 360 degree play, this posed problems, with the cable becoming tangled and getting in the participants' way. This meant that players of *Holopoint* and *Portal Stories: VR* needed to be conscious of the cable and this was a particular problem for *Holopoint* dodging to avoid incoming enemy projectiles and spinning to keep track the enemy location. This problem was different for *Portal Stories: VR* as participants tried to physically walk rather than teleport to solve the puzzle around the virtual space.

Actual and Perceived Exertion

Table 3 shows the actual maximum average exertion experienced by participants in each game. Bearing this in mind, perceived exertion was less than actual exertion (HR) for all but *Hot Squat* which was the opposite, with perceived exertion at heavy and actual exertion as moderate. Meaning the perceived exertion was higher than the actual exertion felt. This game involved only unremitting strength work which has a complex relationship with heart-rate.

Notably participants played all but Hot Squat for their full 10 minutes: only 7 (2 females and 5 males) managed to complete the full 10 minutes for Hot Squat. The participants who played Hot Squat for less than 10 minutes explained their reasons for stopping, which was mainly due to fatigue but also low enjoyment.

Name	Interaction	Movement	Actual Exertion	Perceived Exertion	Enjoyment (SD)	Play Angle
Fruit Ninja	Slice and Cut	Stand on spot, Steps (forward & backward)	Light	Very light	5.5 (± 1.12)	180
Hot Squat	Squatting	Sit up and down	Moderate	Heavy	2.8 (± 1.74)	180
Holopoint	Archery	Dodging, Step side and Spin	Moderate	Light	5.8 (± 0.92)	360
Portal Stories: VR	Teleporting	Stand on spot & Steps	Very light	No exertion	4.2 (± 1.75)	360

Table 3: Game description with game type, interaction methods, actual and perceived exertion (reference from Table 1), enjoyment with stand deviation (Likert scale, from 1, very boring to 7, high enjoyment), and play angle in virtual space.

Holopoint and Fruit Ninja both had a percentage of actual exertion between light and moderate intensity level while their perceived was lower between very light and light intensity. Portal Stories: VR on the other hand, provided very light actual exertion with participants' not feeling any perceived exertion during the gameplay (grey). Lastly, Hot Squat (grey), people felt more exertion than their actual exertion.

The highest enjoyment score was for Holopoint (5.5) and lowest was Hot Squat (2.8) on the 7 Likert scale (1 - very boring and 7 - high enjoyment). Although this is a small set of games, it is striking that game enjoyment was higher for games with the very light to light *perceived exertion*. We describe this as the Goldilocks effect, where VR games that provide just the right amount of exertion, that is not too little and not too much. The games with between 60% - 79% actual exertion and 8 - 12 Borg's perceived exertion were found to be more fun (Table 1). If the exertion is over or less than that it seems to affect the game enjoyment. Somewhat surprisingly, people seemed to actually like to experience a sense of effort from playing VR games.

VRmove Framework

Based on the results of our study, we define a framework called VRmove (Figure 2), which is made up of three different factors which can affect a player's enjoyment while they play VR games: movement, actual, and perceived exertion. Additionally, movement and exertion factors can create a positive or negative effect on a player's enjoyment. For instance, if the game promotes a lot of movement it can distract the player, however, if the focus is on a single movement, players can become bored due to repetitiveness. On the other hand, a lot or heavy movement will only detract from the player's enjoyment as it can cause the player to sweat or become tangled in the cable (if it exists), thus creating a feeling of discomfort.

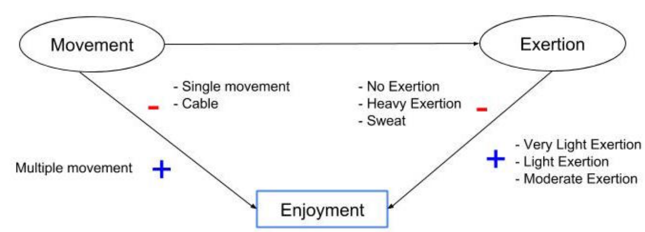

Figure 2: How enjoyment links with the four factors of the VR move framework. Movement and exertion can both positively and negatively impact on enjoyment (+ & -).

Movement
Cable length limits movement during the gameplay for high resolution HMDs that are currently available on the market, such as HTC Vive and Oculus Rift[3]. For the purpose of exercise, VR games released today usually require a lot of movement. In large play areas however, the player's movement is often constricted by being tethered to a computer via a long cable. The cable may not always be an issue for certain games but it could be a problem for safety and can reduce the immersion felt by players as they need to be aware of the cable. This problem may be mitigated in future as HMDs are starting to be released with wireless accessories for cable-free experiences.

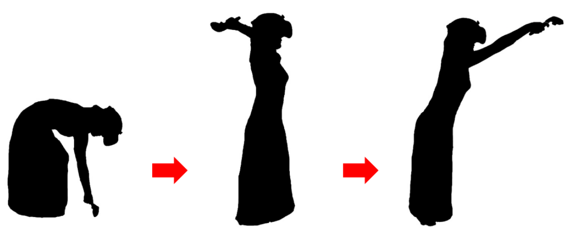

Figure 3: Interaction and movement in Snowballz, players need to pickup a snowball from the ground and throw them at incoming enemies.

Also, VR games with no variation in movements or constricting the player to one type of movement can increase the feeling of exertion and impact negatively on enjoyment. Unnatural movements, such as teleporting, also seem to reduce the feeling of enjoyment.

[3]https://www.oculus.com/

Exertion
We found from our study of the four VR games that VR games with very light to light *perceived exertion* were the most enjoyed. To design VR games for exercise and fun purposes, they should provide between 60% - 79% actual exertion and 8 - 12 Borg's perceived exertion (Table 1). If it is over or less than that it can affect the game enjoyment. People actually like to get some real fatigue from playing VR games.

Game sweat was raised as one of the factor that affected the enjoyment of the participants in the study on commercial VR games. Sweat could affect enjoyment (-) if players get too sweaty as the lenses in the HMD become foggy. For hygiene it is better to use some sort of hygiene eye pad face mask for everyone or use alcohol to wipe the headset after each use. Alternatively, some VR HMD such as Google Daydream can be washed in a washing machine after use.

Applying VRmove framework to the design of a VR game

From the previous section, we presented the VRmove framework to help inform the design of VR exergames with enjoyment. In this section, we will demonstrate the application of the VRmove framework and present our analysis of the VR game we designed and developed, called Snowballz. This game was created in Unity for the HTC Vive HMD.

Design of Snowballz
Snowballz is an arcade-style VR game where the player's goal is to defend their camp-fire base for as long as possible against incoming enemies. To do this, players need to

Figure 4: Overview of Snowballz' main level.

pickup snowballs from the ground and throw them at enemies (Figure 3). Each new wave brings more enemies that move slightly faster, with a boss enemy every ten waves. The game ends when five enemies make it to the camp-fire. Now, we will go through the design based on the four main factors from VRmove framework.

Movement
The movement in Snowballz was informed by study 1, where we found that people enjoyed certain games more if there was more than a single movement required to play (For instance, Holopoint was enjoyed as its interaction consisted of multiple movements). Therefore, Snowballz had three main actions (Figure 3): pick up the snowball, stand up, and then throw it at the enemy. The interaction is open to different play styles by allowing players to throw snowballs in any way they prefer, such as underarm or overarm.

To mitigate problems with the cable, we created Snowballz to have a 180 degree play area. Figure 4 shows the overview of the game. The player location is in the centre of the game environment. Behind the player there is the camp-fire that they need to defend. Enemies only come from the marked yellow area and move towards the player's camp-fire.

Exertion
The gameplay needed to be engaging in order to distract players from actual exertion experienced. Therefore, the game itself was designed so that the exercise would blend into the game seamlessly through the interactions required to achieve the game goals. At the same time, the play requirements need to be easy to understand and make sense [28]. For Snowballz, the design aimed to motivate players to do squats, which uses large muscles and requires exertion, but without making the game having a blatant focus on squats. Rather, squatting is a consequence of needing to pickup snowballs from the ground to throw at enemies.

To reduce the sweat problem, we designed Snowballz in a similar style to tower defence and arcade games, giving the player some respite in between waves. This also helps reduce the chance that the player becomes overexerted, which can potentially cause injury.

Study design
We evaluated Snowballz with 9 participants (3 females and 6 males), aged 21 to 37 (mean: 28). Five reported that they exercised regularly, which the others did not exercise at all. Four had played VR games before. We excluded participants with existing medical conditions that would prohibited them from performing physical activity (based on a pre-study screening questionnaire about susceptibility to motion sickness). The day before the experiment, we advised participants, by email, to avoid heavy eating or drinking an hour before study and to wear comfortable shoes, such as running shoes.

During the study, participants were asked to play for a minimum of ten minutes, but we advised them to stop anytime for any reason. A glass of water and a chair was provided in case anyone needed a break. While they were playing the games, participants wore a heart-rate monitor (Polar H7) so we could collect their heart-rate data, which was stored in an online Polar account. Immediately after finishing the game, participants completed two questionnaires. The first was a Borg scale questionnaire [3, 2], which is the gold standard method for measuring *perceived exertion*. Secondly, participants rated their enjoyment of Snowballz on a Likert scale question, from 1 (very boring) to 7 (very fun). After the questionnaires, we interviewed participants to gain qualitative feedback about their experience with Snowballz. After the study the heart-rate data was downloaded from the Polar website as a csv file (minute by minute data) for us to analyse. We then calculated each participant's average Maximum heart-rate to compare against their Borg score.

Results
The average enjoyment of Snowballz was 4.4 on a Likert scale, which is higher than Portal Stories: VR (4.2) and Hot Squat (2.8).

In regard to the cable, no one raised this as an issue while they played Snowballz, but during the interview, participants suggested that it "*would be better if enemies came from different directions as it would promote whole body movement*".

Movement was quite simple, grab the snowball and throw at incoming enemies, however most participants stood on the spot to do both movements. Therefore even though we used multiple movements, it appears that Snowballz had a higher level of perceived exertion than actual, similar to Hot Squat. This was concurred by participants during the interviews with one suggesting that "*game interaction was very easy to understand but it is kind of boring to grab and throw. It would be much more fun if we needed to go somewhere to pick up the snowballs*".

The average Max heart-rate experienced in Snowballz was 69.61% which indicates *Light* intensity. Perceived Exertion was 13 which is considered *Moderate* intensity according to Table 3. While the game did not over-exert players, their perceived exertion was a lot higher than it actually was, meaning the game was not engaging enough to distract players from the exertion. Snowballz was in the same actual exertion category as Fruit Ninja (light), but perceived was even higher than Holopoint but less than Hot Squat (Moderate). This indicated that, if the perceived exertion is higher than actual exertion, it also could affect the game enjoyment, which is affected by the movement. This could be due to Snowballz having an 8 second pause between each wave, which we implemented with the intention of not overexerting players. However, the wait time was considered too long by most participants, with one commenting that there should be something players can do while they wait, such as "*objects like balloons to practice with, similar to the Longbow VR game*". Such an idea could be combined with power-ups when the player hits enemies, such as score multipliers, which could give players more motivation to keep active between waves.

Design Guidelines

The following is a series of design guidelines that were identified after synthesising the results from the two studies.

Keeping the player engaged. During the game, the player needs to be constantly engaged in order to maintain distraction from the actual exertion felt. Designers should aim to minimise downtime during gameplay, but ensure the player is not overexerted. Rest periods could be integrated into the game naturally by getting the player to do less exerting tasks, such as solving puzzles. This guideline is similar to therapy which utilises VR to distract patients from painful procedures, like bandage changing for burn victims [5, 17].

Exert the player just enough. If it is the goal of the VR game to provide exercise, then the perceived exertion needs to be lower than the actual exertion. If the game provides too much actual exertion, it can impact on player experience - which is the most important factor in order to feel comfortable in the VR game environment. In the end, it all depends on the fitness goals of individual players.

Be hygienic. Playing HMD VR games can make players sweaty after long periods or if the actual exertion is high. To increase comfort and hygiene, players should wear a washable or disposable face mask which absorbs the sweat. This is particularly a problem with shared HMDs and is something that needs to be managed if VR will be incorporated into gym environments in the future.

Sweat could also be reduced by the game tracking the exertion of a player and responding by dynamically adjusting the difficulty or intensity of the game [37]. This could be achieved through heart-rate or sensors.

Make it varied. To keep players engaged the interactions should be varied and enable different play-styles. The game environment itself should give players a sense of progression. Designers should avoid keeping players in the same spot. This could be achieved by giving players a reason to move around, such as collecting resources.

Untethered experiences. VR games that require the player to move around the space in 360 degrees can be affected by cables connected to the HMDs. While this is less of an issue for games that require players to stand in one spot and use only a play angle of 180 degrees, being tethered via a cable can have negative safety and comfort implications. It can also ruin the sense of immersion if the player needs to constantly be aware of a cable. For VR games to truly become a viable platform for exercise, HMDs need to be wireless.

Conclusion

In this work, we defined a design framework called VRmove for balancing exertion in VR games. The framework was derived from the analysis of data from the study of 18 players over four diverse commercial VR games. We validated this framework by applying it to the design and development of a VR game made for exercise. After testing this VR game in a formal user study, we make five design suggestions that can inform the design of future VR games to ensure they provide enough exercise while being fun and engaging.

This work particularly highlights the importance of the Goldilocks effect, where VR games that are made for exercise are designed so that they strike a balance between beneficial levels of exertion, while being engaging enough to distract players from actually feeling it.

Limitations and Future Work

The findings from this work are ultimately limited by the small number of VR games tested (4 commercial and 1 research) and using only the heart-rate measure. Future work will expand on this and test a larger range of VR games along with using a combination of exertion measures, such as breathing, steps, and heat expenditure. However, our work shows that VR designers need to consider not only enjoyment but also the exertion levels their games provide, even if they did not intend on creating an exergame, as this can affect a player's overall enjoyment and experience.

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