Physical Activity Motivating Games: Be Active and Get Your Own Reward

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People's daily lives have become increasingly sedentary, with extended periods of time being spent in front of a host of electronic screens for learning, work, and entertainment. We present research into the use of an adaptive persuasive technology, which introduces bursts of physical activity into a traditionally sedentary activity: computer game playing. Our game design approach leverages the playfulness and addictive nature of computer games to motivate players to engage in mild physical activity. The design allows players to gain virtual in-game rewards in return for performing real physical activity captured by sensory devices. This article presents a two-stage analysis of the activity-motivating game design approach applied to a prototype game. Initially, we detail the overall acceptance of active games discovered when trialing the technology with 135 young players. Results showed that players performed more activity without negatively affecting their perceived enjoyment of the playing experience. The analysis did discover, however, a lack of balance between the amounts of physical activity carried out by players with various gaming skills, which prompted a subsequent investigation into adaptive techniques for balancing the amount of physical activity performed by players. An evaluation of additional 90 players showed that adaptive techniques successfully overcame the gaming skills dependence and achieved more balanced activity levels. Overall, this work positions activity-motivating games as an approach that can potentially change the way players interact with computer games and lead to healthier lifestyles.

Categories and Subject Descriptors: H.1.2 [**Models and Principles**]: User/Machine Systems—*Human factors*; I.2.1 [**Applications and Expert Systems**]: Games

General Terms: Design, Experimentation, Human Factors

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1. INTRODUCTION

One of the key reasons for the increasing obesity epidemic is positive energy balance, that is, the condition where one's energy intake exceeds one's energy expenditure [Vandewater et al. 2004]. While a high energy intake is primarily explained by unbalanced diet and increased caloric consumption, low energy expenditure is explained by an increasingly inactive lifestyle: little physical activity (e.g., walking, sport, exercising) and much sedentary activity (e.g., watching TV, playing computer games, traveling by car).

The very nature of sedentary activity is often addictive and self-reinforcing [Koezuka et al. 2006]. Hence, enticing people to adjust their energy balance by explicitly reducing sedentary activities or replacing them with active ones is challenging. Acknowledging this, we set out to introduce complementary physical activity into a normally sedentary activity, playing computer games. This approach is novel in that it leverages the enjoyable properties of playing to alter the nature of the activity and include bursts of physical activity rather than seeking to reduce the time spent gaming. Our approach encourages players to perform certain physical activity in order to increase their chances of success in a game by gaining in-game rewards.

Unlike the Nintendo Wii and other commercial active game consoles, which primarily facilitate exercising through gaming, our design approach aims to motivate the performance of physical activity. Our design can be applied to a wide variety of games, in which a player and/or game tasks are represented by quantifiable features, such as time limit, energy, skills, ammunition, or speed. The only alteration to the game is the facilitation of earning virtual in-game rewards relating to these quantifiable features in return for performing physical activity [Berkovsky et al. 2010b]. The players are motivated to perform physical activity by (1) modifying the game, such that certain game features are reinforced by the rewards, (2) making the players aware of the possibility of gaining the in-game rewards in return for performing the activity, and (3) equipping the players with external interface instantaneously capturing the performed activity and converting it into the rewards. This game design approach is referred to in the rest of this article as the PLAY, MATE! (PhysicaL ActivitY MotivATing gamEs) design.

This work presents and evaluates an application of the PLAY, MATE! design to a publicly available open-source game called Neverball[1]. Neverball is a time- and goal-based navigation game, in which players collect sufficient coins in a limited period of time. To apply the PLAY, MATE! design to Neverball, a time-based reward system was put in place, such that players were awarded extra time in return for performing a specific physical activity, in this case; on-the-spot jumps. Players were equipped with a triaxial accelerometer configured to recognize jump events, such that for every captured jump players gained the extra time to collect coins and complete the game tasks. Players were motivated to perform the physical activity by reducing the time allocated to accomplish the game levels.

Our first evaluation involved 135 young players. The evaluation ascertained that applying the PLAY, MATE! design increased the amount of physical activity performed while playing and changed the distribution between sedentary and active playing time. Players accurately perceived the amount of performed activity, but did not report a decrease in the perceived enjoyment of playing. The variability in the amount of activity performed was discovered to be dependent on the players' gaming abilities, as players with lower gaming skills performed more activity than players with higher gaming skills. We addressed this shortcoming by developing two techniques for an adaptive application of the PLAY, MATE! design, which tailor the in-game rewards

[1] http://www.neverball.org

obtained by players and personalize the difficulty of Neverball tasks according to the player's observed gaming skills. Our second evaluation involved additional 90 players and showed that the adaptation of the rewards and the personalization of the game difficulty increased the amount of activity performed, balanced the amount of activity performed by players of varying gaming skills, and increased the difficulty of easy game tasks. We also conducted a questionnaire amongst 117 adults, which showed their positive attitude towards the PLAY, MATE! design.

The contributions of this work are threefold. First, we propose the PLAY, MATE! design for computer games that motivate physical activity, apply the design to Neverball, and demonstrate its acceptance in terms of the physical activity performed and the perceived enjoyment of playing. Second, we propose two adaptive techniques for player-dependent application of the PLAY, MATE! design and evaluate their effect on the acceptance of the design. Third, present the application of the design to a new mobile game, *Run, Tradie, Run!*, which will be launched through the App Store and will facilitate future large-scale evaluations in native playing environment and initiate the dissemination of activity-motivating games. In combination, these contributions demonstrate the potential of activity-motivating games in changing the interaction of players with computer games and call for future research on seamless integration of the design into as wide as possible variety of games.

The rest of this article is structured as follows. Section 2 surveys related work on activity-motivating technologies and games. Section 3 presents the principles of the PLAY, MATE! design approach and exemplifies its application to Neverball. Section 4 presents the first evaluation of the activity- and enjoyment-based acceptance of the PLAY, MATE! design. Section 5 discusses the observed dependence between the acceptance of the game and player characteristics. Section 6 outlines the adaptive techniques for application of the PLAY, MATE! design. Section 7 presents the second evaluation of the adaptive techniques. Section 8 presents the evaluation of the acceptance of the PLAY, MATE! design by adults. Section 9 discusses the identified limitations of this work and the ways to overcome these in a new *Run, Tradie, Run!* game. Finally, Section 10 concludes the work and outlines future research directions.

2. RELATED WORK

Information technology solutions to the obesity problem have been studied from various angles. Several works focused just on the design issues of health- and lifestyle-related applications, while others report on their implementation and deployment. Theory-driven design approaches for technologies that support behavioral change were proposed by Consolvo et al. [2009]. Design principles applicable for technologies that motivate the performance of physical activity were discussed in Consolvo et al. [2006]. Specifically, game design principles applicable to fitness promotion applications were discussed in Campbell et al. [2008]. Multiple practical applications overviewed below followed these design principles.

Many applications take a persuasive approach to combating the obesity problem and influencing user behavior [Bogost 2007; Fogg 2003]. ViTo is a home entertainment system remote control that promotes a reduction in TV viewing time and an increase in nonsedentary activities [Nawyn et al. 2006]. Fish'n'Steps is a social application logging the users' physical activity and linking it to the growth and activity of a virtual fish [Lin et al. 2006]. Chick Clique is a mobile application also logging the users' physical activity and sending persuasive text messages encouraging further exercising [Toscos et al. 2006]. In the latter two cases, the activity of the users is quantified by the number of steps captured by a pedometer and then manually fed into the system, which was often found unreliable and inaccurate [Valanou et al. 2006]. UbiFit Garden is a mobile system that captures the users' physical activity, automatically processes it to infer activities like walking, running, and biking, and link the amount of performed activity to the growth of a virtual garden on the mobile phone's screen [Consolvo et al. 2008]. The lifestyle change promoted by the application was found to be often accepted by already motivated users and resisted by others. Similar results were observed in [Zhu 2007], which noted that out of a plethora of surveyed Web-based activity-motivating applications, only two led to a short-term influence in promoting physical activity. In contrast, the PLAY, MATE! design does not rely on external motivational factors, but rather leverages the existing engagement with games to motivate players to perform physical activity.

2.1 Research Prototypes

Several works investigated the practical integration of physical activity into computer games. NEAT-o-Game is an active game, in which a player's activity was captured by an accelerometer and affected the speed of the game character in a race-like interface [Fujiki et al. 2008]. A virtual boxing game developed by Masuko and Hoshino exploits image processing and heart rate monitoring technologies to control the level of player's exercising [Masuko and Hoshino 2006]. GeoKaos and Flareqoor are two arcade games exploiting motion and physiological sensors to adjust the intensity of exercising [Buttussi et al. 2007]. These games were designed as research prototypes exclusively for the academic studies and, therefore, lacked the attractiveness and immersion of the state-of-the-art commercial games. Rather than designing new games and interfaces, the PLAY, MATE! design aims to develop an active gaming design approach that, if integrated with a variety of existing and future commercial games, will motivate players to perform physical activity while playing.

An alternative approach is exertion interfaces [Mueller and Agamanolis 2008], which use the physical actions required to operate a game interface in order to improve the playing experience. Hence, exertion interfaces deliberately require players to invest physical effort as an integral part of their interaction with games. Exertion interfaces can be applied in several domains, such as medical applications, enhanced sport experience, or digital entertainment (or gaming), which is the focus of this work. Many sport-related exertion interface games were developed recently, such as soccer, basketball, table tennis, jogging, skiing, cycling, air hockey, arm wrestling, boxing, tug of war, and others. A detailed description of the exertion interface framework and its applications to several sample games can be found in Mueller et al. [2011]. Unlike exertion interface games, which cannot be played without performing physical activity, the PLAY, MATE! design lets the players decide whether and how much activity they are willing to perform, such that the activity (to be precise, the in-game rewards cause by the activity) improves playing experience.

Although several works investigated applications of artificial intelligence techniques to computer games, very few focus on adaptivity and personalization. Tychsen et al. [2006] proposed to allow players to adjust their goals, appearance, and game character for improving player experience in online role-playing games. Thue et al. [2007] mined the observed interactions of players with a game in order to determine their preferred style of playing and adapt the generated interactive storytelling accordingly. Conati and MacLaren [2006] developed a probabilistic model of player's emotions and evaluated the accuracy of the model with real players. Although the above works discussed and evaluated player adaptivity in games, most of them evaluated the impact of adaptivity on player enjoyment or game playfulness only. In addition to these parameters, our work evaluates the impact of adaptivity on the amount of physical activity performed by players, which is a pivotal indicator of the acceptance of the PLAY, MATE! design.

2.2 Commercial Products

Commercial gaming technologies that involve players performing physical activity have been developed and successfully disseminated by many companies. One of the earliest products on this area was the Power Pad[2] that was produced by Nintendo in the mid-1980s. Power Pad is a floor mat with twelve pressure sensors, which provide players with a control over the game play. The major success of bodily game control devices came in the late 1990s with the Konami Dance-Dance Revolution[3], a dance pad with arrows, on which players step in order to control the game. The Dance-Dance Revolution pad provided a cheap and effective solution for active gaming peripherals and it was integrated with arcade machines and cloned by numerous similar products.

During the 1990s, the integration of exercising and gaming started to attract the interest of gym equipment producers. Nintendo and LifeFitness joined forces in the mid-1990s to produce the Exertainment console[4]: a gym bicycle connected to a Nintendo arcade machine. Exertainment allowed the exercisers to engage in several car and bike racing games using controls clipped to the handlebar of the bicycle. More enjoyable virtual reality products and applications were developed several years later by Tectrix[5]. These included virtual reality biking, climbing, and rowing appliances that allowed the exercisers to pedal, climb, or row through a number of virtual environments and engage in single and multiplayer racing simulations. These appliances were considerably more expensive than the standard noninteractive gym equipment, such that they did not become popular and their production was discontinued.

Almost a decade later, in the mid-2000s, the market of commercial active gaming was revitalized by the advent of modestly priced gaming consoles. The Nintendo Wii[6] was the first console to use peripheral devices (accelerometer- and gyroscope-equipped remote control and sensory balance board) to allow players to interact with games using gestures and body movement. The Wii was hugely popular and sold around 20 million consoles in its first year (90 million after five years), and more than 1,000 game titles were released. Following this success, in 2010 the PlayStation and Xbox rival consoles released their active gaming peripherals. PlayStation Move[7] was a motion-sensing game controller that used the console's camera to track the position of a special remote control wand and inertial sensors in the wand to detect its motion. Xbox Kinect motion sensing device[8] was centered around a Web camera-style peripheral, which allowed players to control and interact with games without the game controller, through a bodily user interface using gestures and spoken commands. The Kinect was also hugely popular with 8 million devices sold in the first two months of sales only. Despite resulting in players performing physical activity, these technologies are commercial products that provide natural interfaces to interact with games that happen to involve some degree of physical activity, rather than products aimed at motivating increases in players' physical activity.

Finally, several game-like software packages encouraging exercising were released. These include My Fitness Coach[9], EA Sports Active[10], and Yoga[11]. These packages

[2]http://en.wikipedia.org/wiki/Power_Pad
[3]http://www.konami.com/ddr
[4]http://www.nintendoworldreport.com/feature/27667
[5]http://www.tulrich.com/tectrixvr
[6]http://www.nintendo.com/wii
[7]http://www.playstation.com/playstation-move
[8]http://www.xbox.com/kinect
[9]http://www.nintendo.com/games/detail/myfitnesscoach
[10]http://www.easportsactiveonline.com
[11]http://www.gamespot.com/wii/yoga

primarily focus on the provision of interactive wellness and exercising coaching and have little direct gaming involved. However, successful performance of physical activity credits players with virtual rewards, trophies, and prizes. These packages typically are not limited to a specific gaming platform and are compatible with many of the above-mentioned consoles.

2.3 Behavioral Theories Supporting PLAY, MATE!

Several reward and motivational theories from behavioral research can by used to underpin the PLAY, MATE! design approach. One of them, operant conditioning, is one of the earliest and most thoroughly investigated behavior modification techniques [Skinner 1938]. The original operant conditioning theory is based on reinforcers and their use to modify animal behavior. When an animal demonstrates a favorable behavior, it is steadily rewarded and, in the long term, learns to demonstrate the favorable behavior without the reinforcement. Similarly, punishment can be used to decrease the frequency of an undesired behavior within the operant conditioning. In the context of the PLAY, MATE! design, players are rewarded for performing physical activity with the virtual in-game rewards, such that the reward is contingent on performing the activity and the players are expected to be motivated to perform the activity even without the rewards. However, the association between the rewards and the game is loose, since the players can continuously play the game without performing any physical activity until they master their gaming skills and can complete the game tasks.

Another related motivational theory is Premack's principle [Premack 1959]. According to it, if two activities have different probabilities of occurring, the high-probability activity can be used to motivate or reinforce the low-probability activity. That is, the high-probability activity motivates the low-probability activity by making the former contingent on the latter. Consider the following example application of Premack's principle in everyday life: children can be motivated to eat vegetables (low-probability activity) by making ice cream (high-probability activity) contingent on the vegetables. In context of activity-motivating games, the sedentary playing should be treated as the high-probability activity and physical activity as the low-probability activity. Thus, the virtual in-game rewards gained in return for performing real physical activity, which is the main motivating factor of the PLAY, MATE! design, can be interpreted as making the game playing (to be precise, the in-game rewards) contingent on performing physical activity. However, Premack's principle aims at long-term behavioral change, which may not be achievable without a motivating factor being applied beyond the scope of activity-motivating games.

Several other considerations related to rewards and motivation should be noted in the context of the PLAY, MATE! design. The origins of the motivation to perform physical activity can be interpreted as intrinsic (related to the drive to complete the game) or as extrinsic (related to the in-game rewards). Likewise, the rewards can be treated as implicit (intangible virtual in-game rewards) or as explicit (extended game playing time). Furthermore, the relationships between the reward and the favorable behavior are difficult to determine in this case. It is reasonable to assume that the computer game comes to reward physical activity, but this has two theoretical drawbacks. The first one refers to rewarding a favorable active behavior with a nonfavorable sedentary one. The second is whether rewarding physical activity has negative effects on the motivation to be active in the long term, that is, to maintain healthy lifestyle, rather than during the activity-motivating game playing only. In summary, it is difficult to pick a single behavioral theory that fully underpins the PLAY, MATE! design, but it rather integrates a suite of reward and motivational theories.

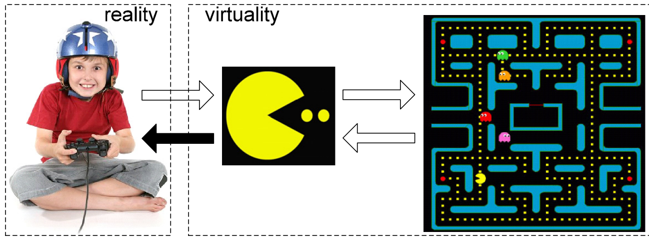

Fig. 1. Player interaction with the game.

3. ACTIVITY-MOTIVATING GAME DESIGN

The core part of the gaming process consists of a player's interaction with a game environment. Typically, the interaction is indirect and is mediated by a game character (or object), which can be considered as the player's embodiment in the virtual game environment. Hence, the player controls the game character, which actually interacts with the game environment. The interaction between the player and game character is unidirectional, that is, the player manipulates the game character and controls its actions. Conversely, the interaction between the game character and the game environment is bidirectional, that is, the game character executes the player's manipulations and influences the game environment, which reacts according to the game logic and reciprocally influences the game character. For example, consider the well-known Pac-Man game. There, the player manipulates the Pac-Man game character to follow the rules and achieve the goals of the game: navigate the Pac-Man character through the maze, avoid ghosts, and collect colored dots and bonus items. The white arrows in Figure 1 schematically depict the interactions occurring between the player, the Pac-Man character, and the game environment.

In most contemporary games, the game character can be modeled by a set of quantifiable features reflecting the state of the character in the game and respective values of these features. For example, consider the following Pac-Man character representation {remaining-time:40, dots-collected:16, maximal-velocity:14}. The value of a feature can either be modified directly by the game environment, for instance, reduction of the remaining time, or by the player: (1) manipulating the game character, for instance, changing the velocity, or (2) controlling the interactions between the game character and the game environment, for instance, collection of dots. It should be noted that these modifications occur simultaneously, while the player manipulates the game character and controls its interactions with the game environment, which responds accordingly.[12]

To achieve a prolonged engagement between the player and the game, the flow of the game is often divided into several tasks or levels of gradually increasing degrees of difficulty, which should be accomplished by the player. Accomplishing a task means reaching the threshold value of a certain feature (or combination of values across a number of features), while satisfying other constraints of the game. For example, consider the following Pac-Man game task: the Pac-Man character is required to escape from the ghosts and collect 50 dots within 3 minutes of playing time. According to the GameFlow model of player enjoyment in games [Sweetser and Wyeth 2005], which is based on the established psychological theory of flow developed by Csikszentmihalyi [1990], the ability to accomplish the game tasks is one of the main factors affecting the

[12] In some games, for instance, Angry Birds, there is no explicit game character. However, they still include quantifiable features, for instance, number of birds or pigs, which represent the player in the game and can be modified by player-game interaction.

enjoyment of playing. Because of this, the tasks should be sufficiently challenging to keep the player engaged, while not too difficult as to discourage the player.

3.1 Design Principles of PLAY, MATE!

Although contemporary games are often linked to negative social stereotypes [Giumetti and Markey 2007; Vandewater et al. 2004], they can be exploited to promote a desired behavior. The goal of the PLAY, MATE! design is to change the inherently sedentary nature of computer game playing to include certain physical activity. In our design, players' engagement with the game and the enjoyment of playing are leveraged to motivate the performance of physical activity and gain virtual in-game rewards. In essence, the motivation to perform physical activity establishes the feedback interaction between the game and the player (black arrow in Figure 1). Hence, it aims to influence the player and achieve the desired behavior, that is, more physically active playing.

The motivation to perform physical activity is achieved by modifying the following components of the game and aspects of interaction between the player and the game environment.

— *Game-related motivator*. The player is made aware of the possibility of gaining virtual in-game rewards in return for performing real physical activity. The game is modified to encourage the player to perform physical activity in order to achieve their goals, accomplish the game tasks, or to do these in an easier/faster way.
— *Activity interface*. The player is provided with an external interface that captures the physical activity performed, instantaneously processes it, and converts the captured real-life activity into the virtual in-game rewards.
— *Game control*. Since performing physical activity simultaneously with controlling the game could be overcomplicated, the player is provided with enhanced control over the flow of the game, for instance, the ability to slow the game down, pause it, and so forth.

Using these modifications, the player is motivated to perform physical activity as follows. First, the game is modified, such that certain game features are disabled or diminished. Second, the player is made aware of the possibility of gaining the in-game rewards, that is, enabling or reinforcing these features, in return for performing physical activity. A combination of these two factors, coupled with the existing engagement of the player with the game and the enjoyment of playing, motivates the player to perform physical activity. The player can use the enhanced game control to interrupt the sedentary playing and perform some physical activity. When performed, the physical activity is captured by the activity interface, processed, and converted into the rewards, which enable or reinforce the game features.

Consider the following example of the PLAY, MATE! design applied to the Pac-Man game. The game-related motivator is applied by limiting the velocity of the Pac-Man character and making it difficult to escape from the ghosts. The player is made aware of the possibility of teleporting the Pac-Man character to a different point in the maze in return for performing physical activity. The teleportation mechanism is implemented in such a way, that the character teleportation distance is proportional to the amount of physical activity performed by the player. The player is equipped with a pedometer, which acts as the physical activity interface. When the player estimates that it is impossible to escape from the ghosts without the teleportation, the game can be paused and the teleportation can be earned through walking. The pedometer counts the player's steps, which are converted into the teleportation distance that is instantaneously shown to the player by the Pac-Man game interface as a gradually expanding circle overlaying the maze. When the number of steps is sufficient to reach the desired teleportation destination, the player can actually teleport the Pac-Man character and resume the sedentary playing.

It is important to highlight the noncoercive nature of the PLAY, MATE! design approach. First, the game-related motivators are introduced in a subtle manner, such that the game tasks are kept accomplishable [Sweetser and Wyeth 2005]. Hence, the player can accomplish the tasks either in a difficult way by sedentary playing only or in an easier way by performing physical activity and gaining the rewards. Second, the reinforced game features are instantaneously visualized by the game, such that the player remains in control of the decision regarding the exact timing and amount of physical activity to perform.

Also, note that the effort and resources required to apply the PLAY, MATE! design to an existing game (game-related motivator implantation and physical activity interface calibration) are deemed to be smaller that those required to design and develop a new active game. This is due to the fact that when the design is applied to an existing game, many available game components, such as the game logic, input and output interfaces, visualization and rendering, and many others, can be reused rather than developed from scratch. Hence, the PLAY, MATE! design is not only applicable to future active games, but can also introduce a new dimension of physical activity to already existing sedentary games and revitalize their popularity.

3.2 Applying PLAY, MATE! to Neverball

To evaluate the PLAY, MATE! design, we applied it to an open-source General Public License game called Neverball[13]. In Neverball, players navigate a ball through a maze shaped surface and collect a required number of coins in a limited period of time in order to unlock the entry point to the next level (note the remaining time indicator highlighted at the bottom part of Figure 2, right). The control over the ball is achieved using the arrow keys or the mouse, which tilt the game surface and cause the ball to roll to the desired direction. The Neverball game consists of multiple levels with gradually increasing degrees of difficulty. We selected and used the first 16 levels of Neverball, supposedly suitable for inexperienced players. The structure of each level, that is, layout, obstacles, and coins, were not changed, following the original design of the game.

Two game-related motivators were implemented and separately applied. The first motivator is applied to the time allocated to accomplish the levels. We shortened the level time limits and made players aware of the possibility of gaining extra time in return for performing physical activity. For each jump captured by the activity interface, players gained extra time to complete Neverball levels. We conjectured that player engagement, enjoyment of playing, and aspiration to accomplish the game levels would motivate them to perform physical activity in order to gain the extra time needed to accomplish the levels. Since the main goal of the Neverball levels is to collect the required number of coins in a limited period of time, this motivator is referred to in the rest of this article as *direct motivator* (DM).

Table I summarizes the original and shortened level time limits (in seconds) for the selected 16 levels and the ratio between the two. The shortened time limits correspond to level completion times exhibited by an expert player at a pilot playing session. As such, the shortened level time limits provide challenging, although achievable, goals for inexperienced Neverball players. In order to keep a balanced difficulty of levels, the ratio between the original and shortened level time limits was kept at either 0.33 or

[13]http://www.neverball.org

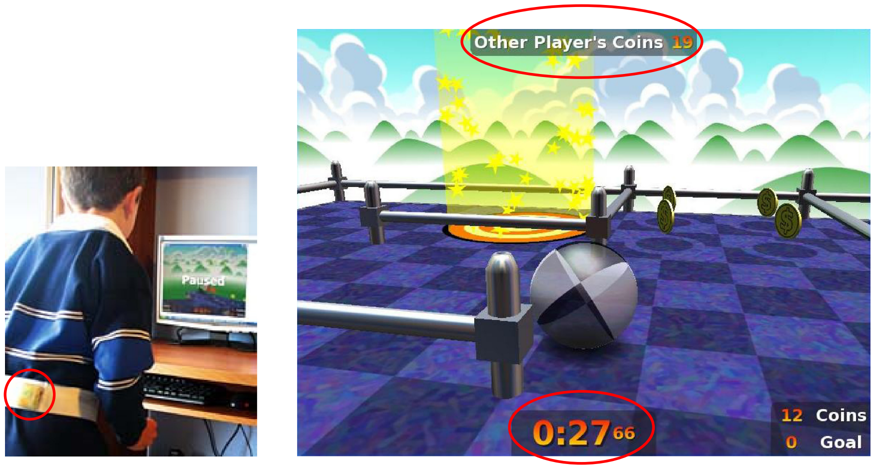

Fig. 2. Accelerometer (left) and Neverball interface (right). (With permission of Robert Kooima for Neverball.)

Table I. Original and Shortened Level Time Limits

level	L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8	L_9	L_{10}	L_{11}	L_{12}	L_{13}	L_{14}	L_{15}	L_{16}
t_{orig}	240	90	120	180	180	90	240	120	180	120	180	300	120	180	240	240
t_{short}	60	38	40	75	75	38	100	40	45	40	60	75	40	60	100	100
t_{short}/t_{orig}	0.25	0.42	0.33	0.42	0.42	0.42	0.42	0.33	0.25	0.33	0.33	0.25	0.33	0.33	0.42	0.42

0.42, excluding levels L_1, L_9, and L_{12}, for which the original time limit was too lenient and the ratio was set to 0.25.

The second motivator exploits the competitiveness of players. We introduced a virtual opponent and players were told that their opponent's playing was synchronized with their own. The graphical interface of the game was modified to visualize the number of coins collected by the virtual opponent (see the opponent's number of coins highlighted at the upper part of Figure 2, right). In fact, we modeled the opponent to outrun players, such that the number of coins collected by the opponent was inversely proportional to the difference between the number of coins collected by the opponent and by the player. Players could halt their opponent's progress by collecting the required number of coins and continuing to perform further activity in order to gain the extra time and collect further coins. That is, the opponent's probability P_c to collect a coin is:

$$P_c(c_p, c_o) = \begin{cases} (c_o - c_p)^{-1} & c_p < T_i \\ 0 & c_p \geq T_i \text{ and activity performed}, \end{cases}$$

where c_p is the number of coins collected by the player, c_o is the number of coins collected by the virtual opponent, and T_i is the target number of point that the player needs to collect for level L_i. We conjectured that player's aspiration to outrun the opponent will motivate them perform physical activity in order to gain the time needed to collect more coins. Since players do not necessarily have to outrun the opponent to accomplish Neverball levels, this motivator is referred to as the *indirect motivator* (IM).

Players were equipped with a wireless accelerometer-based activity interface (presented in the following section) that was configured to recognize jump events (highlighted in Figure 2, left). For every jump captured by the activity interface, players gained one extra second in the game. Since manipulating the ball simultaneously with jumping might be difficult for players, we provided them with an additional control function that allowed players to pause and resume Neverball at any time.

In summary, the PLAY, MATE! design was applied to Neverball as follows. Players were motivated to perform physical activity by applying separately the reduced time and the virual competitor motivators and making them aware of the possibility of gaining one extra second in return for every jump. When the remaining time was perceived to be insufficient, players could pause the game and jump. Their jumps were instantaneously captured by the accelerometer-based activity interface, transmitted to Neverball, and processed, such that the added extra time was visualized by the game interface. When the remaining time was perceived to be sufficient, players could resume the sedentary playing.

3.3 Activity Interface

Several factors were considered when designing and developing the activity interface. The first consideration refers to the aspects of encouraging physical activity. Consolvo et al. [2006] derived four key design requirements for activity-motivating technologies: provide proper credit for activity, provide awareness of activity level, support social interaction, and consider practical lifestyle constraints. The first requires the interface to facilitate accurate measurements of the performed activity. The second refers to the instantaneous feedback loop allowing players to see the amount of activity that was captured. The third and fourth requirements were of a lower importance in case of the activity-motivating version of Neverball, as, respectively, each player played the game individually and the study did not involve prolonged interactions with players in their natural environment.

The second consideration refers to the technology used to capture a player's physical activity. This could have been achieved using a variety of sensing technologies [Andre and Wolf 2007]. For example, an accelerometer, a pedometer, and a gyroscope are examples of physical technologies, while a heart rate monitor, an ECG reader, and a respiration rate monitor are examples of physiological technologies. To increase the accuracy and reliability of measurements, the interface could potentially combine several sensing technologies. The selection of the technology determines the type of activity the player will perform and the position of the activity interface on the player's body. For example, an accelerometer-based activity interface could be attached to the player's arm, wrist, or waist, or just be put in the player's pocket.

The third consideration refers to the physical characteristics of the activity interface, which should conform to the general guidelines for wearable computing devices [Siewiorek et al. 2008]. First, the activity monitor should be compact and lightweight, so as not to interfere with the player's normal motion. To consider practical constraints of the use in activity-motivating games, it should be attachable to the player's body or garment and should support wireless communication mode, so as to not restrict their motion. Second, it should be unobtrusive and not distract player's attention from the game or physical activity. That is, the activity data should be transmitted to the game automatically upon capture.

We considered several commercial products to use as the activity interface. The GT3X by Actigraph[14] is an accelerometer-based pedometer that requires cable connection to transfer the data into the game. ForeRunner by Garmin[15] is a wireless exercise monitor that requires users to press a button for data upload, thus, being obtrusive. Pi-Node by Philips[16] is a highly accurate accelerometer-, gyroscope-, and

[14]http://www.theactigraph.com/products/gt3x/
[15]http://www.garmin.com/products/forerunner/
[16]http://wockets.wikispaces.com/file/view/Pi-Node.pdf

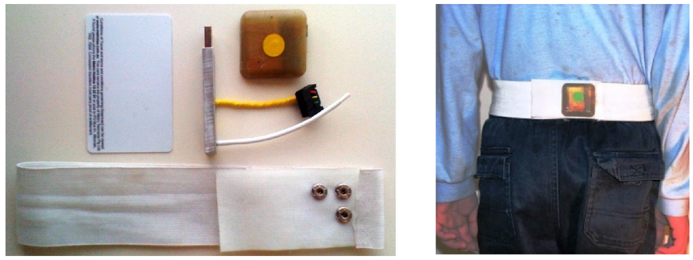

Fig. 3. Wearable accelerometer used as activity interface: system (left) and on subject (right).

magnetometer-based motion detector, which supports instantaneous wireless data upload. However, it requires applying complex signal processing techniques for activity recognition and pricewise cannot be integrated with activity-motivating games.

To comply with these design considerations, we used a triaxial accelerometer to capture a player's physical activity [Helmer et al. 2008]. The accelerometer is compact (42 x 42 x 10 millimetres) and lightweight (15 grams). It is clipped to an elastic band and attached to the player's waist (see Figure 3). This way, the activity interface can be attached to the player's body or any garment and does not interfere with the player's normal motion. The three-dimensional acceleration signal is wirelessly transmitted 500 times per second using an RF wireless communication technology to a receiver plugged into the computer running Neverball. Thus, every player's activity is captured and instantaneously transferred to the game. The activity is immediately processed using a simple threshold-based computation[17] and converted into the in-game time reward that is shown by Neverball interface. To provide the feedback loop, the updated remaining level time is highlighted for a short period of time and unique sound alert is played. Figure 3, left depicts the elastic band with the clips, accelerometer, and USB receiver compared to a standard-size magnetic card. Figure 3, right, depicts the activity monitor attached to the player's waist. More details about the activity interface can be found in Berkovsky et al. [2010a].

4. ACCEPTANCE EVALUATION

We conducted an experimental evaluation aimed at ascertaining the acceptance of the PLAY, MATE! design. In this evaluation, the amount of physical activity performed while playing and the perceived enjoyment of playing were considered as the main indicators of the acceptance. The participation in the study was voluntary: a call for participation was distributed in schools, the volunteers were requested to obtain the consent of their parents/guardians to participate in the study, and no remuneration was offered to the participants. The study was conducted in three primary schools in Hobart (Australia) during the normal school hours.

We recruited 135 participants. We presumed that the Neverball game was appropriate for players aged between 9 and 12 and recruited participants accordingly: 22 players were 9 years old, 41 were 10 years old, 48 were 11 years old, and 24 were 12 years old. 60 of the players were boys and 75 were girls. The average Body Mass Index[18] (BMI) was 16.5 for boys and 16.8 for girls and the proportion of overweight or obese players was 13% for both gender groups. Players having previous experience

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[17] Sample tests with children and adults performing physical activity of various degrees of intensity verified the accuracy of this activity identification mechanism. More sophisticated signal processing techniques [Yang et al. 2008] and mobile technologies [Anderson et al. 2007] can be applied to improve the accuracy of the activity monitoring.

[18] The BMI scores are based on self-reported height and weight figures and may be inaccurate.

with Neverball or having any medical limitations preventing them from performing mild physical activity were excluded from the evaluation.

The players were divided into three groups of 45 players. The first group played the normal sedentary version of Neverball, that is, no game-related motivators were applied. This group is considered the *baseline group* (BL), since they represent the sedentary gaming process, which does not require players to perform any physical activity. The second group played Neverball enhanced by the *indirect motivator* of virtual competitor and it is referred to as IM. The third group played Neverball enhanced by the *direct motivator* of the shortened level time limits and it is referred to as DM. The players were randomly assigned to one of the three groups and post-hoc analyses showed that the distribution of players across the groups in terms of their age, gender, and BMI was close to uniform. In all three conditions players gained the same extra time of one second in return for every jump and this was fixed for the entire evaluation reported in this section.

The participation of players in the evaluation included the following activities. Initially, they answered a prestudy questionnaire that collected their demographic details, such as age, grade, gender, height, and weight, and information regarding their gaming skills, such as preferred gaming platforms and average playing time. Then they played three introductory levels of Neverball (see Appendix 1). The goal of these levels was to familiarize the players with the constraints and controls of the game, and at the same time assess their gaming skills (will be elaborately discussed later). The time limits of these levels were lenient, in order to let the players familiarize themselves with Neverball at their own pace. After accomplishing the three introductory level, the players answered a questionnaire addressing their perceived enjoyment and difficulty of playing (see Appendix 2). Next, the players were equipped with the activity interfaces and informed about the possibility of gaining extra time in return for performing physical activity. However, the players were not directed as to when and how much activity they need to perform and this was left to their discretion. Then, they had a free and unconstrained 20 minute playing session, in which they played the version of Neverball according to their group: BL, IM, or DM. Finally, they answered a poststudy questionnaire and reflected on their perception of the playing session and the factors that made their play enjoyable (see Appendix 3). The parents of the players who participated in the evaluation were sent a separate questionnaire assessing their attitude towards activity-motivating games (see Appendix 4).

It should be noted that the players in all three groups were equipped with the activity interface and were made aware of the possibility of gaining extra time in return for the performed physical activity. While we presumed that the introduced game-related motivators would encourage players in the IM and DM groups to perform some physical activity, players in the BL group had no apparent motivation to perform any activity. However, they were still provided with the activity interface and were made aware of the extra time that can be gained through jumping. This was done in order to uniformly account for the possible “novelty effect” of the introduced game interaction. By doing this, the increased attention to the new game interactions mode through the activity interface, which allows players to get the in-game rewards and may motivate them to perform physical activity even if this is not required by the game environment, was balanced across the three experimental groups.

4.1 Activity-Based Acceptance

Previous studies have shown that the enjoyment of playing is one of the main motivators for playing computer games [Hsu and Lu 2004; Sweetser and Wyeth 2005]. From a health perspective, the main indicator of the acceptance of the PLAY, MATE! design

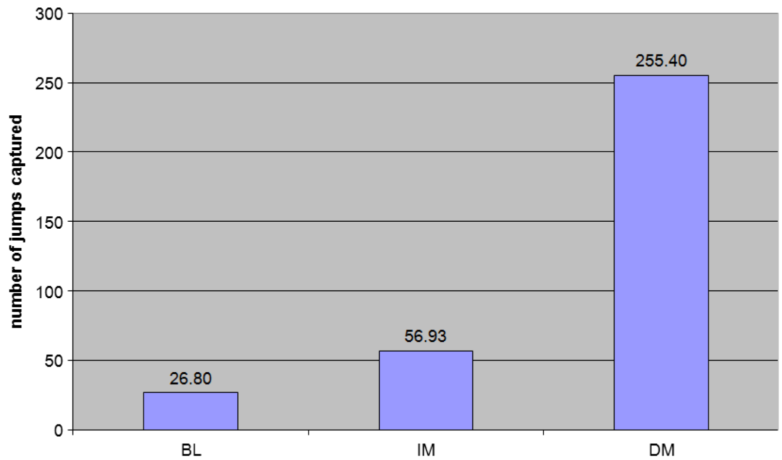


Fig. 4. Average number of jumps captured.

is the amount of physical activity performed while playing. From a gaming perspective, the main indicator is the perceived enjoyment of playing. Hence, the evaluation focused on these two indicators. The first shows whether the PLAY, MATE! design motivates players to perform physical activity, while the second shows whether they find the activity-motivating version of the game enjoyable.

The amount of physical activity performed was quantified by the number of jumps captured by the activity interface. Figure 4 depicts the average number of jumps performed across the different groups. The results show that the number of jumps performed by players in the BL group, who had no real motivation to perform physical activity, is lower than the number of jumps performed by players in the other groups. The number of jumps recorded increases for the IM and DM groups. The differences are statistically significant, $p = 0.0084$ for the IM and $p = 5.45E\text{-}21$ for the DM group.[19] To validate this observation, we compared the sedentary playing time (referred to as T_{sed}) and the physical activity time (referred to as T_{act}) observed during the 20 minute playing session. These were quantified by the periods of time Neverball was played and paused, respectively, assuming that players did not spend time on unrelated activities,[20] separating between the playing and jumping activities,[21] and neglecting the transition time between the two.

Figure 5 depicts the average relative time distribution between T_{sed} and T_{act} across the three groups. The results show two patterns of behavior. For the BL group, the vast majority of the 20 minute session time (96.75%) was spent on sedentary playing and very little portion of time (3.25%) on performing physical activity. A similar time distribution was observed for the IM group, although the physical activity time increased moderately: 94.07% of time was sedentary, while 5.93% of time was active. However, for the DM group, the time distribution was different: only 76.01% of time was sedentary, while 23.99% of time was active. The difference between the IM and BL groups was statistically significant, $p = 0.0490$. The difference between the DM and BL groups was also statistically significant, $p = 3.84E\text{-}22$. It is worth mentioning that the

[19] All statistical significance results hereafter refer to a two-tailed t-test assuming equal variance.
[20] Very little degree of activity related neither to playing nor to physical activity (e.g., socializing, conversations, questions to investigators) was observed.
[21] Playing and jumping were separated by the experimental design: players were not allowed to jump unless the game was paused and obviously could not play while jumping as the game was paused.

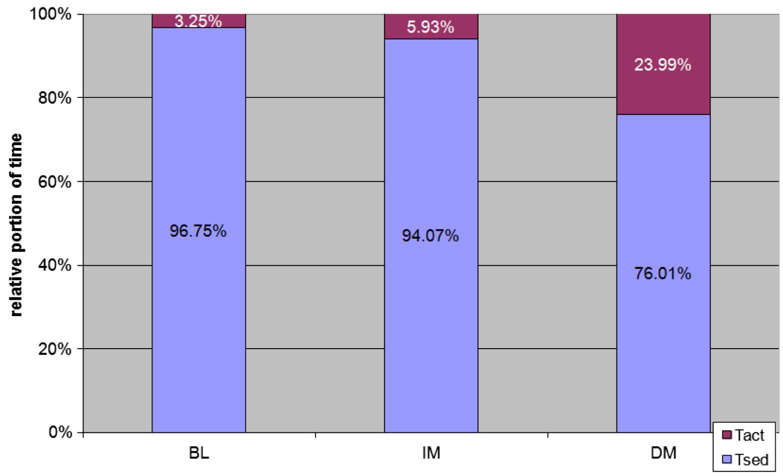


Fig. 5. Distribution between sedentary and active time.

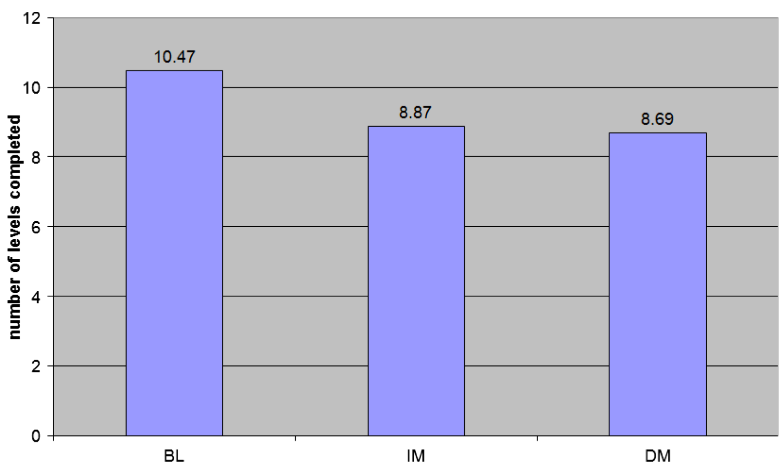


Fig. 6. Average number of levels completed.

time distribution observed for the BL group supports our assumption regarding the probability of activities in context of the Premack's principle and game playing: sedentary playing is the high probability activity and physical activity is the low probability activity.

To understand the influence of game motivators on players and their interaction with Neverball, we consider two other variables. Figure 6 depicts the average number of levels completed by players in each group. As can be seen, the BL group outperforms the other groups. The difference between the BL and IM groups is statistically significant, $p = 0.0050$, as well as the difference between the BL and DM groups, $p = 0.0083$. The IM and DM groups are comparable with the difference between them not being statistically significant.

Figure 7 depicts the average number of coins c_i collected while playing Neverball level L_i. We plot the values of c_i for the initial 10 levels only, as for the remaining levels that number of players who completed the levels was too low. It should also be noted that although the difficulty of the levels generally increases, the number of

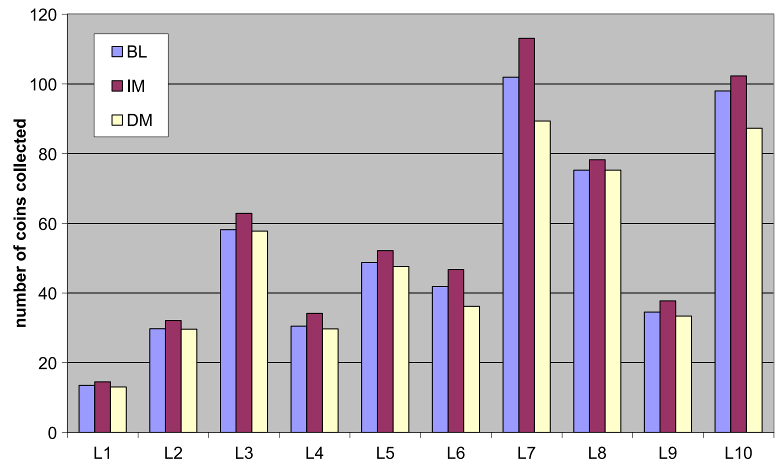


Fig. 7. Average number of coins collected.

available coins and the period of time allocated vary across the levels. Hence, direct comparison of the level difficulty and c_i as performance indicators across the levels is inappropriate. However, the results still show that for all levels the players of the IM GROUP achieved the highest c_i. For most levels, the BL group outperformed the DM group; this can be clearly seen for levels L_6, L_7, and L_{10}. However, the differences between the three groups were not statistically significant.

Figures 4–7 allow us to better understand the interaction of players with Neverball and the influence of game-related motivators. The number of levels completed in the 20 minute playing session was highest for the BL group. Hence, in the IM and DM groups the players spent more time on each level and the game motivators did influence their interaction with the game. However, the actual influence of the motivators varied, as the amount of physical activity performed by the players in these groups was different. We will analyse these differences and compare the observed interaction of players in the IM and DM groups.

— *IM*. Compared to the BL group, the indirect motivator increased the amount of physical activity performed while playing and also increased c_i. Hence, the players spent more time on each level and collected more coins. This was achieved without performing much more activity, as the level time limits were not shortened and the allocated time was still sufficient for most players. We believe that instead of motivating the players to perform more activity, the indirect motivator mainly motivated them to collect more coins than it was required for a level, in order to outrun the virtual opponent. It should be noted, however, that when the remaining level times were perceived insufficient, the players still performed some physical activity.
— *DM*. Compared to the BL group, the direct motivator increased the amount of physical activity performed and decreased c_i. Since the level time limits were shortened, the allocated time was mostly insufficient to accomplish the levels. Hence, players performed physical activity to gain the extra time and be able to complete the levels. As a result, the time spent on each level increased and the distribution of sedentary and active time changed. That is, this motivator did achieve its goal and the players performed more physical activity while playing. The number of coins collected decreased compared to the BL group (although it was still sufficient for accomplishing the levels), as the players were focused on accomplishing the levels in time rather than on collecting more coins than it was required for a level.

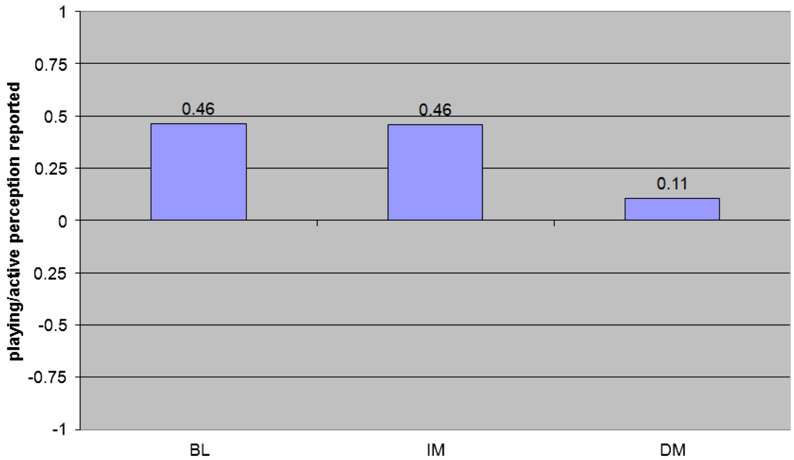


Fig. 8. Average perception of playing.

4.2 Enjoyment-Based Acceptance

In addition to the amount of physical activity performed, the enjoyment of playing is another crucial indicator of the acceptance of the PLAY, MATE! design applied to games [Hsu and Lu 2004]. Before analysing the players' reported enjoyment, we assessed their subjective perception of the amount of physical activity they performed. In the poststudy questionnaire the players reflected on their perception of the 20 minute playing session on a [−1, +1] scale, where +1 indicates pure sedentary playing and −1 indicates pure physical activity (see Appendix 3). Figure 8 depicts the average perception across the three experimental groups.

As can be seen, average perception of playing in the BL and IM groups is +0.46, that is, players perceive the playing session as mostly sedentary activity. However, for the DM group the perception is only +0.11, that is, players perceive the playing session as almost equally balanced sedentary and physical activity. The difference between the BL and IM groups was not statistically significant. However, the difference between the DM group and the BL and IM groups was statistically significant, respectively, p = 5.52E-06 and p = 2.38E-05. This shows that the players' perception is generally accurate, as it corresponds to the amount of physical activity performed and active time shown in Figures 4 and 5. It should be noted that even for the DM group, the players perceive the playing session as more sedentary than physical activity. That is, they still perceive the gaming component to be more important than the activity component, which is a positive observation from a gaming perspective.

To validate that the perception of players is accurate, Figure 9 (respectively, 10) depicts the playing perception as a function of the number of jumps (relative physical activity time T_{act}) and the linear regression of the reported perceptions of players. The slope of the linear regression in both cases is negative and the value of Pearson's correlation between the perception of playing and the number of jumps (relative physical activity time) is −0.392 (−0.476). This ascertains that the perception of the players is generally accurate, that is, the players' perception of the playing session as a sedentary activity is inversely correlated to the number of jumps they performed while playing (relative period of time they spent on performing physical activity).

This observation is important when interpreting the next result, related to the perceived enjoyment of playing. From the players' perspective, the main purpose of the playing session was to play Neverball rather than to perform physical activity. When

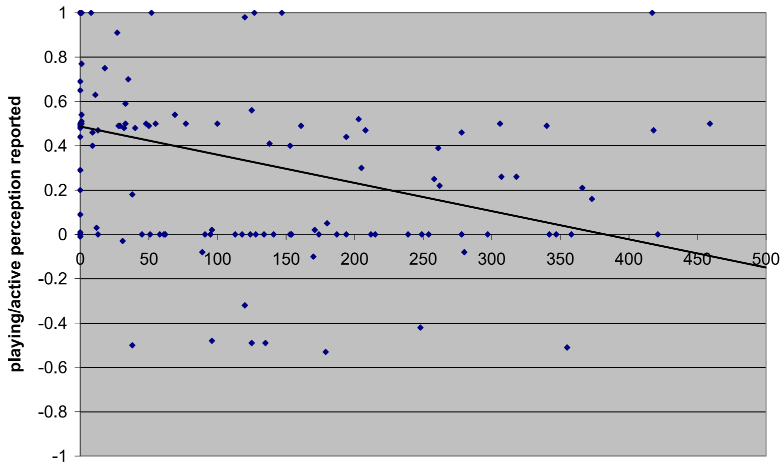


Fig. 9. Perception of playing vs. number of jumps.

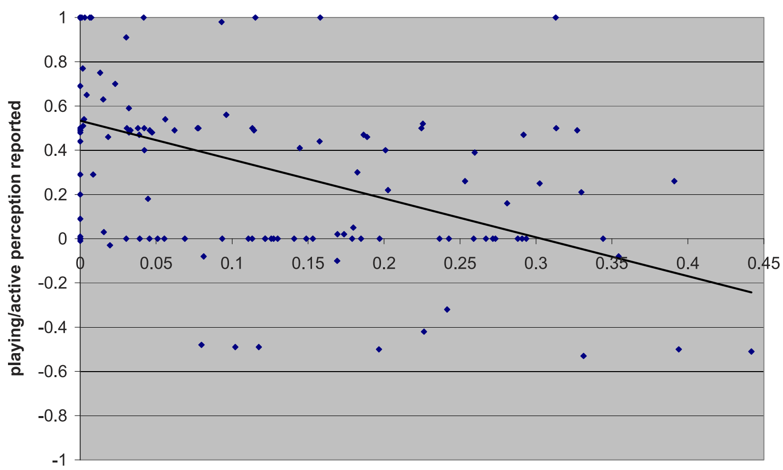


Fig. 10. Perception of playing vs. relative activity time.

the activity motivators were introduced in the IM and DM groups, the players performed more physical activity (reflected by the number of jumps captured) and played the game less (reflected by the sedentary playing time and the number of levels completed) than in the BL group. Although the players accurately perceived the amount of activity performed, they did not report a decrease in the perceived enjoyment of playing. In the poststudy questionnaire, the players reflected on their subjective enjoyment of playing on a 6-Likert scale ranging from "absolutely hated" to "was cool, really loved" (see Appendix 3). Their answers were mapped onto a discrete [1,6] scale, where 6 is the highest evaluation. Figure 11 depicts the reported enjoyment of playing across the groups. The reported degree of enjoyment is very high in all three groups and the differences between the groups are not statistically significant.

We conjecture that applying the PLAY, MATE! design to Neverball had a mixed influence on the enjoyment. On one hand, performing physical activity while playing interrupted the designed flow of the game, as the intended sedentary playing activity became interlaced with performing physical activity. This could have potentially

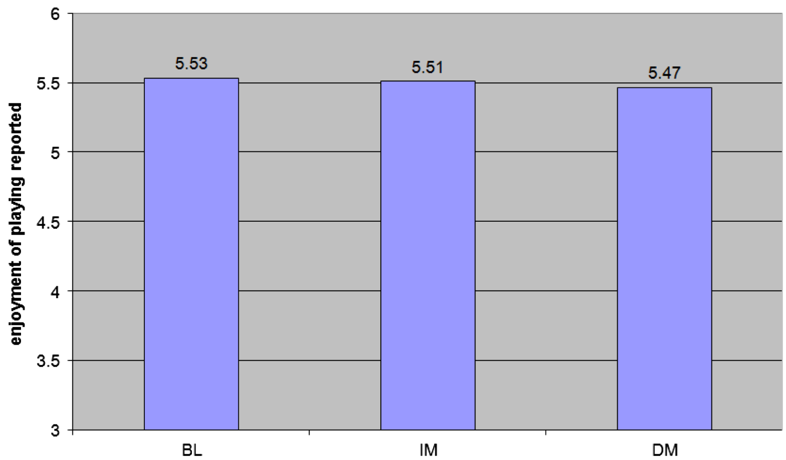


Fig. 11. Average enjoyment of playing.

Table II. Playing Enjoyment Factors

I liked to ...	BL	IM	DM
... control the ball in the maze	73.33%	71.11%	62.22%
... get more time by doing physical activity	33.33%	44.44%	64.44%

decreased the perceived enjoyment of playing. On the other hand, players were provided with a new game interaction mode through the activity interface and the ability to gain virtual in-game rewards. This interface is new for the players, as it is not available in the state of the art sedentary computer games and it allows more control over the game. Both the new interface and the ability to gain the rewards could have potentially increased the perceived enjoyment of playing. The results in Figure 11 show that these factors balanced each other, such that the change in the reported enjoyment was minor.

The results of the poststudy questionnaire indirectly support this conjecture. In the questionnaire, the players were asked to reflect on the factors that made their playing experience enjoyable. They were presented with a list of possible enjoyment factors and asked to mark the factors that they enjoyed (see Appendix 3). Table II shows the percentage of players, who agreed with two factors of a particular relevance to the above discussion. The first factor refers to controlling the ball and tangentially addresses the sedentary playing component. The percentage of players who liked this decreased in the DM group, where the players interrupted the designed flow of the game and performed the greatest amount of physical activity. The second factor refers to the active component, that is, to the possibility of gaining extra time in return for performing physical activity. As can be seen, the percentage of players who liked this increased slightly for the IM group and substantially for the DM group, indicating that the players liked the new game interaction mode through the activity interface. Overall, these two factors balanced each other and, as shown in Figure 11, the change is the average perceived enjoyment of playing across the three groups was not statistically significant.

5. PLAYER AND DIFFICULTY DEPENDENCE

While the activity- and enjoyment-based acceptance of the PLAY, MATE! design are important, we were also interested to understand its performance across various types of

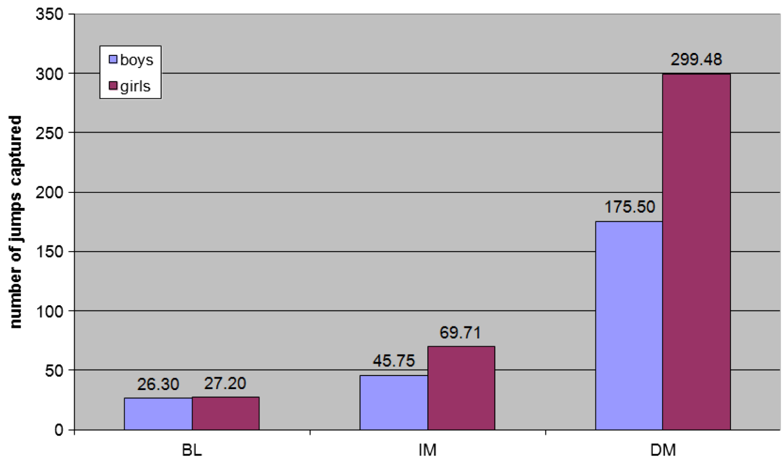


Fig. 12. Average number of jumps captured.

players and game tasks. We segmented the players according to several demographic and gaming-related criteria, and compared the results obtained for different segments. It should be highlighted that in the following analysis we refer only to the amount of physical activity performed by the players, as the reported enjoyment of playing was comparable across all the groups and segmentation criteria.

The first criterion refers to the gender of the players. Previous research revealed noticeable differences in gaming habits and attitude towards computer games between boys and girls of the same age, such that boys spend more time playing games more than girls[22] and possess better gaming skills [Buchman and Funk 1996]. We computed the number of jumps performed by boys and girls. Figure 12 depicts the average number of jumps across the different groups. The results show that girls performed more physical activity than boys and this observation is valid across all three groups. A similar conclusion can be drawn from observing the distribution between the sedentary T_{sed} and active T_{act} time across the groups.

The second criterion refers to the observed gaming skills of the players. At the beginning of the evaluation the players played three introductory levels of Neverball. We used the observed completion times t_1, t_2, and t_3 to quantify players' gaming skills. Hence, we segmented the players into three equal-sized gaming skill clusters, *high*, medium, and *low*, according to the observed (t_1,t_2,t_3) vectors of completion times of the three introductory levels[23] Algorithm 1 summarizes the player segmentation process.

In this algorithm, p_i denotes player i, gs_i denotes the gaming skills of p_i, *sort(s,x)* denotes a function that sorts set s according to criterion x, $||y||_2$ denotes the Euclidian norm of y, N denotes the overall number of players, *centroid(s)* denotes a function that computes the geometric centre of mass of a set of points s, and c_n denotes the centroid of cluster n. In lines (1)–(2) of the algorithm, the gaming skill of each player is quantified using the Euclidian norm of a vector of observed completion times t_1, t_2, and t_3. The players are sorted in increasing order of gaming skills in line (3). Then, the players are divided into three skill clusters in lines (4)–(6) and the centroids of the clusters are computed as the centers of mass of the vectors of all players in these clusters.

[22]This was supported by our prestudy questionnaire, where boys reported longer playing times than girls.
[23]Very weak correlation was identified between the gaming skills obtained through segmentation of players and those self-reported in the prestudy questionnaire (see Appendix 1).

Algorithm 1. Segmentation of players into three skill clusters according to their level completion times

Input: Vector (t_1,t_2,t_3) of completion times of the three introductory levels for each players.
Output: Classification of each player into one of the three gaming skill clusters.
(1) **for** each player i, $p_i = (t_{i1},t_{i2},t_{i3})$
(2) **for** each p_i, compute $gs_i = ||p_i||_2$
(3) $sort(\{p_i\},gs_i)$ for all N players
(4) **for** j = 1,..,N/3 cluster(p_j) = *high*
(5) **for** j = N/3,..,2N/3 cluster(p_j) = *medium*
(6) **for** j = 2N/3,..,N cluster(p_j) = *low*
(7) **for** each class n, $c_n = centroid(\{p_i\})$ for all p_i s.t. cluster(p_i) = n

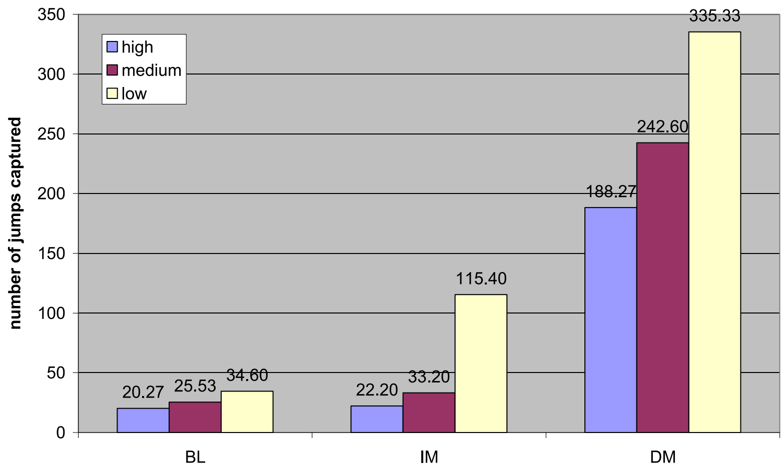


Fig. 13. Average number of jumps captured.

Figure 13 depicts the average number of jumps observed in the *high*, *medium*, and *low* gaming skill clusters across the three experimental groups. As the overall number of players in each group was 45 and the clusters were equal-sized, each cluster contained 15 players. The results show that the players with higher gaming skills performed less physical activity than the players with lower gaming skills. This is reflected by the increased number of jumps, that is, players with high gaming skills performed fewer jumps than those with medium gaming skills. Similarly players with medium gaming skills performed fewer jumps than those with low gaming skills. This observation is valid across the three experimental groups. Hence, the amount of physical activity performed by players was inversely correlated to their gaming skills. This finding is not surprising, given that players with higher gaming skills had higher chances of success in accomplishing the levels without requiring the rewards than players with lower gaming skills. As such, the former needed the rewards to a lesser degree than the latter and, accordingly, performed less activity. Indirectly, this finding is supported also by the gender segmentation comparison, as boys (having spent more time playing games and, presumably, having higher gaming skills [Buchman and Funk 1996]) performed less physical activity than girls.

A similar analysis was carried out with the BMI- and age-based segmentation of players. The players were segmented into three equal-sized clusters according to their BMI computed using their height and weight, and the amount of activity performed by

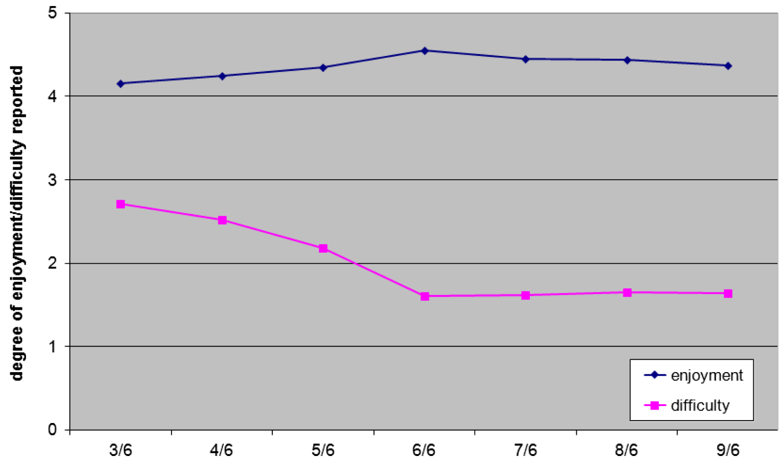


Fig. 14. Reported enjoyment and difficulty of levels.

players in these clusters was compared. No dependence was found between BMI and the amount of player activity. The average amount of activity performed by players in the highest and lowest BMI clusters was comparable and slightly higher than the activity performed by players in the middle cluster. Recall that BMI was based on self-reported height and weight and may be inaccurate. Likewise, no dependence was found between the age of players and the amount of activity they performed. Players aged 9/10 and players aged 11 performed comparable amounts of activity, whereas 12 year old players performed slightly more activity. As such, no decisive conclusions can be drawn from these analyses.

From a health perspective, the observed gender- and skill-based player dependence means that the effect of the PLAY, MATE! design on experienced players was weaker than on novice players. From a gaming perspective this could potentially be a weakness of the design, as if the game is not sufficiently challenging for experienced players, their enjoyment of playing may decrease. Another experimental finding supports this weakness. While playing the introductory levels of Neverball, players reported on their expected degree of enjoyment and perceived degree of difficulty of playing, if the level time limit was modified to $k \cdot t(L_i)$, where $t(L_i)$ is the observed completion time for level L_i and k is a parameter varying between 3/6 and 9/6 for different questions (see Appendix 2). Both the expected enjoyment and the perceived difficulty were measured on a 6-Likert scale. Figure 14 depicts the average reported enjoyment and difficulty.

As can be seen, the highest enjoyment is reported when the level time limit matches the observed completion time, that is, the level difficulty is adapted to player's gaming skills. This finding supports one of the conclusions of Sweetser and Wyeth [2005], that "games should be designed to have a level of challenge that is appropriate [for a player] and not discouragingly hard or boringly easy". When a level time limit was shortened, the reported enjoyment was lower as the game is perceived more difficult. Conversely, when the time limit was extended, the reported enjoyment was lower too (although to a smaller extent than with the short time limits) as the game is not perceived challenging enough. As expected, the reported difficulty decreased in a linear manner with the level time limit, until it reached the observed completion time. Surprisingly, after this point the reported difficulty stabilized despite the extended time limits. That is, being able to complete a level within a certain time, the players do not perceive the level easier if the time limit was extended beyond their completion time.

6. ADAPTIVE APPLICATION OF PLAY, MATE!

The observed discrepancy between experienced and novice players and the maximal degree of enjoyment reported for the time limit matching a player's observed completion time highlight the need for player tailored and adaptive persuasive techniques [Berkovsky et al. 2012] that facilitate player-dependent applications of the PLAY, MATE! design [Berkovsky et al. 2010c]. This section presents two adaptive techniques. Their goal is to motivate all players to perform a similar amount of physical activity, while making the game tasks neither too easy nor too difficult and retaining the enjoyment of playing. In a similar manner, they could facilitate prescribed amounts of activity to be carried out (or a number of calories to be burnt), regardless of a player's gaming skills.

6.1 Tailored Reward

The goal of the tailored reward (TR) technique is to balance the amount of physical activity performed by various players. In the context of Neverball and time-based in-game rewards, one way to achieve this is to modify the reward times gained by players for each activity captured. For example, the rewards gained by experienced players in return for each jump can be reduced, inherently requiring them to jump more. Similarly, the reward times of novice players can be increased in order to retain their enjoyment of playing.

The tailored reward technique predicts a suitable reward time for players using a stereotypical prediction algorithm [Shani et al. 2007]. That is, we initially determine a player's gaming skill stereotype by classifying them into one of the three skill clusters, low, medium, or high, and then adaptively assign reward times according to the skill cluster. The classification algorithm requires a knowledge base of players. Hence, we used the data gathered on players who participated in the evaluation reported in section 4 and segmented them into three equal-sized gaming skill clusters, low, medium, and high. This process was identical to that presented in Section 5, where the completion times t_1, t_2, and t_3 observed for the three introductory levels of Neverball served as the basis for the segmentation. At play time, we select the reward time for a new player p' by classifying the player into the most appropriate cluster based on their completion times for the three introductory levels (line (1) of the pseudocode) and assigning the reward time of the cluster to p' (line (2) of the pseudocode). Algorithm 2 summarizes the online stage of setting the reward time. It should be noted that a player's reward time is not truly personalized, but rather stereotypically tailored to a skill cluster into which the player is classified.

6.2 Personalized Difficulty

The goal of the personalized difficulty (PD) technique is to set the difficulty of a level in a player-dependent manner, such that it motivates players to increase the amount of physical activity performed, while retaining the essential enjoyment of playing. In the context of Neverball, when the time allocated to complete a level is shortened, the new

Algorithm 2. Setting of the tailored reward time for a player

Input: Centroids of the three gaming skills clusters and vector (t_1,t_2,t_3) of completion times of a new player.

Output: Reward time of the player.

(1) cluster(p') = $\text{argmin}_{n=\{low,medium,high\}} ||p'-c_n||_2$

(2) reward(p') = reward(cluster(p'))

time limit should be sufficiently challenging to motivate players to perform physical activity, while neither too short to discourage players nor too long to bore players.

The personalized difficulty technique predicts a player's completion time for a level using a collaborative filtering-based algorithm [Herlocker et al. 1999]. That is, we initially compute player-to-player similarity using the completion times observed for previously played levels. Then, we select a subset of most similar players and, finally, aggregate the completion times of these similar players for the target level, in order to predict the completion time of the target player. The personalized difficulty technique is implemented as follows. For each player p_i and each completed level L_j, we capture the level completion time $t(p_i,L_j)$. Note that here we refer only to the sedentary playing time component, that is, the period of time the player interacted with the game, and disregard time spent performing physical activity. We use the observed completion times to adaptively predict the completion time $t'(p_x,L_y)$ for the target level L_y that will be played by the target player p_x and shorten or lengthen the level time limit accordingly. The degree of similarity $sim(p_x,p_i)$ between p_x and another player p_i is computed using the completion times (t_1,t_2,t_3) observed for the three introductory levels and the times observed for already completed levels $L_1,L_2,\ldots,L_{y-1}$ of the free playing session. After selecting the neighbors, that is, set of players most similar to the target player p_x, the predicted completion time $t'(p_x,L_y)$ is computed by aggregating the observed completion times $t(p_i,L_y)$ of the neighbors in a weighted manner according to their player-to-player similarity degree $sim(p_x,p_i)$. Finally, the time limit for player p_x and level L_y is set to the predicted completion time $t'(p_x,L_y)$. Algorithm 3 summarizes the personalized level time limit prediction computation.

Algorithm 3. Computation of personalized level time limit for a player and a level

Input: Completion times of previous levels of a player and all completion times of all other players.
Output: Personalized level time limit for the player.
(1) **for** each p_i, compute $sim(p_x,p_i)$
(2) *sort*($\{p_i\}$,$sim(p_x, p_i)$) for all N players
(3) *select-top-K*($\{p_i\}$,$sim(p_x, p_i)$) out of all N players
(4) **for** each of K selected p_i, $t'(p_x,L_y) = [\sum(t(p_i,L_y)\cdot sim(p_x,p_i))]/[\sum sim(p_x,p_i))]$

In the pseudocode, p_i denotes player i and K denotes the number of neighbors in the $t'(p_x,L_y)$ computation. In line (1) of the algorithms the player-to-player similarity degree is computed. Then, the players are sorted and K neighbors—most similar players—are identified in lines (2)-(3). Finally, the predicted level completion time for the target user and target level is computed as a weighted according to player-to-player similarity average of the observed level completion times of the selected neighbors. Note that unlike the tailored reward time, the personalized difficulty uses a truly personalized technique, as both the similarity of players and the predicted completion times are computed on an individual basis.

7. ADAPTIVITY EVALUATION

We evaluated the impact of the adaptive application of the PLAY, MATE! design on the amount of physical activity performed and the perceived enjoyment of playing. 90 players participated in the evaluation: 28 were 10 years old, 31 were 11 years old, and 31 were 12 years old. 47 players were boys and 43 were girls. None of them had participated in the evaluation reported in Section 4, as players having previous experience with Neverball were excluded from the evaluation. The flow of the evaluation was similar to the flow presented in Section 4, that is, the players played the same three introductory levels of Neverball, then were informed about the opportunity to gain extra time in return for performing physical activity, then they had the 20 minute playing session, and, finally, reflected on their perception of playing.

The 90 players were uniformly divided into two groups of 45 players: one for tailored rewards and one for personalized difficulty. The baseline group used in this evaluation was the DM group from the evaluation reported in section 4, as these players were motivated by the shortened time motivator to perform physical activity and they played the nonadaptive activity-motivating version of Neverball. That is, in the DM group the level time limits and the in-game rewards were identical for all players, that is, level time limits were shortened uniformly and for every jump all players gained one second of extra time.

The first experimental group played the adaptive activity-motivating version of Neverball with uniform level time limits and *tailored rewards* (referred to as TR). In the evaluation reported in Section 4, players in the *low* gaming skill cluster performed on average 196.30 jumps, in the *medium* skill cluster, 142.43 jumps, and in the *high* cluster, 109.38 jumps. To balance the number of jumps performed by players in different skill clusters, we applied reward times, which were inversely proportional to the numbers of jumps observed in section 4. That is, we set reward(*low*) = 196.30/142.43 = 1.38, reward(*medium*) = 1, and reward(*high*) = 109.38/142.43 = 0.77 second. The level time limits in this group were set in a uniform manner for all players, similarly to the shortened time limits of the DM group shown in Table I.

The second experimental group played the adaptive activity-motivating version of Neverball with uniform reward times of one second for each jump, as per the evaluation reported in Section 4, and *personalized difficulty* of levels (referred to as PD). The difficulty of levels was personalized in order to motivate players to increase the amount of physical activity performed, while retaining the enjoyment of playing. The time limits for each player and level were predicted using the collaborative filtering-based computation, as detailed in Section 6. We used Pearson's correlation to compute player-to-player similarity degrees and aggregated the observed completion times of K = 5 neighbors to predict a level time limit. The reward times in this group were set in a uniform manner for all players, similarly to the DM group, that is, for every jump the players gained one second of extra time.

7.1 Tailored Rewards

The goal of the tailored reward technique was to balance the amount of activity performed by players of varying gaming skills. To evaluate the impact of this technique, we segmented the players into low, medium, or high clusters based on to the completion times (t_1,t_2,t_3) observed for the three introductory levels, in similar to the classification presented in section 6. Then we computed the average number of jumps performed by players in each cluster during the 20 minute free playing session. Figure 15 depicts the average number of jumps captured for each cluster in the DM and TR groups.

The overall trend in the three gaming skill clusters remains the same: higher-skilled players performed less physical activity as they needed the extra time to a lesser degree than lower-skilled players. Although applying the tailored reward technique did not entirely equalize the number of jumps across the three skill clusters, the amounts of activity were more balanced and reduced differences between the clusters were observed. The number of jumps decreased from 335.33 to 297.20 in the low cluster, increased from 242.60 to 273.33 in the medium cluster, and increased from 188.27 to 242.33 in the high cluster. The decrease in the low cluster was not statistically significant, while the increases in the medium and high cluster were both statistically

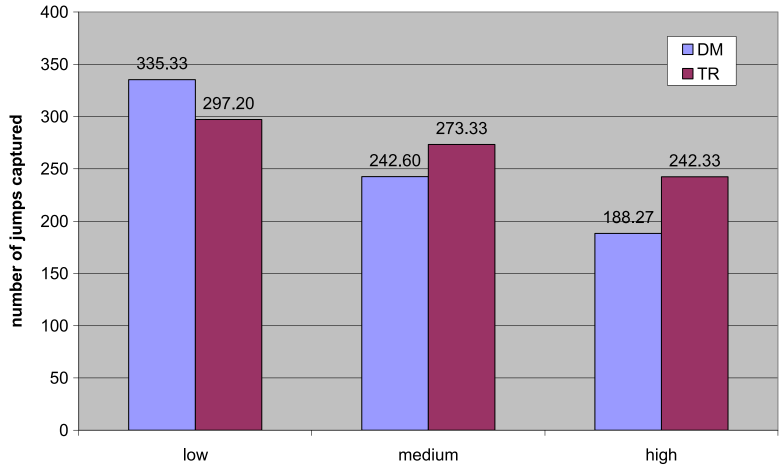


Fig. 15. Effect of tailored rewards on physical activity.

significant, p = 0.0270 and p = 0.0189, respectively. Overall, the ratio between the numbers of jumps captured in the low and high clusters dropped from 1.78 in the DM group to 1.23 in the TR group.

In summary, the tailored rewards technique was an important step towards balancing the amount of physical activity performed and motivating all the players to perform comparable amounts of activity. As a result of applying this technique, novice players performed less activity and experienced players performed more activity. From a health perspective, the tailored rewards technique adjusted the amount of physical activity performed and helped each player to reach the desired degree of activity. From a gaming perspective, the tailored rewards technique demonstrated that the virtual in-game rewards of the PLAY, MATE! design can be set in an adaptive and player-dependent manner.

7.2 Personalized Difficulty

The goal of the personalized difficulty technique was to set level difficulty, that is, the level time limits, in a personalized player-dependent manner, in order to motivate the players to increase the amount of physical activity performed, while maintaining the enjoyment of playing. To evaluate the impact of this technique, we first computed the accuracy of the level completion time predictions. For this, we used the Normalized Mean Average Error (NMAE) predictive accuracy metric [Herlocker et al. 1999], computed by:

$$NMAE(l_y) = \frac{\sum_i^{N_r} = l|t(p_x, L_y) - t'(p_x, L_y)}{N_y t'(L_y)}$$

where $t'(p_x,L_y)$ is the predicted and $t(p_x,L_y)$ is the observed completion time for target player p_x and level L_y, N_y is the number of players who completed level L_y, and $t'(L_y)$ is the uniform completion time for level L_y set for the DM group.

Figure 16 depicts the NMAE scores computed for players in the PD group for the first 10 levels of Neverball (for the remaining levels the number of players who completed these levels was too small) and the logarithmic regression of the NMAE scores. As can be seen, NMAE generally decreases with the number of levels completed. This aligns with the outcomes of prior collaborative filtering research, which showed that the accuracy of the predictions improves with the amount of information available

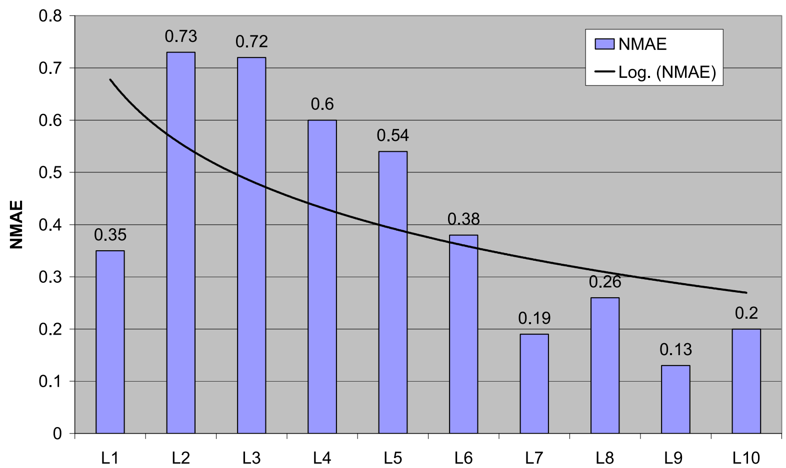


Fig. 16. NMAE of personalized level completion times.

about the users [Herlocker et al. 1999]. The only clear outlier for this trend is level L_1. Due to the very low degree of difficulty of L_1, the observed completion times were practically identical for most players, such that the predicted completion times were highly accurate.

We computed the error between predicted completion time $t'(p_x,L_y)$ and the observed completion time $t(p_x,L_y)$. Note that in this case, we were interested in the exact rather than absolute value of the prediction error. If the observed completion time is shorter than the predicted one, a player has spare time and does not need to perform any physical activity. However, if the observed completion time is longer than the predicted one, a player needs to perform physical activity in order to gain the extra time. Also, in this case, we did not normalize the computed error by the uniform completion time, as we did not compare the errors across different levels. Hence, we used the Mean Average Error (MAE) metric [Herlocker et al. 1999], computed by:

$$MAE(l_y) = \frac{\sum_{i=l}^{N_j} t(p_x, L_y) - t'(p_x, L_y)}{N_y}.$$

Figure 17 depicts the MAE scores computed for players in the DM and PD groups for the first 10 levels and Figure 18 depicts the average number of jumps performed by players in the DM and PD groups for these levels. A comparison of the MAE scores shows that the personalized level time limits in the PD group were more accurate than the uniformly set level time limits in the DM group. For the PD group, the MAE values fluctuated around 0, as the predicted time limits are personalized to a player's gaming skills, whereas higher errors were observed for the DM group. For example, the highest error of the personalized time limits in the PD group was around 5.5 seconds (observed for L_4, L_7, and L_{10}), whereas the highest errors of the uniform time limits in the DM group were 53.45 seconds for L_7, 32.40 seconds for L_3, and 27.07 seconds for L_5. The difference between the groups was statistically significant, $p = 0.0006$.

We would like to distinguish between two types of levels. For levels L_2, L_3, L_4, and L_5, MAE of the predicted times for the DM group was positive. That is, the observed completion times were longer than the uniformly predicted completion times, that is, the uniform time limits were too tight and insufficient to complete these levels. Hence, the players needed to perform physical activity in order to gain the extra time and

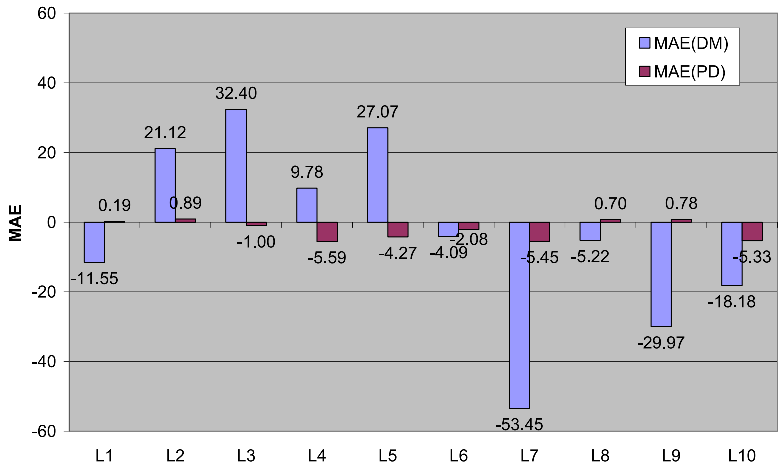


Fig. 17. Effect of personalized difficulty on predicted level time limits.

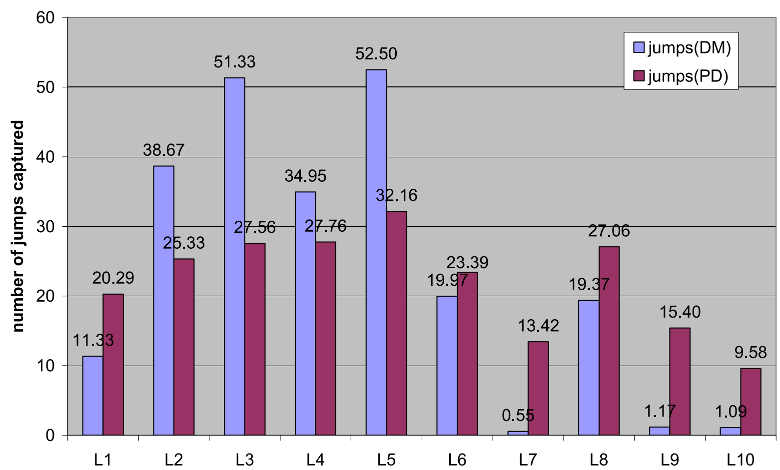


Fig. 18. Effect of personalized difficulty on the number of jumps.

complete these levels (we call these levels difficult). In contrast, for levels L_1, L_6, L_7, L_8, L_9, and L_{10}, MAE of the predicted times for the DM group was negative. That is, the observed completion times were shorter than the uniformly predicted completion times, that is, the uniform time limits were too lenient. Hence, the players had some spare time remaining when they completed these levels and then did not need to perform any physical activity (we call these levels easy).

Considering the correlation between the personalized level time limits shown in Figure 17 and the number of jumps performed shown in Figure 18, the impact of applying player-dependent time limit was mixed. For difficult levels L_2, L_3, L_4, and L_5, adapting the time limit in the PD group extended the time limit and made the levels easier. Hence, the players needed to gain less extra time and the number of jumps they performed decreased. For easy levels L_1, L_6, L_7, L_8, L_9, and L_{10}, adapting the time limit in the PD group shortened the time limit and made the levels more difficult. Hence, the players needed extra time, performed physical activity, and the number of jumps captured increased. The observed decrease (for difficult levels L_2, L_3, L_4, and

L_5) and increase (for easy levels L_1, L_6, L_7, L_8, L_9, and L_{10}) in the number of jumps were both statistically significant: p = 0.0005 for the decrease and p = 0.0306 for the increase.

Also in this case the change in the perceived enjoyment of playing was minor: the average reported enjoyment of playing in the DM group was 5.47 and in the PD group it was 5.55, both comparable to those reported in Figure 11. On one hand, personalizing the level time limits increased the number of jumps the players performed while playing and interrupted the flow of playing, which could have potentially decreased the perceived enjoyment. On the other hand, personalizing the time limits adapted a player's interaction with Neverball to their gaming skills, which could have potentially increased the enjoyment. As the change in the reported enjoyment was not statistically significant, the personalized level time limits retained the enjoyment of playing.

In summary, the personalized difficulty technique allowed us to adaptively control the difficulty of Neverball levels by setting personalized player-dependent time limits. The impact of the personalization on health outcomes was mixed: for easy levels the number of jumps performed increased, but for difficult levels it decreased. That is, if aiming at maximizing the amount of activity performed while playing, the personalized difficulty technique should be applied for the prediction of level completion times. Then, the time limit should be set to a time slightly shorter than the predicted completion time, in order to motivate players to perform physical activity, but not to reduce the time limit to be discouragingly short.

8. ACCEPTANCE OF ACTIVITY-MOTIVATING GAMES BY ADULTS

In addition to assessing the activity- and enjoyment-based acceptance of the PLAY, MATE! design by young players, we assessed its acceptance by parents: those who often make the decisions regarding the games the children will player. For this, we distributed a questionnaire among the parents of the players who participated in our evaluations (see Appendix 4). Parents were asked to estimate the average daily period of time they allowed their children to play sedentary games as well as their average monthly expenditure on sedentary games and accessories. The answers ranged from "less than 30 minutes" to "more than 2 hours" for the playing time and from "less than \$20" to "more than \$100" for the expenditure. Then, we introduced the main ideas of the PLAY, MATE! design and the ways it can be applied to convert sedentary games into active ones. Finally, we asked the parents to estimate the average daily period of time they would allow their children to play and the average monthly expenditure they would spend on games and accessories, if all the sedentary games were substituted by their active analogues.

The survey was completed by 117 parents. The average age of respondents was 42.5, 89 of them were females and 28 males. Most of the respondents do not play computer games at home, as reflected by their reported perception of their own gaming habits, that is, 52.14% answered, "I don't play computer games at all," 29.06% answered, "I play very rarely, usually not at home," 11.11% answered, "I usually play at home, 1–2 times a week, less than 1 hour every time," 4.27% answered, "I usually play at home, 4–5 times a week, less than 1 hour every time," and only 3.42% reported that they played more than that.

The left bars in Figures 19 and 20 referring to the sedentary games depict the distribution of the parent responses for the average daily period of time they allowed their children to play and their average monthly expenditure on games and accessories. For the daily playing time, over half (51.28%) of parents answered "less than 30 minutes" and an additional third (35.90%) answered "30 minutes to 1 hour". For the monthly expenditure, 90.60% of parents answered "less than \$20"; 9.40% of parents, "\$20 to \$50"; and none answered "\$50 to \$100" or "more than \$100". The right bars in depict the

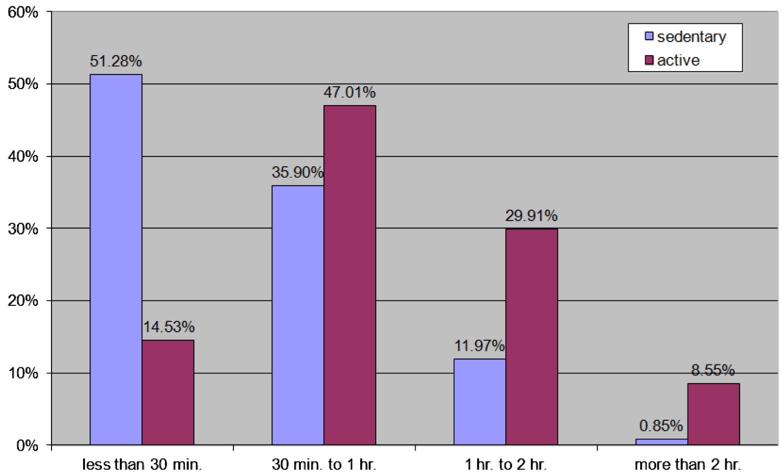


Fig. 19. Parent questionnaire answers for daily playing time.

Fig. 20. Parent questionnaire answers for and monthly expenditure.

distribution of the parents' responses for the active analogues of the games applying the PLAY, MATE! design. For the playing time, 14.53% of parents answered "less than 30 minutes"; 47.01% of parents, "30 minutes to 1 hour"; and close to 40%, "1 hour to 2 hours" or "more than 2 hours". For the expenditure, 54.70% of parents answered "less than $20"; more than 40%, "$20 to $50"; and around 4%, "$50 to $100" or "more than $100". Both the increase in the daily playing time and in the monthly expenditure were statistically significant, p = 2.87E-11 and p = 1.87E-17, respectively.

Overall, 55.55% of parents indicated that they would allow their children to play for longer and 39.32% indicated that they would agree to increase the expenditure on games and accessories, if current sedentary games were substituted by their active analogues. Furthermore, 32.48% of respondents indicated that they would both allow their children to play longer and agree to increase the expenditure. These results show a positive attitude of adults towards activity-motivating games played by their children. They are willing to increase both playing time and monetary expenditure, if the games included aspects of physical activity. Hence, the PLAY, MATE! design offers a new type of game enjoyed by young players and accepted by their parents.

9. DISCUSSION

The results of the evaluations confirm the validity of the main hypothesis behind the PLAY, MATE! design: engagement with computer games can practically motivate players to perform physical activity at game play. Players were motivated by (1) modifying the game, such that certain game features can be reinforced by virtual in-game rewards, (2) making the players aware of the possibility of gaining the virtual rewards in return for performing real activity, and (3) providing the players with an interface that captures the real activity and converting it into the rewards.

In this section, we survey the identified limitations of the PLAY, MATE! design and its application to Neverball, and discuss obstacles that could potentially impede wide dissemination of activity-motivating games. Naturally, these limitations can be the basis for further research, and the discussion below positions them in the broader context of human-computer interaction and gaming research. Finally, we present Run, Tradie, Run!, a new activity-motivating mobile game, in which we demonstrate the application of the design in the mobile space and illustrate how we address part of the identified limitations.

9.1 Limitations

Long-term health impact. The physical activity performed by players of the PLAY, MATE! design was assessed is in the context of a single 20 minute game playing time segment. While this provides a positive change to normally sedentary playing behaviour, there is little evidence to indicate that this would result in increased amounts of activity being performed over a long period of time or would lead to a healthier lifestyle. The fact that players are active while playing is one dimension of the required lifestyle improvement and it must be acknowledged that in its current form the overall impact on health and wellbeing is questionable. As argued in clinical studies, the long-term impact of active games on energy expenditure of children and young adolescents is mixed, and no clear health benefits can be shown [Daley 2009]. To support long-term behavioral change, players would need to be rewarded for any activity performed as part of their lifestyle, primarily for activities performed outside the playing context. For example, consider a scenario where a player's daily activity is captured and accumulated, and then traded for in-game rewards during the game play. This would enhance the PLAY, MATE! design, as players would be motivated to increase their overall activity levels, and convert it into a generic game-based activity motivator.

Game-related activity. From a gaming perspective, one of the key limitations of this work is the lack of logical linkage between the in-game actions of the game character and the performed physical activity. Due to the simplicity of Neverball, the game flow did not correspond to players' jumps and, vice versa, jumps did not match any particular action in the game. Although not observed in the study, this decoupling could potentially interrupt the game flow, decrease player engagement and the enjoyment of playing, and potentially discourage players from playing activity-motivating games. Thus, strong linkages between the gameplay and the activity rewarded should be established, in order for the activity to be perceived an integral part of completing the game tasks [Stach and Graham 2011]. For example, consider a different application of the PLAY, MATE! design to Neverball, where players' jumps charge the battery of the ball in Neverball and allow it to jump over the obstacles in the maze. This linkage between jumping in the physical world and the ball jumping in the virtual world could further increase player enjoyment and sustain the engagement of players with the activity-motivating games.

Wide applicability. In a similar vein, care should be taken when selecting the motivating component applicable to a specific game and/or genre of games. As was shown by the conducted Neverball evaluation, the virtual competitor indirect motivator affected players significantly less than the direct time-based motivator: in the former case they performed less activity and the sedentary/active time distribution was close to that observed in the baseline group. This can be explained by the poor appropriateness of the virtual competitor motivator to Neverball. Not only does the design of Neverball inherently lack any competitive dimension, focussing solely on a player's individual performance, but this performance centers primarily around time rather than around coins, which are the focus of our virtual competitor. Hence, the details of the application of the PLAY, MATE! design to various games and/or genres should be considered in the context of specific games, in order to set suitable rewards that motivate players and match the game flow. Furthermore, it is important to analyse and compare the developed categories of rewards and game applications, in order to derive motivators applicable to certain genres of games.

Activity interface. In this application of the PLAY, MATE! design to Neverball, player activity was monitored using a 3D accelerometer. Although the accelerometer is relatively cheap and compact, it should be treated as yet another gameplay device that needs to be purchased and maintained, that is, charged and updated, which could potentially hinder the dissemination of activity-motivating games. To resolve this, it is important to develop games that exploit activity monitoring technologies offered by available, reliable, and affordable devices. For example, active games developed for existing game consoles could use their native gaming peripherals, such as the Wii remote or the Kinect's camera-based motion sensor. Not to limit the long-term impact on health, mobile activity-motivating games could use the built-in accelerometers and the GPS positioning technologies widely available in modern smartphones. Considering rather abstract scenarios, activity interfaces can potentially leverage a variety of ubiquitous sensors deployed in instrumented smart environments [Tapia et al. 2004]. If developing a designated activity interface, consideration should be taken to exploit physiological sensing technologies, for instance, heart rate and/or respiration monitors. These measure not only the amount but also the intensity of physical activity performed, facilitating the rewarding of players according to their activity levels and increasing the health benefits of activity-motivating games.

Balancing activity and enjoyment. Adaptive applications of the PLAY, MATE! design clearly highlighted the importance of balancing the health-oriented goals of activity and the game-oriented goals of enjoyment. This is yet another manifestation of a well-known trade-off between enjoyment and (typically learning-oriented) goals of serious games [Frank 2007]. To strike this balance correctly, activity-motivating games should effectively motivate players to perform physical activity, while retaining the focus on playing and maintaining or increasing playfulness and enjoyment through the activity component. Adapting the game difficulty to players' gaming skills is one step in this direction, but many other dimensions of player-game interaction could be enhanced. For example, consider matching the virtual in-game rewards to the player's gaming style (e.g., preferred strategy, developed skills, or selected avatar) or progressively increasing the amount of activity required to gain rewards. Potentially, the enjoyment of performing physical activity can also be boosted through linking the activity to the game flow, like in pervasive and mixed-reality games. These features can potentially increase both the enjoyment of players and the amount of activity performed.

Commercial transfer. In order to apply the PLAY, MATE! design to a game, the game needs to be modified to integrate the motivational component. The application of the PLAY, MATE! design to Neverball was straightforward, as Neverball is a General Public Licence game with accessible and modifiable source code. However, this task may be challenging for commercial games, which in the majority of cases neither disclose their source code nor support unsanctioned modifications. This limitation can be mitigated if active games were developed by commercial gaming companies. As discussed earlier, the leading commercial game consoles already provide peripherals capable of capturing player's activity. This work showed the appeal and acceptance of activity-motivating games, and it naturally invites commercial production and distribution. Given the standardized peripherals and the availability of the source code, the effort required by large-scale games companies to develop an active version on top of an existing sedentary game is modest. Furthermore, the life cycle of a single game is short, such that the uptake of the PLAY, MATE! design by large-scale companies and its integration with multiple game titles and established series of games could increase the chances of the desired impact on health.

9.2 Run, Tradie, Run!

In response to these limitations and to facilitate a large-scale evaluation, we developed Run, Tradie, Run! (RTR!), a new activity-motivating game following the PLAY, MATE! design. RTR! is a mobile game developed in collaboration with Secret Lab[24], a software development company that specializes in games and digital entertainment applications.

In RTR!, players take the role of a tradesman (in short, Tradie), who is solving the problems plaguing a virtual city: burst water pipes, power failures, gas leaks, and so on. Tradie has a limited time to resolve the problems and is required to cover large distances between the problem sites. Tradie's navigation through the city to the sites is guided by green arrows, which direct the Tradie towards the next problem that should be solved (Figure 21, left). When Tradie arrives at a site, he resolves the problem (Figure 21, right) and then directed to the next site. The game clock is always counting down, and the game is over when the time runs out. However, successfully approaching a problem site earns the Tradie extra time, such that the goal is to navigate as swiftly as possible from one site to another, while running around building and various city obstacles.

RTR! is designed such that it is difficult, although not impossible to complete in the allocated time. Being an activity-motivating game, players are able to "purchase" in-game commodities using virtual points, earned through real physical activity. These commodities assist Tradie in the game: simplify navigation or increase the Tradie's speed. The commodities can be divided into two categories: single-shot and session-based. Single-shot commodities include powerful jumps that allow to leap over buildings/obstacles, and speed boosts that turn on the Tradie's turbo speed for a limited time (Figure 22). The number of commodities available to purchase is limited by the points accumulated, but once acquired they can be used as and when players find appropriate. Unlike the single-shot commodities, session-based commodities remain in the Tradie's disposal for the rest of the playing session. Examples of permanent commodities include an overlay map that shows the location of the problems and visual aids that show multiple problem sites at once, allowing the Tradie to strategize his

[24]http://www.secretlab.com.au

Fig. 21. RTR!: city navigation interface (left) and problem site (right).

Fig. 22. RTR!: use of consumable commodities: jump (left) and boost (right).

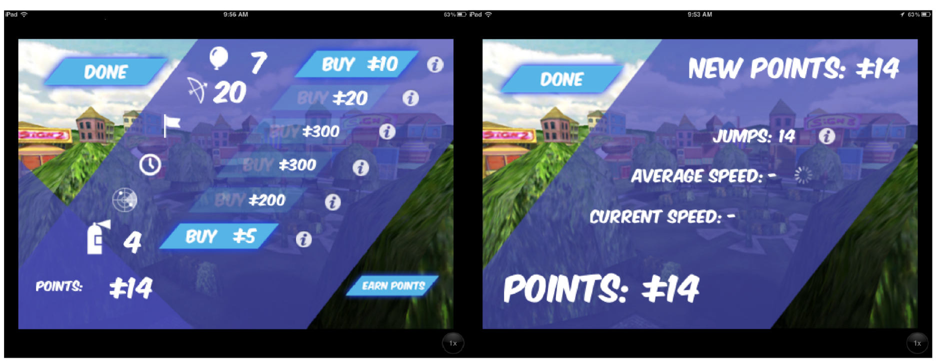


Fig. 23. RTR!: repository of commodities (left) and activity component (right).

approach to problems. The permanent commodities are generally more useful than the single-shot ones and require more points to purchase. Players can access the repository of commodities at any time and purchase more commodities (Figure 23, left).

As mentioned, players can purchase the in-game commodities using points that are earned by performing real physical activity. RTR! differs from the initial Neverball design in that players can earn points both during and separately of game play. While still allowing the players to pause the game and earn points, RTR!, can log players' activity sessions external to the game and accumulate points for use in game play.

The points are earned using an activity logging feature of RTR!, such that players can earn points when performing casual physical activity. The activity component recognizes and tracks two types of physical activity: jumping and running/walking. Jumping is detected via the mobile device's built-in accelerometer, which measures the acceleration and forces that the device is being subjected to. Running and walking are measured using the device's positioning service, which determines the players current location via GPS. The raw count of jumps and the distance captured by the activity component are shown to the player, and they are also converted into the game points (see Figure 23, right).

RTR! directly addresses two of the previously discussed Neverball's limitations: long-term health impact and activity interface. The activity performed by RTR! players is taken beyond the immediate context of the game. That is, players can earn points not only when these are needed by the gameplay, but at any time. For example, the activity component can be invoked when walking outdoors, such that the distance traversed and the activity performed are captured by the activity logger and converted into points, which can be later used to purchase game commodities. This facilitates higher impact on health and lifestyle, as the increased motivation to perform physical activity pertains not only to the game playing segment, but to an entire daily routine. Also, the requirement for a dedicated activity interface is satisfied, as mobile phones provide several sensing technologies, two of which (accelerometer and GPS) are exploited by RTR!. As such, the mobile phone serves as the game interface and the activity interface at the same time.

Three other limitations, wide applicability, commercial transfer, and game related activity, are addressed to a limited extent in RTR!. With respect to the applicability limitation, RTR! practically exemplifies the application of the PLAY, MATE! design to a new type of games. In this case, the in-game rewards pertain not only to one parameter of the game, as in Neverball, but they enrich player experience and provide several aids of differing nature and longevity. Thus, RTR! provides another example for the application of the design and supports our conjecture that the PLAY, MATE! design is applicable to a variety of games, which model player-game interaction using quantifiable features, like time, energy, or skills. Also, RTR! is developed in collaboration with a commercial game development company and it will be marketed as a typical mobile game through the established distribution channels of the App Store. Although RTR! is not aimed at the three leading game consoles, the involvement of commercial company indicates the attractiveness of the design for the gaming industry and increases the potential of future large-scale commercial transfer. Furthermore, the segment of mobile gaming is growing steadily in the recent years, such that the App Store marketing of the game could increase the uptake of RTR! and boost this transfer. Finally, RTR! demonstrates a better integration of physical activity with the game than Neverball, as jumping and running in real world allows Tradie to leap over buildings and turn on the turbo speed, that is, to jump and run in the game. However, the instantaneous rewards for activity performed while playing were not included in RTR!, primarily due to the theme and platform of the game. For example, allowing Tradie to leap over buildings if players jump in reality was found too difficult when controlling the game on a handheld device, and this feature was not included.

Finally, the limitation of balancing between activity and enjoyment was not addressed in RTR! due to the differing nature of mobile game sessions. The mobile playing is characterized by relatively short gaming sessions, for instance, when commuting or between other activities. The short playing sessions aggravate the task of gathering sufficiently accurate player information needed for personalization. As a result, we opted not to include any personalized or player-adapted functionalities in RTR!. We intend to address this limitation and apply gamification to the performance of physical activity through mixed reality techniques in future activity-motivating games we plan to develop.

RTR! will be marketed through the App Store and it will provide us with a testbed for uncontrolled evaluation of the acceptance of the activity-motivating games in players' natural environment. Not only we will be able to assess the uptake of the game and its popularity (number of downloads), but we will also obtain valuable information regarding the amount of casual activity performed by players and the role of the game in motivating this activity.

10. CONCLUSIONS AND FUTURE WORK

In this work we presented and evaluated the PLAY, MATE! design for computer games that motivate players to perform physical activity. The main idea underpinning the design is that a players' engagement with computer games and their enjoyment of playing can motivate them to perform physical activity. In the design, performing real physical activity was rewarded with virtual in-game rewards. We presented the main components of the design, exemplified its application to a publicly available game, and experimentally evaluated the acceptance of the design.

We presented the results of a two-part user study involving more than 200 players aged between 9 and 12 years old. The study allowed us to draw several important conclusions. First, it confirmed the validity of the main idea of the design, showing that engagement with games can be leveraged to motivate the players to perform physical activity while playing. Second, it showed that despite performing more physical activity and accurately perceiving the amount of activity performed, the players did not report a decrease in perceived enjoyment of playing an activity motivating game. Analysis of players according to their observed gaming skills showed that the amount of physical activity performed is inversely correlated to a player's gaming skills, leading to more skilled players performing less activity. To address this, we developed adaptive techniques that balance the amount of activity performed regardless of player skills. Our evaluation showed that the adaptive techniques addressed the imbalance of activity performed without making the game sessions less enjoyable. We discovered that the adaptive techniques could be applied to increase the difficulty of game tasks and increase player enjoyment. Finally, a questionnaire aimed at parents of the study participants showed that the PLAY, MATE! design was accepted by adults.

In summary, this work provides several important contributions. First, it presents the PLAY, MATE! design for activity-motivating games and demonstrates the acceptance of the design. Second, it proposes two techniques for adaptive application of the design. Thirdly, it discusses the limitations of the current design and presents the application of the design to a new mobile game. These contributions demonstrate the potential of activity-motivating games. The conducted evaluation shows that physical activity can be practically integrated into normally sedentary games and successfully increase the amount of activity performed by players without changing their perception and enjoyment of playing. Furthermore, adaptive application of the design does not impact on the enjoyment of playing but can balance the amount of activity being performed. Finally, the new application of the PLAY, MATE! design demonstrates how it can be applied in the mobile gaming environment.

These findings also raise several challenging research questions that will be investigated in the future. The first one addresses a better integration of physical activity with the active games. Due to the simplicity of Neverball and the mobile platform of RTR!, the activity was decoupled from the gameplay and did not match any particular action of the game character. This decoupling could potentially decrease the enjoyment of playing and discourage players from performing the activity. Hence, we will investigate the ways of linking the physical activity to the game mechanics and the use of wearable activity interfaces, which allow players to control the game simultaneously with performing physical activity. Also, we will investigate ways to further improve the enjoyment of playing and increase the amount of physical activity performed. We intend to offer different rewards for various types of activity, intentionally diversify the rewards in ways that reflect their interaction with the game, and explore the ways to make the physical activity more enjoyable. These can upgrade the PLAY, MATE! design into a ubiquitous motivator of physical activity.

APPENDIXES

Appendix 1. Prestudy Questionnaire

Age		
Grade		
Gender	☐ boy	☐ girl
Height	_____cm	
Weight	_____kg	

Gaming habits	☐ I don’t play computer games at all
	☐ I play very rarely, usually not at home
	☐ I usually play at home, 1–2 times a week, less than 1 hour every time
	☐ I usually play at home, 4–5 times a week, less than 1 hour every time
	☐ I usually play at home, every day, less than 1 hour every time
	☐ I usually play at home, every day, more than 1 hour every time

I usually play	☐ Internet/online games
	☐ Usual computer games
	☐ Playstation/XBox games
	☐ Wii/Wii sport games
	☐ Gameboy/Nintento-DS games
	☐ Other: ____________________

Appendix 2. Introductory Levels Questionnaire

Congratulations! You have just completed level L!

It took you only X seconds to complete this level. Well done!

How much you enjoyed this level?	How difficult was this level for you?
☐ absolutely hated it	☐ very difficult
☐ did not like	☐ quite difficult
☐ OK, but could be better	☐ somewhat difficult
☐ liked it	☐ somewhat easy
☐ it was fun	☐ quite easy
☐ so cool, really loved it	☐ very easy

Imagine your time limit to complete this level would be Y>X seconds.

How much would you enjoy it?

☐ would absolutely hate it
☐ would not like
☐ would be OK, but could be better
☐ would like it
☐ would be fun
☐ would be cool, would really love it

How difficult would it be for you?

☐ very difficult
☐ quite difficult
☐ somewhat difficult
☐ somewhat easy
☐ quite easy
☐ very easy

Imagine your time limit to complete this level would be Z<X seconds.

How much would you enjoy it?

☐ would absolutely hate it
☐ would not like
☐ would be OK, but could be better
☐ would like it
☐ would be fun
☐ would be cool, would really love it

How difficult would it be for you?

☐ very difficult
☐ somewhat difficult
☐ quite difficult
☐ somewhat easy
☐ quite easy
☐ very easy

Appendix 3. Poststudy Questionnaire

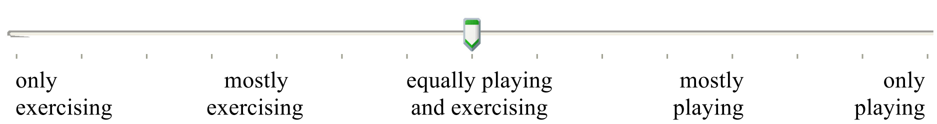
How much you enjoyed playing Neverball today?

☐ absolutely hated it
☐ did not like
☐ OK, but could be better
☐ liked it
☐ it was fun
☐ was cool, really loved it

(If previous answer was not 'hated' or 'did not like')
What made it enjoyable? (tick as many as you want)

☐ I liked to navigate the ball through the maze
☐ I liked to collect coins in the maze
☐ I liked to be able to stop the game
☐ I liked to use the pedometer
☐ I liked to exercise and play at the same time
☐ I liked to get control over the remaining time
☐ I liked to stretch myself after playing a while
☐ I liked to see that exercising gives me more time
☐ I liked to see the number of coins of the other player *
☐ Other: ____

Would you say that you were playing or exercising? Drag the slider to the position that you will is the most suitable. Leftmost means only exercising, rightmost means only playing.



Appendix 4. Parent Questionnaire

Dear Parent/Guardian,

Recently, your child has participated in a study of physical activity motivating games. This is a new type of computer games, in which physical activity of the player becomes part of the game. The player is equipped with a tiny activity monitor that captures the performed activity and transmits it to the game. This information is processed and the game rewards the player depending on the amount of the performed activity. That is, the player trades real physical activity for virtual game rewards.

In this questionnaire we would like to estimate your attitude towards the physical activity motivating games. This will help us to better estimate the potential of a wide spread distribution of such games.

Let us start with the existing gaming habits.

How long do you allow your child to plays computer games every day?
☐ less than 30 minutes
☐ 30 minutes to 1 hour
☐ 1 hour to 2 hours
☐ more than 2 hours

How much do you spend on computer games and accessories every month?
☐ less than $20
☐ $20 to $50
☐ $50 to $100
☐ more than $100

Imagine that in the future all the existing sedentary computer games would be replaced by their active versions, in which the players have to perform physical activity as part of the game.

How long would you allow your child to play active games every day?
☐ less than 30 minutes
☐ 30 minutes to 1 hour
☐ 1 hour to 2 hours
☐ more than 2 hours

How much would you spend on active games and accessories every month?
☐ less than $20
☐ $20 to $50
☐ $50 to $100
☐ more than $100

Some information about you

Age	------
Gender	☐ male ☐ female
Gaming habits	☐ I don’t play computer games at all ☐ I play very rarely, usually not at home ☐ I usually play at home, 1–2 times a week, less than 1 hour every time ☐ I usually play at home, 4–5 times a week, less than 1 hour every time ☐ I usually play at home, every day, less than 1 hour every time ☐ I usually play at home, every day, more than 1 hour every time

Upon filling this questionnaire out, please return it to the school. Thank you in advance for your cooperation!

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