Towards Player Adaptivity in Mobile Exergames

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Abstract. Exergames require obtaining or computing information regarding the players' physical activity and context. Additionally, ensuring that the players are assigned challenges that are adequate to their physical ability, safe and adapted for the current context (both physical and spatial) is also important, as it can improve both the gaming experience and the outcomes of the exercise. However, the impact adaptivity has in the specific case of virtual reality exergames still has not been researched in depth. In this paper, we present a virtual reality exergame and an experimental design aiming to compare the players' experience when playing both adaptive and regular versions of the game.

Keywords: Exergames · Adaptivity · Virtual reality · Mobile
Game development · Pervasive games

1 Introduction

Exergames (games that promote some form of physical exercise in the gameplay) require obtaining or computing information regarding the players' physical activity and, often, current location and context. Additionally, ensuring that the players are assigned challenges that are adequate to their physical ability, safe and adapted for the current context (both physical and spatial) is also important, as it can improve both the gaming experience and the outcomes of the exercise. So, the relevant information gathering of both player and context proves to be useful in determining the performance of the former in the latter. There are some models that combine the challenge's difficulty and the player's skill, for both regular games and, more recently, exergames, the Game Flow Model [32] or the Dual Flow Model [27] respectively.

However, determining the actual impact and player perception of adaptivity in virtual reality exergames is different as the level of immersion of the experience is distinct from that of traditional games.

Our work, presented in this paper, aims to provide insights into how to develop a workflow towards adaptivity for mobile virtual reality exergames. We present two versions of the same game, both authored via a custom tool, one with fixed difficulty and another adaptive and propose a comparison between them in regards of player

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performance, physical exertion levels as well as immersion and tiredness perception. Our proposed methodology allows for a comparison between non-adaptive and adaptive gameplay sessions, helping game designers in understanding the impacts and adequacy of the difficulty and strain their exergames and their player profiles may cause.

2 Player Adaptivity

An adaptive game [10, 21] has been defined, as a type of games that recognize player input and are able to adequately change their behavior (be it gameplay mechanics or game elements [4, 20]) so as to ensure a better experience.

As such, this methodology can be applied to different games, such as exergames [26] or health games [12, 28], mobile games [8] and others, entertainment or otherwise [20].

The importance of game adaptivity in location-based games and exergames was also explained in [17], as a means to overcome the issues these types of games commonly present.

Adaptivity plays an important role in this work as it will cover the part of the solution where the game will dynamically change itself in order to better accommodate the current player's status.

3 User Profiling

The creation of player profiles to drive the adaptation of a game's behavior is not recent. There is a patent dated from as early as 1997 that claims "A method of adaptive computer game play based on profiling" [3]. Furthermore, the relation between player personality types and game behavior has also been explored with positive results, identifying personality types with actions in games [31] and vice versa, presenting a relationship between demographics, game preferences and in-game behavior [19].

Player-centered game-design also benefits by the ability of correctly profiling users and their interests [10], be it to dynamically adapt the game to the player's preferences or to create a game that appeases to the tastes of a generic user profile. User profiling can be used as a basis for adaptivity, by matching a player's behavior to the closest profile that fits, and treating the player as having that profile and game preferences.

User profiling can contribute towards player adaptivity, as it helps identifying the type of player and adequate challenges to them. Since location-based exergames have several dynamic game conditions, such as the player's physical state or the location the game is being played at, these variables, that may better define the context for adaptivity purposes, are not considered when adapting a game solely through user profiling techniques.

4 Exergames and Serious Games

Exergames have been popularized by the Nintendo Wii and PlayStation Eye. However, exergaming can be traced back to the 1980's, through the Nintendo accessory, the

PowerPad, and was also present in the 1990's via Konami's Dance Dance Revolution [33]. Studies have shown how these games are more physically intensive than regular videogames and positively impact the user's health [29, 34]. Although many of these games focus on being fun, mainly those sold by the entertainment industry, there are many with other goals, such as rehabilitation and health maintenance. These are called serious games, as they are games whose main focus is not entertainment.

Serious exergames are used, primarily as training, maintenance or rehabilitation tools [33].

A large number of rehabilitation games appeared as rehabilitation tools, thanks to the availability of the Nintendo Wii and Wii Fit. These studies have shown, from an early start, that these games could be useful in therapeutic scenarios [30], and even how they could be useful in the areas of prognosis and treatment of physical disabilities [22] such as Cerebral Palsy [15] and Parkinson [2, 28]. Even in scenarios where the goal is to treat psychological ailments, exergames show their potential [24].

Training exergame-based tools, such as the Online-Gym show the feasibility [9] of creating a virtual environment where physically remote people may interact and perform exercises virtually side by side. Balance and fall-prevention exergames have also shown positive results. A study of static balance assessment in patients suffering from chronic stroke showed that participants that used the Wii-Fit performed better than those training only with conventional methods, even after three months [16]. Other studies with an elderly population showed how these games can potentially improve balance, particularly as they allow the patients to practice safely in their homes [1, 5].

The potential benefits of serious exergames is widely recognized in many areas of application. These exergames could also benefit from adaptation and player-specific profiles to potentially tailor and adequate their mechanics and goals to the player's physical condition and whereabouts.

5 Context-Aware Exergames

Context-aware exergames are defined by being exergames that have some awareness, via sensors or remote services, of data or information that is relevant to their goals and challenges [14], being similar to a context-aware application or service in that regard [25].

Unlike many exergames, these context-aware games monitor services and sensors to ensure the player is being challenged in a way that blends with the current context. Usually through GPS, heart rate and accelerometer sensors, the game can be aware of the player's physical condition. Mobile phone's camera and location services' APIs can provide the application with some information regarding the surroundings of the player [8, 13].

This context awareness can be used to not only improve the gaming experience itself [26], but the quality of measurements, such as more accurately calculating the expended energy in a gaming session [23].

The players of these games could potentially benefit from adaptivity. However, these games are currently very limited as to how aware they are of the player's surroundings and how they can take into account the geo-information and adapt the game's challenges and goals with it.

6 Estimating Player Effort

There are several methods for calculating and estimating a person's gait, expended energy and effort. In the context of this work, we focused on Eqs. 1 to 3, used for calculating the players' effort. The reasoning behind this is two-fold: not only are these equations well known, they also rely on the parameters of Age (A), Resting Heart Rate (RHR) and Current Heart Rate (CHR), which are easily acquirable.

So, by using the Haskell equation for calculating the Maximum Heart Rate [11]

$$MHR(A) = 220 - A \tag{1}$$

and Karnoven's Heart Rate Reserve formula [18]

$$HRR(MHR, RHR) = MHR - RHR \tag{2}$$

it is possible to determine the current intensity of the physical exercise using the Karvonen method [18]

$$E(CHR, RHR, HRR) = \frac{CHR - RHR}{HRR}. \tag{3}$$

An effort value of 0, when the current heart rate is the same as that of the resting heart rate, means that the person can be considered to be rested. Conversely, an effort of 1 is attained when the person's heart is performing at the theoretical maximum. As the above formula shows, effort values vary linearly with the CurrentHR (as the RestingHR and HRReserve are considered constants, even though they can vary from person to person).

7 Grappher – A Node-Based Editor for Pervasive Games

A traditional issue with the creation of adaptive, mobile exergames is the constant need of tweaking, reparametrizing, deploying and testing the game with different players in order to collect data and restart this cycle. The possibility of applying a RAD (Rapid Application Development) philosophy is of interest to the area of adaptive game development as it could allow designers to focus on testing and readjusting the game as quickly as possible, avoiding the need of redeploying and restarting the game.

Grappher is a Unity3D editor plugin that allows for a game designer to quickly parametrize a game's setting via a node-based editor. The user can choose different sources of data (sensors, web-services, game parameters or functions, Grappher parameters, etc.) or program his/her own (see Fig. 1.). Any graph created in Grappher is stored in a remote server, and can be reused in other graphs.

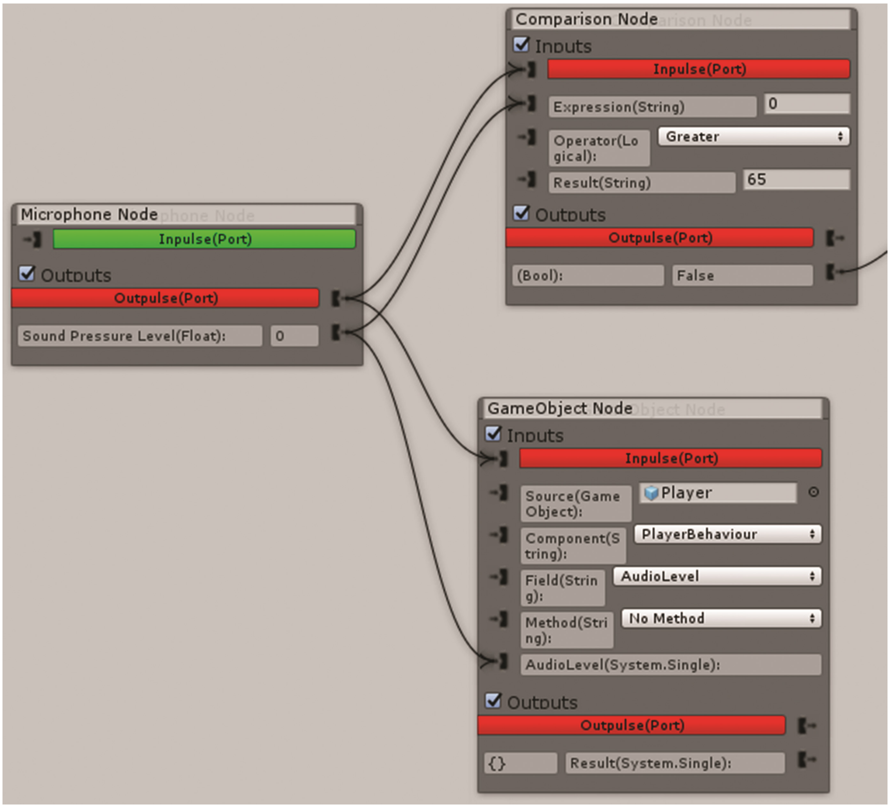

Fig. 1. Depiction of a graph with three nodes (a sensor, a component and a comparison node) in Grappher.

Any saved graph can be loaded via the Grappher Loader component (see Fig. 2). Additionally, this component allows the developer to specify when the graph should be

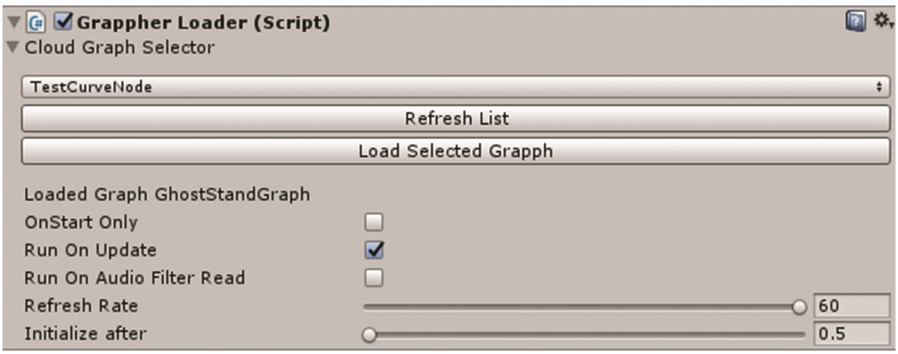

Fig. 2. Grappher Loader Component in Unity3D.

executed (if continuously, only once, or on a certain event), as well as how frequently should the application check for a new version of this graph. This allows for a deployed game, using these graphs, to be reparametrized remotely, as it will automatically update to the latest version of every graph (if possible) during runtime. This can, ultimately, remove the need to redeploy or repackage the application, and incentives developers to tweak and test the game with minimal effort.

8 User Study

In order to assess the impacts that the use of Grappher may have regarding player adaptivity it would be necessary to compare the players' experience of playing a game that can be both adaptive and non-adaptive. As such, it was necessary to develop such a game and to expose its mechanics so as to parametrize them to either be adaptive (depending on several factors) or not. In this paper, we present GhostStand, a mobile virtual reality exergame that allows us to test the impact that player adaptivity may have in the experience of playing this type of games.

8.1 GhostStand – A Mobile Virtual Reality Exergame

The GhostStand game is a VR (Virtual Reality) First Person Exergame where the player must fend off enemy ghosts from his/her position, using a sword.

In the real world, the user is equipped with a mobile head mounted display (HMD), headphones, a smartwatch and a mock sword as per Fig. 3. The game requires the player to be alert as the ghosts can come from different directions. Interactions are limited to looking around (3 degrees of freedom) and swinging the sword (3 degrees of freedom) at the incoming enemies.

Fig. 3. User playing GhostStand with a Mobile HMD, Headphones, Smartwatch and Sword.

As Fig. 4 shows, a dark and gloomy atmosphere characterizes the game from an early start. This was to help minimize possible problems with immersion or discomfort, as with current mobile VR technology it is not uncommon for the space between pixels to be visible to the naked eye. So, a darker image helps in masking this effect.

Fig. 4. Concept art for the GhostStand game.

The game has the following characters and items:

- **Ghosts**: the enemies in the game. They are attracted to the player and will attempt to kill him.
- **Pillars of Light**: four of these structures are present in the scene. They serve two purposes. To serve as beacons, making the orientation of the player relative to them an easier task, and as a spawn location for the Ghosts.
- **Restless Samurai Spirit**: the player embodies this character, a spirit continuously tormented by the Ghosts.
- **Spirit Sword**: the player's character wields a sword capable of defeating the incoming Ghosts. It can be used defensively, by blocking the Ghosts' attempts to harm the player or by shoving them away, or offensively, by violently hitting the Ghosts, banishing them definitely.
- **Gloomy Moon**: A big, dark moon rests low and centered between the four Pillars of Light. It serves no purpose, other than providing ambiance and as a very specific point of reference to the player, as it is used for the calibration process of the sword.

These game elements behave in accordance to the following mechanics:

Pillars of Light:

- Spawn Ghosts at certain intervals
- Spawned Ghosts share the same characteristics, within parametrized limits (speed, hit speed resistance and time to live)

Ghosts:

- Have varied maximum speeds, resistance (the minimum sword swinging speed they must be hit at in order to die) and a time-to-live of 40 s.
- Will attempt to converge at the Player's position. They will gravitate towards the player, from their own spawn points. However, they are susceptible to bumping

against the ground, each other, the Player, and the sword, meaning that their initial straight trajectory can become curved or elliptical.
- Cast a red shadow on the platform the Player's avatar is at, making it easier to guess their distance and position.
- When bumping against the player, will remove one point from the player's life points pool.
- When hit, will either flash in a red color and move away from the player, if the speed it was hit was less than their resistance, or, if said speed is greater than their threshold, they will instantly die.

Player:

- Can freely look around.
- Can move the sword around by moving his/her right hand around the three axes (the player cannot, however, thrust the sword forward).
- Can block Ghosts from attacking, by placing the sword between the ghosts and himself/herself.
- Can push away Ghosts by swinging or flicking the sword gently.
- Can kill Ghosts by hitting them with great arm speed.
- Is awarded points based on the speed at which each Ghost was killed.
- Can die when player life points pool reaches zero points, from an initial 100 points.
- Can re-align his/her field of view with the sword by looking at the Gloomy Moon, placing his/her right hand on the chest and, with the left hand, touching the Smartwatches display. A small vibration is felt on the wrist, indicating that the calibration process was concluded.

The Fig. 5 shows a perspective view of the game, in design time. The player is standing between the four pillars of light. Since the player does not know from where the next enemy spawned will be coming from, he/she must periodically look around at the pillars of light.

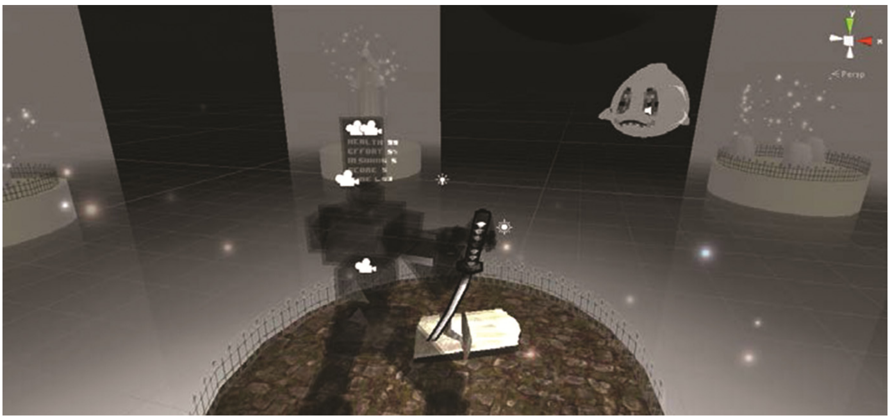

Fig. 5. Third person view of the game in design time.

The player's avatar body is translucent, so as to give the player the ability to see his/her avatar's body, in first person, but without intruding too much on the game itself. Also noticeable (Fig. 5) is that the avatar's arms and wrists follow the swords orientation. This is thanks to the avatar being fully rigged as a humanoid, allowing for the game engine's (Unity3D) inverse kinematic features to be used, fully. As such, as the player moves the wrist around, so do the avatar's hands, arms and shoulders, further enhancing the player's experience. The size of the platform the player is standing at is roughly the same length of that of the sword. This means that whenever the ghosts cast their red shadow on the platform, they will most likely be in range of the player's sword.

The Fig. 6 is representative of what the players see when experiencing the Ghost-Stand game. In this particular screenshot, in Fig. 6, the player did not have the sword within view. The game's UI present in this screenshot is meant for debugging only and was changed for the experimental setup, by removing "Effort", "Maximum Swing Speed" and "Time Left" from it, and leaving only "Health" and "Score" for the player to see.

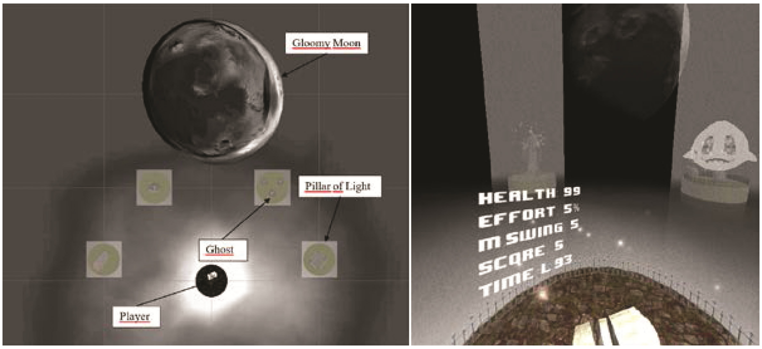

Fig. 6. Layout of a level in ghostStand (Left). In-game screenshot (Right).

A slight vignette effect and monochromatic noise were added to each individual camera image, better hiding the current limitations of the smartphone-based head-mounted displays used, as they usually have very big, visible pixels and the dark space between them is often also noticeable. Sound effects for ghost spawning, dying, and hitting the player were added, as well as for the sword swinging and hitting the ghosts. An eerie music with random sound effects (such as heavy breathing, maniacal laughter and storm brewing) was added in order to muffle external sounds and enhance the experience and immersion levels.

9 Experimental Setup

To ascertain the impact of player adaptivity in GhostStand, two game versions were designed using Grappher: a non-adaptive and an adaptive one. Both feature the same game elements, albeit with different parametrizations.

– **Non-adaptive version** (Fig. 7): This version defines a constant spawn interval (15 s) between each ghost. One of the four possible spawning locations is chosen randomly.

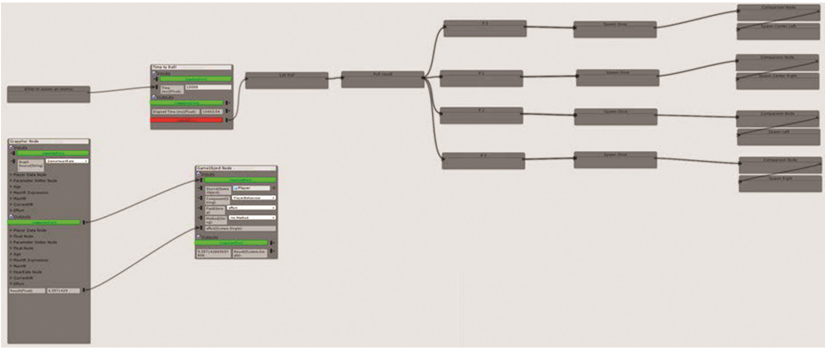

Fig. 7. Graph of the non-adaptive version. The split between four possible spawn locations is visible. The lower part (a distinct sub-graph) is responsible for computing the player's effort.

– **Adaptive version** (Fig. 8): The adaptive version of the game considers the player's Effort (presented in the section Estimating Player Effort of this paper) and uses a custom function to calculate a spawn interval, depicted in Fig. 9.

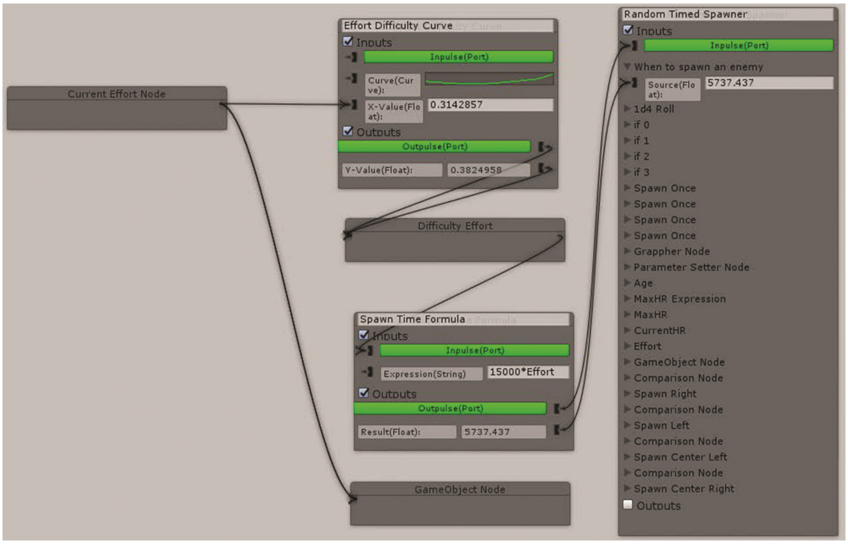

Fig. 8. Graph of the adaptive version. The non-adaptive configuration (rightmost node) is reused and reparametrized to become adaptive.

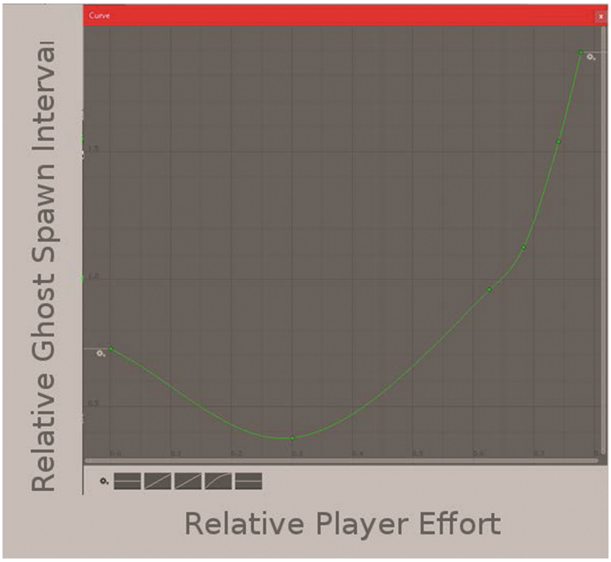

Fig. 9. Function defining the relation between player effort and spawning interval (relative values).

The adaptivity function, $f(Effort)$, allows for calculating the ghost spawn interval, depending on the current effort reading. The function's domain (0 to 1) represents the effort percentage from 0% (at rest) to 100% (maximum theoretical physical strain). Its range represents the coefficient to be multiplied by the non-adaptive ghost spawning interval of 15 s. So, the actual ghost spawning interval in the game is, at each moment, calculated by the following expression.

$$GhostSpawnInterval(s) = 15 \times f(Effort). \tag{4}$$

The Fig. 9 shows that the relative spawning interval of ghosts decreases (from an initial value of 0.7) as the player starts performing more exercise, up until approximately 0.3 (30%) of effort (at which point, it has a value of 0.4). Afterwards, the spawning interval increases steadily up until 70% effort (value of 1, approximately) accelerating past a value of 1.8 of relative spawning interval past that.

The idea behind the exemplified adaptivity function is multifold:

- The game has an initial warming-up phase, where the game's pace accelerates as the player's effort increases, well beyond that of the non-adaptive version.
- It defines an optimal player effort of about 30%. Any value above it and the game will decrease its pace.
- If the player pushes beyond this, progressively being more strained, the game will reduce the ghost's spawn rate concomitantly. This is meant to serve as a means of both ensuring the player's safety (as the game will not require the user to maintain the current degree of physical effort).

The experiment itself was designed for indoors, limiting the amount of possible external factors. As such, a sound lab available at the facilities was used, as it had sound insulation and controlled lighting.

The following list details the equipment required for the user to play the game, visible in Fig. 10:

- A BoboVR Z3 mobile HMD case for the mobile phone to be placed in it
- A OnePlus One smartphone, running Android 6.0.1
- A LG Watch R smartwatch, running Android 6.0.1
- A wired stereo headset
- A lightweight plastic "sword", designed to add heft to the players' arm movement

Fig. 10. Equipment used in the GhostStand experiment.

Both a questionnaire and informed consent form were created. The questionnaire is meant to provide insight about player perception of the game and how it may correlate with data from the player's gameplay session. The Informed Consent Form was needed to inform the players of potential health hazards (motion sickness, malaise, fatigue or injuries).

The questionnaire was based on the Game Engagement Questionnaire [6] and on an adaptive exergame master thesis questionnaire [7]. The GEQ questions provide insight into the psychological state and general gaming experience of the players, useful for determining if the players did enter a state of flow, boredom or stress, while the other questions are specifically tailored for exergames, useful in evaluating the physical state the player was in during gameplay.

10 Conclusion

This paper presented a study into the importance and impact player adaptivity may have in virtual reality exergames, a relatively novel type of games. We have presented Ghost-Stand, a VR mobile exergame with adaptive game challenges that asks its players to strike down ghosts by moving their arms in the real world. Our methodology for determining the potential benefits of adaptivity in this genre of games was to create two versions of GhostStand, using our tool Grappher, one with no adaptivity and another where the player's age and heart rate play an important role in deciding the pace of the game. We do not claim that the adaptivity profile used in the GhostStand adaptive version is ideal, as other variables could also be added to it (swing speed, hit rate, life remaining, etc.). However, in order to determine if there are differences between an adaptive and non-adaptive version of the same game, these would be unnecessary. The preliminary results suggest that, much like their classic brethren, VR exergames do benefit from adaptivity, ensuring that the player is motivated to be physically pushed all the while ensuring that the player is not risking harm. Additionally, in the particular case of virtual reality games, ensuring that these mechanisms do not break the immersion of the virtual reality experience is also of interest. Further testing GhostStand with improved and varied adaptivity profiles, as well as testing other games, the addition of new variables and frameworks for supporting the easier creation of adaptivity profiles for these types of games are also part of our future line of research.

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