Evaluating the Actual and Perceived Exertion Provided by Virtual Reality Games

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Abstract

Virtual Reality games have shown potential to make exercise fun and engaging. This is because many virtual reality games, using devices like the HTC Vive, offer engaging experiences where interaction requires the player to physically move around, moving their arms and body. This paper presents the first work evaluating the *actual* and *perceived* exertion in four existing virtual reality games. Our key contribution is in the insights about the exertion provided by four diverse types of VR games, highlighting their potential value for improving exercise levels. Our work points to the need for standards to classify VR games in terms of both the cardiovascular level and the particular muscle groups.

Author Keywords

Virtual Reality; Exergames; HTC Vive; Exertion

ACM Classification Keywords

H.5.1. [Multimedia Information Systems]: Artificial, augmented, and virtual realities – Miscellaneous.

Introduction

Exercise is important for health and it can reduce the risk of diseases. Authoritative national guidelines [2, 11] recommend exercise at least 2.5 to 5 hours a week. However, many people find it hard to achieve these recommended levels [1, 17]. Exergames offer a

Fruit Ninja VR Players hold a virtual "sword" in each hand to slice fruit that appears in the air. The player attempts to slice as much fruit as possible in one minute. This mode was replayed for 10 minutes.

Hot Squat Barriers move towards the player, who must squat to duck under upcoming barriers and stand between them. Progressively, the distance between barriers decreases and their speed increases.

Holopoint The player fires arrows, using similar movements to real archery. Enemies approach the player from all directions and the player must shoot them. Upon being hit, enemies shoot a projectile at the player who must dodge this.

Portal Stories: VR The player progresses through different rooms, each with their own puzzle to be solved by moving objects around. The player moves using a teleport gun.

Table 1. Overview of the four games.

way to overcome this, because they can be motivating and convenient. The term, exergame, was created to describe the combination of physical exercise and video games [16]. Previous research has demonstrated that exergames have the potential to motivate people to exercise [8], leading to both cognitive [9] and physical health benefits [20]. They can also be an effective tool for rehabilitation, particularly among the elderly [7, 12].

Exergames have been widely used with controllers such as the Wii Remote or through the Microsoft Kinect sensor. However, the games for these devices are not fully-immersive and it can be difficult to follow what is happening on screen, particularly when performing complicated movements, such as dance moves [6]. By contrast, Virtual Reality (VR) is fully-immersive and is becoming a promising tool to overcome the barriers to exercise. It has been demonstrated to motivate and engage sedentary users to exercise [18], increasing their performance.

The HTC Vive platform consists of a head mounted display (HMD) and a pair of controllers that the user holds in their hands. These three objects are tracked in real time, allowing the user to interact with VR experiences through the position and movement of their head and hands. In many games, the player is holding a virtual object, whose location is determined by the position of the controllers in the real world.

Much previous research on VR exergaming has involved exercise machines, such as exercycles for traversing around virtual worlds [3, 10, 18]. Other work has explored running-in-place with activity tracked by a smartphone's accelerometer [21].

Our work aims to address the gap in knowledge about the exercise people *actually* get, and how much they *perceive*, when playing VR exergames. To do this, we conducted a study where 10 people played the 4 diverse games described in Table 1. We asked participants about perceived exertion and measured their heart-rate for actual exertion. We interpret these along with other participant feedback and observations. Together, these provide insights into the potential of VR games as a tool for exercise.

Related Work
Exertion in exergames can be measured in terms of two important aspects: *perceived* and *physical*. Perceived exertion is commonly measured using the Borg Rating of Perceived Exertion (RPE) scale [4, 5], where users rate how hard exercise was on a 16 level scale. This has been mapped to an estimated heart-rate, by multiplying the level by 10 (e.g. 7 * 10 = 70 beats per minute) [4]. A corresponding measure of actual exertion can be captured using heart-rate monitors [9, 10].

There have been informal reports that VR games can provide considerable exertion, even though they may not have been explicitly designed as exergames. For example, in one such report in a Facebook note [19], the author explains how they found HTC Vive games motivating and could be used to exercise quite hard, especially when using weights. Another informal report makes a rather strong claim about weight loss (6.53 kgs in 50 days) exclusively from using VR games to exercise [14]. Ours is the first work to go beyond such informal reports of exertion in VR games.

Figure 1. Screenshots of games: (A) Fruit Ninja, (B) Holopoint and (C) Hot Squat

Study Design

For this study (ethics approval ID 2016/089), we selected four existing VR games from the Steam store that supported the HTC Vive head mounted display (HMD). Three of the games, Fruit Ninja VR, Hot Squat, and Holopoint (shown in Figure 1) require considerable body movement. We chose each game to provide a different form of physical interaction. Table 2 shows this with the number of ticks indicating how much that part of the body is exerted. Broadly, Fruit Ninja involves just arms, Hot Squats, the large leg and gluteal muscles needed to squat and Holopoint has a mix. The fourth game, Portal Stories: VR, was our baseline low exertion condition; it was more of a puzzle game requiring little physical movement.

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

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

Pre-study

We excluded participants with medical conditions that prohibit physical exertion. Participants completed a pre-study questionnaire which asked about physical health, susceptibility to motion sickness, if they do regular exercise and whether they have played exergames.

Session

Each session ran up to one hour. Participants wore a chest strap heart-rate monitor and a HTC Vive HMD while holding the Vive controllers (Figure 2). Each session started with the Vive tutorial for 6.5 minutes, introducing them to VR. Then, each started their first game. The order of the three exertion games (all but Portal Stories) was counter-balanced. Each game was played for at least five minutes to a maximum of ten. (We advised participants to stop if they became tired). After each game, there was a 2 to 10-minute break. In this time, participants did the Borg questionnaire [4, 13], for perceived exertion then explained their score. The last game each participant played was Portal Stories: VR, used as a baseline of low exertion.
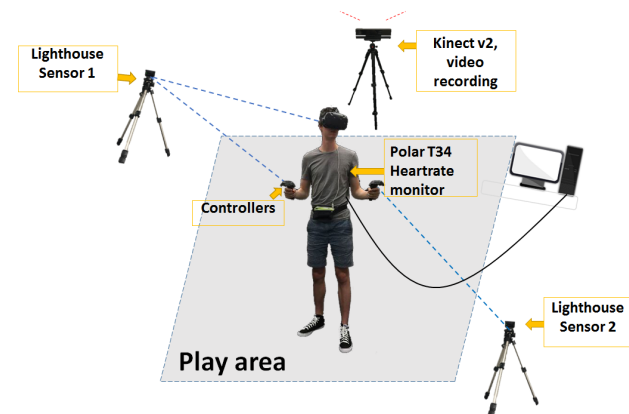

Figure 2. Study setup showing a person wearing the HTC Vive HMD while holding the Vive Controllers. The Kinect was used for video recording.
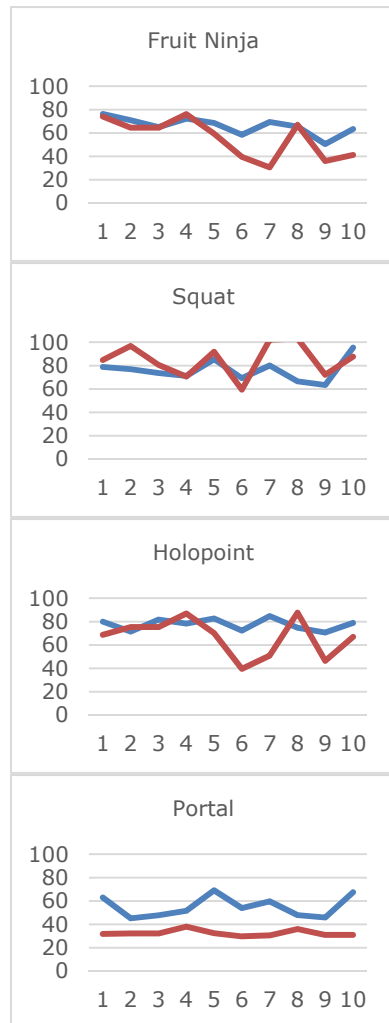
Figure 3. Heart-rate and Borg RPE data charts. Blue line = Heart-rate; Red line = Borg RPE

At the end of the session, participants completed a questionnaire, rating their enjoyment of each game (Likert scale, from 1, very boring, to 7, high enjoyment).

Results

Our ten participants (3 females and 7 males) were aged between 18 to 37. Three exercise weekly, with others not exercising at all. In addition, 5 had used VR before.

Exertion

Table 3 summarises the exertion results, as an average over all the participants, and the standard deviation. The first column shows the average heart-rate as a percentage of the maximum heart-rate, calculated by subtracting the participant's age from 220. We use this measure to make the heart rates comparable across the participants. Next is the Borg average, followed by the average enjoyment rating, and finally the average time spent on each game.

Figure 3 shows the individual data for each participant for each game. The y-axis shows the percentage of the maximum heart-rate in blue and the red line shows the corresponding mapping of the Borg score [4]. The x-axis represents each participant, ordered with P1 to P5 aged between 30 and 36, and P6 to P10 between 18 and 29.

Fruit Ninja's Max heart-rate was equal to light exercise (Table 4), with the average Borg rating 10, indicating lower perceived than actual exertion. Figure 3 shows that this is accounted for by four participants (6, 7, 9, 10). Notably, P7 had the largest gap; they explained

Game	Max HR % (SD)	Borg Score (SD)	Enjoyment (SD)	Time (SD)
Fruit Ninja	66 (±7.01)	10 (±2.99)	5.5 (±0.97)	10:12 (±0:16)
Hot Squat	76 (±9)	16 (±2.74)	2.9 (±2.07)	6:43 (±02:42)
Holopoint	78 (±4.72)	12 (±21.25)	5.6 (±1.07)	10:14 (±00:33)
Portal Stories: VR	55 (±8.58)	6 (±0.42)	4.7 (±1.56)	10:08 (±01:16)

Table 3. Physical and perceived exertion scores for each game with the standard deviation (SD) in brackets. Red indicates the maximum per column.

this rating as follows: "*Fruit did nothing on my arms*" and "*It provided no exertion at all as I did not have to utilize my whole arm*".

Hot Squat has a perceived heart rate of 16, which is considered heavy (Table 4). Its heart-rate percentage was 76, which is moderate intensity (Table 4). This is the only game where participants stopped short of the 10 minutes. Table 3 shows that the average was just under 7 minutes. This is because they were tired. This was due to the particular muscles involved in doing squats, rather than cardio-vascular exertion our heart-rate measures. This is consistent with Figure 3 which shows that 8 participants rated the perceived exertion

Intensity	Max HR %	Borg Score
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
Maximal	100	19 - 20

Table 4. Mapping of intensity classification to heart rate as %-age of maximum heart rate and Borg Score.

higher than the actual measure and P7 and P8 rated it over the 100% score (102%, 103%). Only P6 and 10 rated it lower; notably, they were two of just three participants who played the full 10 minutes in this game. Also, they stated that they thought the game was too simple and saw it as just exercise.

Holopoint's heart-rate measure of 78% is moderate intensity (Table 4). However, the perceived intensity is only 12, which is light intensity, reflecting that this games' perceived intensity due to just the cardio-vascular exertion measured by heart-rate. Additionally, the %-age of maximum heart-rate was quite similar to Hot Squat but Hot Squat's perceived exertion (Borg score) was higher. Furthermore, we observed that participants playing both Holopoint and Hot Squat breathed heavily and were visibly sweating.

Portal Stories had the lowest exertion measures, as expected. The heart-rate maps to very light activity (Table 4) and the Borg score to no exertion. The Figure 3 picture is strikingly different from the other games, with perceived exertion consistently below the actual heart-rate measure. Additionally, a t-test revealed that there is a significant difference.

Enjoyment
We now consider the third column in Table 3. We asked about enjoyment of the games since this is important for interpreting perceived exertion. We expected that people will not perceive exertion as much if they are enjoying the game. All but Hot Squat have similar scores, around 5 on a scale of 7. Hot Squat scored lower, with the greatest standard deviation. One participant enjoyed Hot Squat because he found it good exercise. Another found it rather simple, not making

good use of the VR platform. This reflects the fact that, in Hot Squat, the player stands in one position and obstacles come from one direction, not using Vive for 'room scale'.

By contrast, Holopoint was designed to use every direction of the space and utilized more of the body than the other games in our set. In addition, it provided a good experience with one participant comparing it to *"doing archery in real life but better because it required me to move around and shoot targets in 360 degrees, something that is not possible at a range"* and *"it made me feel like Legolas from Lord of the Rings"*. Another participant explained that they preferred Holopoint over Hot Squat as it *"was more fun and felt like I was in the Matrix. Hot Squat on the other hand was boring"*.

Fruit Ninja was rated highly in terms of enjoyment. Participants enjoyed Fruit Ninja as it had fine grain controls and *"it's got things people can relate to: Fruit Ninja aspect, as some people might think it's cool to be a ninja"*. In addition, participants considered it one of the easiest games to play for someone who is not proficient at playing games.

Two participants (P7, P8) particularly enjoyed Portal Stories: VR for its storytelling and use of environment queues *"it was like the narrator knew exactly my physical presence no matter where I went"*. Another participant commented that *"I think the teleportation thing is pretty awesome"*.

Post-study follow up results
The day after each session we collected feedback from participants by email. Every participant reported they had mild DOMS, delayed onset muscle soreness, in

their gluteal muscles and legs the next day, regardless of whether they regularly exercised. In addition, all participants said that they enjoyed the experience overall, such as one participant who said that it "*encourages people like me to do some exercise*".

Gameplay
In Holopoint, every participant was bothered by the HMD cable, *"Holopoint was a fun game but the cables often got in my way"*. This cable was also disconnected twice when participants became entangled. This was not a problem for Hot Squat, where the cable ran down the participant's back while they were squatting; some mentioned this, indicating it was as slightly distracting and affected the feeling of immersion.

Motion Sickness
Only one participant (P2) who experienced motion sickness in each game. P2 had no VR experience. This did not impact the time they spent in each game, however he later mentioned he tend to suffer from claustrophobia. This suggests future studies should use this as an exclusion criterion.

Implications
There are three main implications from this work.

 (1) If VR games are engaging like Portal, then the perceived exertion may be low compared with the actual exertion, and there is still some physical exercise benefit.

(2) Existing VR games can provide enough exertion to be considered exercise, as Fruit Ninja's Borg score is comparable to walking, while Hot Squat's to running, and Holopoint to dancing [5].

(3) It would be valuable to establish exercise ratings for VR games, based on studies like ours which used heart-rate as an objective measure of cardio-vascular exertion, along with coding the forms of exertion in terms of muscle groups, as we did in Table 2.

We note that these games could easily be made more challenging if people wore weights. It may also be valuable to use heart-rate measures to enable people to see their actual exertion levels. This is an interesting future direction to explore.

Conclusion and Future Work
In this paper, we reported the first systematic exploration of the potential of the emerging class of VR games for providing exercise. We conducted a laboratory study evaluating four existing HTC Vive games with 10 participants, measuring *perceived* and *actual* exertion levels. The results from this study point towards VR being able to deliver enough exertion to be considered exercise. In addition, we chose games with diverse exertion demands. This suggests that an important future direction is provide standardized exercise gradings for the growing body of VR games so people know what interactions and muscle groups are involved, how much exertion they can expect, and how make their games a valuable part of their broader physical activity.

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