Physical Activity Motivating Games: Virtual Rewards for Real Activity

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ABSTRACT

Contemporary lifestyle has become increasingly sedentary: little physical (sports, exercises) and much sedentary (TV, computers) activity. The nature of sedentary activity is self-reinforcing, such that increasing physical and decreasing sedentary activity is difficult. We present a novel approach aimed at combating this problem in the context of computer games. Rather than explicitly changing the amount of physical and sedentary activity a person sets out to perform, we propose a new game design that leverages user engagement to generate out of game motivation to perform physical activity while playing. In our design, players gain virtual game rewards in return for real physical activity performed. Here we present and evaluate an application of our design to the game Neverball. We adapted Neverball by reducing the time allocated to accomplish the game tasks and motivated players to perform physical activity by offering time based rewards. An empirical evaluation involving *180* participants shows that the participants performed more physical activity, decreased the amount of sedentary playing time, and did not report a decrease in perceived enjoyment of playing the activity motivating version of Neverball.

Author Keywords

Serious games, game design, physical activity, motivation, behavioural change, user study.

ACM Classification Keywords

H.5.2 [**Information Interfaces and Presentation**]: User Interfaces, Interaction Styles, I.2.1 [**Artificial Intelligence**]: Applications and Expert Systems, Games.

General Terms

Design, experimentation, human factors.

INTRODUCTION

According to the World Health Organisation, over *1.6* billion individuals worldwide are overweight or obese [19]. One of the reasons for this phenomenon is positive energy balance, i.e., the condition where one's energy intake exceeds one's energy expenditure. While a high energy intake is explained by unbalanced diet and increased caloric consumption, low energy expenditure is explained by an increasingly sedentary lifestyle: little physical and much sedentary activity.

The nature of the sedentary activity is often addictive and self-reinforcing [8]. Hence, adjusting the energy balance by explicitly increasing the amount of physical and decreasing the amount of sedentary activity is not easy. In our research we present an alternative approach aimed at combating this problem. Rather than setting out to explicitly decrease the amount of sedentary activity in one's normal lifestyle, we propose to change one common sedentary activity, video game playing, to incorporate certain forms of physical activity. We present a novel design of computer games, which leverages players' enjoyment and engagement with a game to motivate them to perform some physical activity during what otherwise would have normally been a pure sedentary activity.

Our design can be applied to a wide variety of games, in which a player's game character (or avatar) is represented by quantifiable features, e.g., remaining time, energy, and maximal speed. To motivate players to perform some physical activity while playing, we modify the design of computer games such that players can gain virtual game rewards in return for the real life physical activity they perform [1]. Note that the physical activity is not necessarily related to the game, such that the motivation is considered as *out of game*. Physical activity is captured by wearable sensors attached to players. In our design, at any point in time players can perform physical activity, which will instantaneously reinforce their game character, e.g., gain time, energy, or speed. This reinforcement increases the likelihood of accomplishing the game tasks and players' enjoyment, while gradually increasing the difficulty of the tasks to motivate players to perform further physical activity. This novel game design is referred to in this paper as *PLAY, MATE!* (PhysicaL ActivitY MotivATing gamEs).

This paper presents and evaluates an application of the *PLAY, MATE!* design to a publicly available game, Neverball. In Neverball, players navigate a ball to avoid obstacles and collect coins, while accomplishing these tasks in a limited time. We adapted Neverball according to the *PLAY, MATE!* design: reduced the time allocated to accomplish the game

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tasks, and motivated players to perform physical activity by offering time based game rewards. Players were equipped with a tri-axial accelerometer configured to recognise jump events, such that for every captured jump the players gained one extra second to accomplish the game tasks.

We conducted an empirical evaluation involving *180* participants aged *9* to *12*. The evaluation ascertained that applying the *PLAY, MATE!* design significantly increases the amount of physical activity performed while playing and changes the distribution between sedentary and active playing time. The results obtained for different groups of participants showed that players having lower gaming skills were observed to perform more physical activity than players having higher gaming skills. Although participants performed physical activity, they did not report a decrease in perceived enjoyment of playing.

Hence, the contributions of this work are three-fold. Firstly, we propose and exemplify the novel *PLAY, MATE!* design for physical activity motivating games. Secondly, we empirically evaluate the acceptance of the design and its influence on real players. Thirdly, we show that the acceptance of the design is player dependent. These results demonstrate the great potential of physical activity motivating games and call for future research on adaptive application of the *PLAY, MATE!* design to other games.

RELATED WORK

Information technology solutions to the obesity problem have been studied from various perspectives. Several works focused on the design issues of such applications. Consolvo *et al.* discussed general design principles of physical activity motivating technologies [4]. Campbell *et al.* focused on specific game design principles that can be applied to fitness applications [3]. Several practical applications followed these design principles.

Lin *et al.* developed a social application recording users' physical activity and linking it to the growth and activity of a virtual fish [9]. Toscos *et al.* developed a mobile application recording the users' physical activity and sending persuasive messages encouraging further exercising [17]. In both cases, the physical activity of the users was quantified by the number of user's steps captured by a pedometer and then manually fed into the system. Hence, the users were requested to carry the pedometer everywhere and to periodically feed the counter reading into the system. From the technical perspective, physical activity self-reporting was often discovered to be inaccurate [18]. From the behavioural perspective, the lifestyle change was mostly accepted by already motivated users, while other users resisted it.

An alternative approach offered by Mueller *et al.* was exertion interfaces, which deliberately require users to invest physical effort as an integral part of the interaction [12]. Recently developed exertion interfaces include soccer, basketball, table tennis, jogging, air hockey, arm wrestling, boxing, tug of war, and other sports related activities.

Several applications take a persuasive approach to combating the obesity problem and influencing users. Nawyn *et al.* developed a home entertainment system remote control promoting a reduction in TV viewing time and an increase in non-sedentary activities [13]. Maheshwari *et al.* presented a user study evaluating the effectiveness of persuasive motivational SMS messages for overweight individuals [10]. Out of a plethora of online physical activity motivating applications surveyed by Zhu [20], only two led to short-term influence in promoting physical activity. Similarly to the information technologies, persuasive applications were mostly accepted by already motivated users and resisted by others.

Game technologies involving players' physical activity have been developed and successfully disseminated by commercial products, like Dance-Dance Revolution (www.konami.com/), Nintendo Wii (www.nintendo.com/), and PCGamerBike (www.pcgamerbike.com). The first is a dance pad with arrows, on which players step to control the game. The second uses an accelerometer-equipped input device, allowing players to control the game by their body movements. The third is a programmable controller using bicycle pedalling motion to control the game. Despite being similar to the proposed approach in motivating players to perform physical activity while playing, all the above should be treated as commercial products providing bodily interfaces (or controllers) to interact with computer games rather than motivators of physical activity.

Two works investigated practical integration of physical activity into computer games. Fujiki *et al.* developed NEAT-o-Games, in which a player's activity captured by an accelerometer were transmitted to a PDA and visualised by a simple race-like game interface [5]. The captured data affected the speed of the game character and its standing in comparison to other players, while facial expression of the player's avatar reflected satisfaction with the activity performed. Stanley *et al.* developed a variant of chess, in which attacking and defensive skills of chess pieces depended on a player's accumulated activity level captured by mobile sensors [15]. However, the above games were designed for the studies and lacked the attractiveness and immersion of real commercial games. Rather than designing new games and interfaces, our work aims to develop and disseminate a new game design that, if integrated with a variety of existing and future games, will motivate players to perform physical activity while playing [1].

PHYSICAL ACTIVITY MOTIVATING GAME DESIGN

The core part of the gaming process consists of player interaction with the game environment. Typically, the interaction is indirect and is mediated by the game character, which can be considered as the player's embodiment in the virtual game environment. Hence, a player controls the game character, which actually interacts with the game environment. The interaction between the player and game character is unidirectional: the player manipulates the game character and controls its actions. Conversely, the interaction between the game character and the game environment is bidirectional: 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. The light arrows in Figure 1 schematically depict the interactions taking place between the player, the game character, and the game environment.

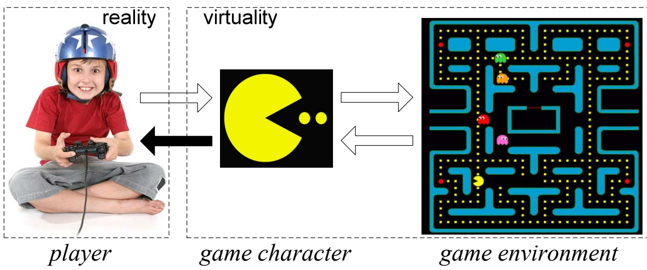

Figure 1. Player interaction with the game environment.

Since no direct interactions normally occur between the players and the game environment, we consider the game character as the model of the player in context of the game. In most contemporary games, the game character can be modelled by a set of quantifiable features reflecting its state in the game and respective values of these features. The value of a feature is modified either directly by the game environment, e.g., reduction of the remaining time, or by the player: (1) manipulating the game character, e.g., changing the velocity, or (2) controlling the interactions between the game character and the game environment, e.g., collecting game artefacts. It should be noted that these modifications mostly occur simultaneously and the player controls the interactions between the game character and the game environment to respond accordingly.

To sustain a prolonged engagement of the player with the game, the flow of the game is normally divided into several tasks of gradually increasing degrees of difficulty, which should be accomplished by the player. Accomplishing a task means reaching the threshold value of a certain critical feature (or combination of values across a number of features), while satisfying other constraints and non-critical features of the game. According to [16], the ability to accomplish the tasks is one of the main factors for the enjoyment of playing.

Design Principles of *PLAY, MATE!*

The goal of the *PLAY, MATE!* design is to change the sedentary nature of game playing to include certain forms of physical activity. In our design, players' engagement with the game and enjoyment of playing is leveraged to motivate them to perform physical activity and gain virtual game rewards. In essence, the motivation to perform physical activity establishes the missing feedback interaction between the game environment and the players (the black arrow in Figure 1). Hence, it aims to influence the players and eventually achieve the desired behavioural, i.e., more active game playing.

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

- Game related motivator. The player is made aware of the possibility of gaining virtual rewards in the game in return for performing real physical activity. In addition, the game is modified in a way that motivates the player to perform physical activity: certain features of the game are disabled or diminished and these can be enabled or reinforced by the activity rewards.
- Activity monitor. The player is provided with an external wearable interface capturing the physical activity performed, instantaneously processing it, and converting the captured activity of into virtual game rewards.
- Game control. Since performing physical activity and controlling the game simultaneously could be complicated the player is provided with enhanced control over the flow of the game (speed, pausing, etc).

Using the above modifications, the player is motivated to perform physical activity as follows. Firstly, the game is modified such that certain game features are disabled or diminished. Secondly, the player is aware of the possibility of gaining virtual rewards, i.e., enable or reinforce the features, in return for performing physical activity. A composition of these two, combined with the existing engagement of the player with the game and the enjoyment of playing, motivate the player to perform physical activity. The player can use the enhanced game control to interrupt the sedentary play and perform physical activity. When performed, the physical activity is captured by the activity monitor, processed by the game and converted into virtual game rewards.

We would like to highlight the non-coercive nature of the *PLAY, MATE!* design. First, the game related motivators are introduced in a subtle manner, such that the game tasks are still accomplishable [16]. Hence, the player can accomplish the tasks either in a difficult way by sedentary playing or in an easier way by performing physical activity and gaining the rewards. Second, the reinforced game features are instantaneously visualised, such that the player remains in control of the decision regarding when and how much physical activity to perform.

Note that the effort required to apply the *PLAY, MATE!* design to an existing game (game related motivator implantation and activity monitor calibration) is negligible in comparison with the effort required to design and develop a new game. This is due to the fact that when the design is applied to an existing game, many available components, such as game logic, input/output, visualisation, and others, can be reused rather than developed from scratch.

APPLYING *PLAY, MATE!* TO NEVERBALL

To empirically evaluate the *PLAY, MATE!* design, we applied it to an open source Neverball game (www.neverball.org). In Neverball, players have to navigate a ball to a target point through a maze shaped surface and collect a required number of coins, all in a limited time (see Figure 2-left). Control over the ball is achieved by inclining the game surface, which causes the ball to roll. Neverball consists of multiple levels with gradually increasing degrees of difficulty: the maze structure, location of obstacles and pitfalls, number of coins to collect, and amount of time allocated vary considerably across different levels. We selected and used in the evaluation *16* levels suitable for inexperienced Neverball players.

Figure 2. Activity monitor (left), Neverball interface (right).

Two game related motivators were applied. The first motivator refers to the amount of time allocated to accomplish the levels. We shortened the level times[1] and made players aware of the possibility of gaining extra time in return for performing physical activity (highlighted in Figure 2-left). We conjectured that players' engagement with the game and aspiration to accomplish the levels would actually motivate them to gain extra time by performing physical activity. Since players have to collect the required number of coins in a limited time to complete Neverball levels, this motivator is referred to as the *direct motivator*. Table 1 summarises the original and shortened level times (in seconds) and the ratio between the two.

level	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
t_{orig}	*240*	*90*	*120*	*180*	*180*	*90*	*240*	*120*
t_{short}	*60*	*38*	*40*	*75*	*75*	*38*	*100*	*40*
t_{short}/t_{orig}	*0.25*	*0.42*	*0.33*	*0.42*	*0.42*	*0.42*	*0.42*	*0.33*

level	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*
t_{orig}	*180*	*120*	*180*	*300*	*120*	*180*	*240*	*240*
t_{short}	*45*	*40*	*60*	*75*	*40*	*60*	*100*	*100*
t_{short}/t_{orig}	*0.25*	*0.33*	*0.33*	*0.25*	*0.33*	*0.33*	*0.42*	*0.42*

Table 1. Original and shortened level times.

[1] The shortened level times were based on playing times exhibited by an expert player in a pilot session.

The second motivator refers to the competitiveness of players. We introduced a virtual opponent and players were told that their opponent's playing was synchronised with their own. The graphical interface of the game was modified to visualise the number of coins collected by the opponent (highlighted in Figure 2-left). In fact, we modelled the opponent to outrun players, such that the opponent's probability to collect coins was inversely proportional to the difference between the number of coins collected by the opponent and the player. Players could stop the opponent's progress by collecting the required number of coins and performing physical activity. We conjectured that players' aspiration to defeat the opponent will actually motivate them to gain extra time by performing physical activity. Since players do not necessarily have to defeat the opponent to accomplish Neverball levels, this motivator is referred to as the *indirect motivator*.

We used a compact tri-axial accelerometer as the activity monitor to capture player's physical activity [6]. The activity monitor was attached to the player's waist (not to interfere with player's motion) using an elastic band (see Figure 2-right) and wirelessly transmitted the three acceleration signals *500* times per second to a receiver attached to the computer. Let us denote by $x(t)$, $y(t)$, and $z(t)$ the three acceleration signals and by X, Y, and Z the respective baseline signals obtained when the accelerometer was still. We approximated the accelerating magnitude by:

$$AM(t) = [(x(t)-X)^2 + (y(t)-Y)^2 + (z(t)-Z)^2]^{1/2}$$

We filtered out noise and abnormal spikes, performed time based normalization, and applied magnitude and time based thresholds to discretise the acceleration signal into activity bursts, which are referred to in the rest of the paper as *jumps*. The jumps were converted into time based rewards in Neverball, such that for every jump players gained one extra second to accomplish a Neverball level. The increased remaining time was instantaneously visualised, such that players were in control of the amount and timing of the physical activity they perform.

In summary, the *PLAY, MATE!* design is applied to Neverball as follows. Players are motivated to perform physical activity by applying the reduced time and competitor motivators and making them aware of the possibility of gaining extra time by performing physical activity. When the remaining time is perceived to be insufficient, players can pause the game and perform physical activity, e.g., jump, or step on the spot. The physical activity is instantaneously captured by the activity monitor, transmitted to Neverball, processed and visualised. When the remaining time is perceived to be sufficient, the player restarts the game and resumes the sedentary playing.

EMPIRICAL EVALUATION

We conducted an empirical evaluation aimed at ascertaining the acceptance of the *PLAY, MATE!* design as indicated by the amount of physical activity performed and perceived enjoyment of playing. *180* participants from three primary schools in the Hobart (Australia) area participated in the evaluation. We presumed that the Neverball game is appropriate for players aged between *9* and *12* and recruited accordingly: *25* participants were *9* years old, *49* were *10* years old, *74* were *11* years old, and *32* were *12* years old. *88* of them were boys and *92* were girls. Participants having previous experience with Neverball or having limitations preventing them from performing mild physical activity were excluded.

The *180* participants were randomly divided into four groups of *45*. The first group played the normal sedentary version of Neverball, i.e., no game related motivator was applied. This group is considered the baseline group (*BL*), since they represent the current sedentary gaming process, which does require players to perform physical activity. The second group was introduced with the *indirect motivator* of virtual competitor and it is referred to as *IM*. The third group was introduced with the *direct motivator* of the shortened level times and it is referred to as *DM*. The fourth group was introduced with *both motivators* (*BM*): the virtual competitor was visualised and the level times were shortened.

The participants were involved in the following activities. Initially, they answered a pre-study questionnaire collecting their demographic details (age, grade, gender, height, and weight) and information regarding their gaming skills (gaming platforms used and average playing time). Then, they played three introductory Neverball levels. The goal of these three levels was to familiarise the participants with the constraints and controls of the game and gain some indication of their objective gaming skills (will be discussed later). Next, the participants were equipped with the activity monitors and instructed about the possibility of gaining extra time in return for performing physical activity. Then, they had a free and unconstrained *20* minute playing session, in which they could play the version of Neverball according to their group classification. Finally, they answered a post-study questionnaire and reflected on their perception of the playing session and the factors that made their playing enjoyable.

It should be highlighted that all the participants regardless of their group classification were equipped with the activity monitor and aware of the possibility of gaining extra time in return for the performed physical activity. Even in the *BL* group, the participants could perform physical activity, although they had no real motivation to do this. This minimises the novelty effect of using the activity monitor.

Activity-based acceptance

From our perspective, the main indicator of the acceptance of the *PLAY, MATE!* design is the amount of physical activity performed while playing. Hence, to ascertain its acceptance, we focus on two indicators: (1) the amount of physical activity performed, and (2) the players' reported perception of the enjoyment of playing. The first shows whether the *PLAY, MATE!* design can actually motivate players to perform physical activity, while the second shows whether they still find the game enjoyable.

The amount of physical activity performed was quantified by the number of jumps captured by the activity monitor. Figure 3 depicts the average number of jumps performed across the different groups.

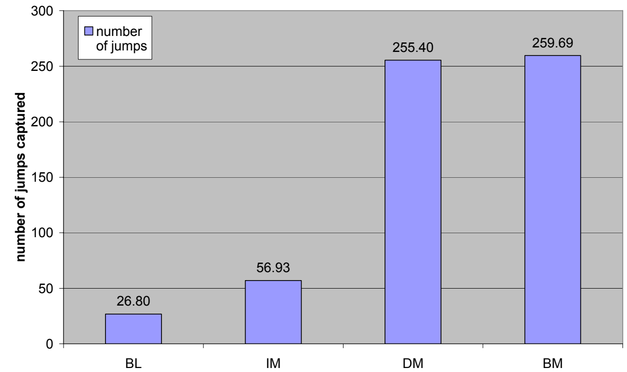

Figure 3. Average number of jumps captured.

The results show that the number of jumps performed by users in the *BL* group, who had no motivation to perform physical activity, is lower than the number of jumps performed by users in the other groups. The number of jumps recorded increases moderately in the *IM* group and considerably in the *DM* and *BM* groups. The differences are statistically significant: $p=0.0084$ for the *IM* and $p=1.84E\text{-}07$ for the *DM* group[2]. No statistically significant difference was observed between the *DM* and *BM* groups.

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 informed by the amount of time the Neverball game was played and paused, respectively, assuming that participants did not spend time on unrelated activities and neglecting the transition times. Figure 4 depicts the average relative time distribution between T_{sed} and T_{act} across the different groups.

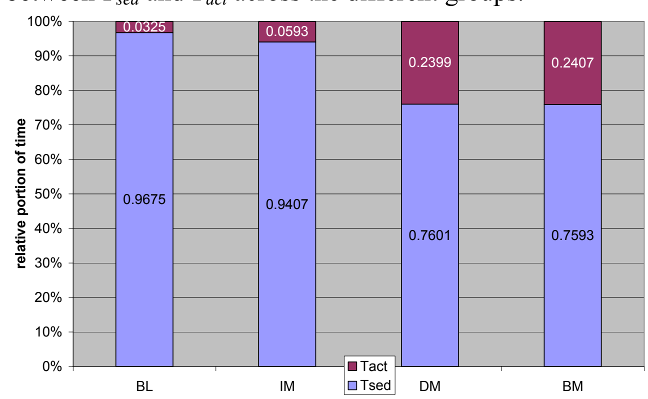

Figure 4. Distribution between sedentary and active time.

[2] All statistical significance results hereafter refer to a two-tailed t-test assuming equal variances.

The results show two patterns of behaviour. 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. However, for the *DM* and *BM* groups the time distribution was notably different. Respectively, *76.01%* and *75.93%* of time was sedentary, while *23.99%* and *24.07%* of time was active. The difference between the *IM* and *BL* groups was statistically significant, $p=0.049$. The difference between the *DM* and *BL* groups was also statistically significant, $p=3.84E\text{-}22$. The difference between the *BM* and *DM* groups was not statistically significant.

Comparative Analysis of Interaction

To understand the influence of game motivators on the participants, we compare the interaction with the game across the different groups. For this, we use two other observations. Table 2 shows the average number of levels completed by the participants. As can be seen, the *BL* group clearly outperforms the other three groups. The difference between the *BL* group and (the next best) *BM* group is statistically significant, $p=0.014$. The *IM*, *DM*, and *BM* groups are comparable with the difference between them not being statistically significant.

group	BL	IM	DM	BM
levels completed	10.47	8.87	8.69	8.96

Table 2. Average number of levels completed.

Table 3 shows the average number of coins c_i collected while playing Neverball level number i. It should be highlighted that although the difficulty of the levels generally increases with i, the number of available coins and the amount of time allocated for the levels vary. Hence, direct comparison of c_i across the levels is inappropriate. However, the results show that for any i the maximal value of c_i was achieved by the the *IM* group. The *BL* group outperformed the *DM* and *BM* groups (clearly seen for levels 6, 7, and 10). The *DM* and *BM* groups were comparable and the difference between them was not statistically significant.

level	1	2	3	4	5
BL	13.52	29.76	58.20	30.51	48.75
IM	14.52	32.11	62.89	34.16	52.16
DM	13.02	29.62	57.76	29.70	47.64
BM	13.07	29.73	56.84	28.87	47.34

level	6	7	8	9	10
BL	41.86	101.92	75.23	34.52	98.00
IM	46.73	113.01	78.22	37.75	102.29
DM	36.18	89.35	75.22	33.38	87.27
BM	35.88	85.69	73.10	32.44	85.86

Table 3. Average number of coins collected.

Figures 3 and 4 and Tables 2 and 3 allow us to understand the influence of game motivators. The number of levels completed in the *20* minute playing session was highest in the *BL* group. Hence, in the *IM*, *DM*, and *BM* groups the participants spent more time on average on each level and game motivators did influence their interaction with the game. However, the actual influence of game motivators was diverse. We will analyse this influence and compare the *IM*, *DM*, and *BM* groups to the *BL* group.

- *IM*. The indirect motivator slightly increased the amount of physical activity performed while playing and increased c_i. Hence, the participants spent more time on each level and collected more coins. This was achievable without performing much physical activity as the level times were not shortened and the allocated time was sufficient. That is, the indirect motivator mainly motivated the participants to collect more coins than was required for each level. It should be noted, however, that when the level times were perceived insufficient, the participants did perform physical activity.
- *DM*. The direct motivator considerably increased the amount of physical activity performed and decreased c_i. Since the level times were shortened, the allocated time was mostly insufficient to accomplish the levels. Hence, participants performed physical activity to gain extra time. 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 participants performed physical activity while playing. The number of coins collected decreased slightly (although still remaining sufficient for accomplishing the levels), as the participants were mainly focused on accomplishing the levels in time rather than on collecting more coins.
- *BM*. Applying both motivators resulted in game interactions, which were very similar to the interaction observed when only the direct motivator was applied. This shows that the influence of the direct motivator, i.e., the shortened level times, was stronger than the influence of the indirect motivator of the virtual opponent.

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 [7]. Before analysing the participants' reported enjoyment, we assessed their perception of the amount of physical activity they performed while playing. In the post-study questionnaire the participants reflected on their perception of the *20* minute playing session on a [*-1*,*+1*] continuum, where *+1* is perceived as sedentary playing and *-1* is perceived as physical activity. Table 4 shows the average perception across the different groups.

group	BL	IM	DM	BM
playing perception	0.46	0.45	0.11	0.10

Table 4. Average perception of playing.

As can be seen, average perception of playing in the *BL* and *IM* groups is *+0.46*, i.e., the participants perceive the playing session as mostly sedentary activity. However, in the *DM* and *BM* groups the perception is *+0.11* and *+0.10*, respectively, i.e., the participants perceive the playing session as almost equally balanced sedentary and physical activity. This perception corresponds to the amount of physical activity shown in Figures 3 and 4.

To validate this, Figure 5 depicts the playing perception as a function of the number of jumps. A linear regression of the reported perceptions has a negative slope. Pearson's correlation value between the number of jumps and the perception of playing is *-0.47*. This ascertains that the perception of the participants is realistic: the perception of playing as a sedentary activity is inversely correlated with the number of jumps performed.

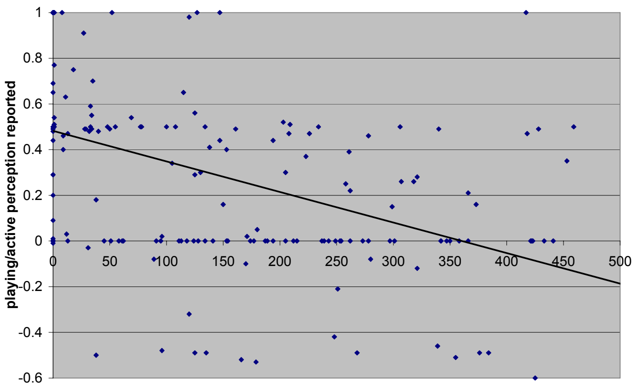

Figure 5. Perception of playing vs. number of jumps.

Although they realistically perceived the amount of physical activity performed, the participants did not report a decrease in perceived enjoyment of playing. Table 5 shows the average enjoyment of playing reported on a 6-Likert scale across the different groups. The reported enjoyment of playing in all four groups is very high and comparable, such that the differences are not statistically significant.

group	*BL*	*IM*	*DM*	*BM*
playing enjoyment	*5.53*	*5.51*	*5.47*	*5.49*

Table 5. Average enjoyment of playing.

We conjecture that applying the *PLAY, MATE!* design to Neverball had mixed influences on the enjoyment factors of playing. On one hand, performing physical activity while playing the game interrupted the flow of playing, as sedentary playing activity became interlaced with physical activity. This could have decreased the enjoyment of playing. On the other hand, players were provided with a new interaction mode with the game through the activity monitor. It is a new interface not available in the state of the art computer games, which allows more control over the game and could have increased the enjoyment. The results in Table 5 show that these factors balanced each other, such that the reported enjoyment did not change considerably.

The post-study questionnaire supports this conjecture. In the questionnaire, the participants were asked to reflect on the factors that made the playing experience enjoyable. They were presented with a list of factors and asked to tick all the questions with which they agree. Table 6 shows the number of participants that agreed with two questions of a particular interest.

The first question tangentially refers to the sedentary playing component. The agreement level slightly decreases in the *DM* and *BM* groups, in which the participants performed the greatest amount of physical activity. The second question refers to the possibility of gaining extra time in return for performing physical activity. As can be clearly seen, the agreement level increases considerably in the *DM* and *BM* groups, indicating that the participants liked the new interaction mode through the activity monitor.

I liked to ...	*BL*	*IM*	*DM*	*BM*
... control the ball in the maze	*33*	*32*	*28*	*27*
... get more time by doing physical activity	*15*	*20*	*29*	*31*

Table 6. Playing enjoyment factors.

Player dependency

In addition to assessing the acceptance of the *PLAY, MATE!* design, it is important to analyse its fluctuations across various types of players. For this, we segmented the participants according to several criteria and compared the results obtained for these segments. It should be highlighted that in the following analysis we refer only to the amount of physical activity performed by the participants, as the enjoyment of playing was similar across all the groups.

The first segmentation criterion refers to the gender of the participants. Previous studies showed a great degree of difference between boys and girls in terms of their gaming habits and attitude towards computer games [2]. According to most studies, boys play video games more than girls[3] and possess better gaming skills. We segmented the participants into boys and girls and compared the number of jumps and distribution between active and sedentary time. Figures 6 and 7 depict the results across the different experimental groups.

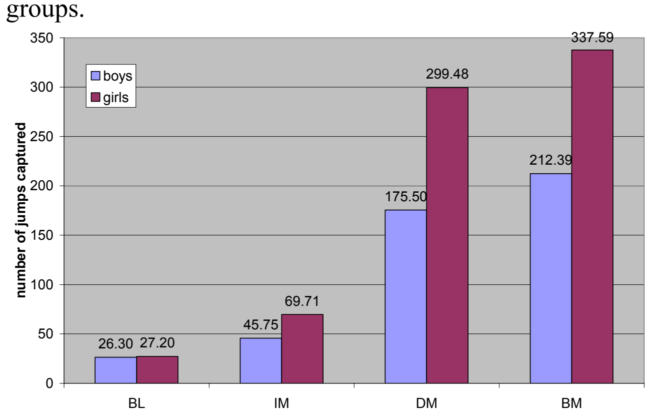

Figure 6. Average number of jumps captured.

[3] This was supported by our observations. In the pre-study questionnaire boys reported longer playing times than girls.

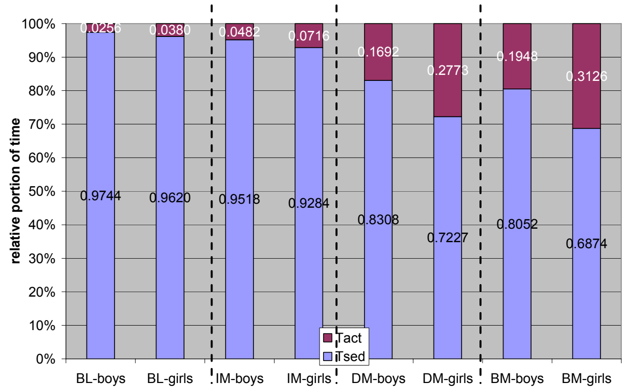

Figure 7. Distribution between sedentary and active time.

The results show that girls performed more physical activity than boys. This is reflected by the increased number of jumps and different time distribution: relative T_{act} observed for girls was longer than for boys, and respectively, relative T_{sed} observed for girls was shorter than for boys. This observation is valid across all the groups. The differences between boys and girls (both for the number of jumps and time distribution) are statistically significant for the *DM* and *BM* groups: p varies from $p=1.78E\text{-}04$ to $p=2.49E\text{-}05$ and not significant for the *BL* and *IM* groups.

The second segmentation criterion refers to the observed gaming skills of the participants. At the beginning of the study the participants played three introductory levels of Neverball. We used the observed playing times t_1, t_2, and t_3 that they spent to accomplish these levels as a basis for the gaming skills segmentation. We implemented a standard *K*-means clustering algorithm [11], which for $K=2$ segmented the participants into two groups, having higher and lower observed gaming skills, basing on their (t_1,t_2,t_3) vectors. Then, we compared the number of jumps and distribution between active and sedentary time in these segments. Figures 8 and 9 depict the results across the different experimental groups.

The results show that the participants having higher observed gaming skills performed less physical activity than the participants having lower gaming skills. This is reflected by both the increased number of jumps and time distribution between active and sedentary time. This observation is also valid across all experimental groups. The differences between the higher and lower skilled players (both for the number of jumps and time distribution) are statistically significant for the *BL* and *IM* groups: p varies from $p=2.52E\text{-}02$ to $p=3.58E\text{-}03$ and not significant for the *DM* and *BM* groups.

The results obtained for the two segmentation criteria can be generalised: the amount of physical activity performed is inversely correlated with the gaming skills of the player. This finding is expected, given that players having higher gaming skills have better chances of accomplishing the levels without requiring the rewards than players having lower gaming skills. As such, the former need the rewards to a lesser degree than the latter and perform physical activity accordingly.

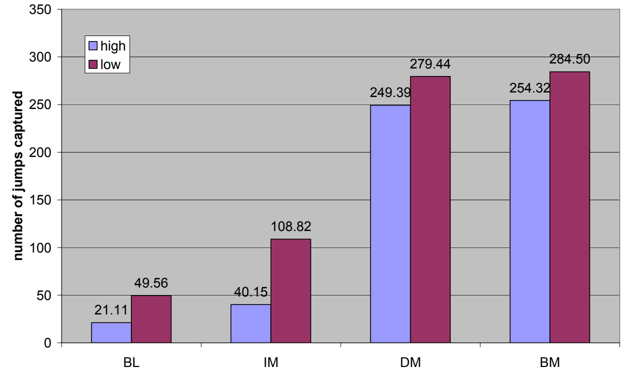

Figure 8. Average number of jumps captured.

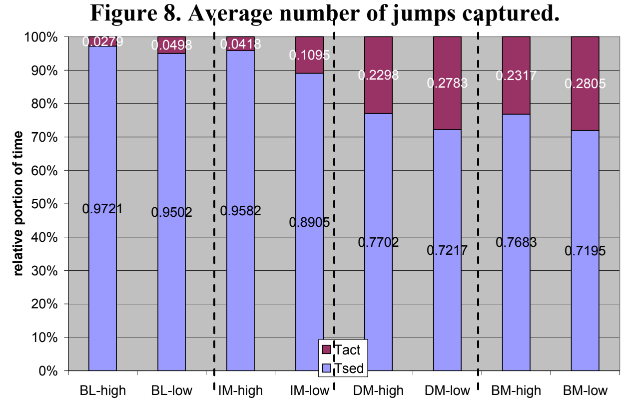

Figure 9. Distribution between sedentary and active time.

DISCUSSION

The results of the evaluation ascertain the main hypothesis behind the *PLAY, MATE!* design: engagement with games can motivate players to perform physical activity while playing. In this section we will discuss the most important design considerations stemming from the application of the design to Neverball and the lessons learnt from the study involving real users. These lay the basis for future development of physical activity motivating games.

Game difficulty. A player's ability to accomplish game tasks is one of the factors for the enjoyment of playing [7]. Hence, when the game is modified to introduce game related motivators, the difficulty of the game should be calibrated carefully, such that it will not become too difficult. Supported by the results of Figures 6 and 8, this introduces the issue of player dependent goal setting. In case of Neverball, the modified time limit to accomplish the levels can be tailored to player's gaming skills.

Virtual game rewards. Similarly to game difficulty, game rewards should also be player dependent. In the case of Neverball, the extra time gained in return for every jump can be tailored to player's gaming skills. This will allow to maintain a required amount of activity performed by all players and tailor the amount of activity performed to player's gaming skills.

Game integrated activity. Due to the simplicity and limitation of Neverball, the physical activity was decoupled from the game flow, i.e., the jumping activity did not match any particular player action in the game. Despite this, the time based reward successfully motivated players to perform physical activity and they did not report a significant decrease in perceived enjoyment of playing. However, this decoupling could interrupt the game flow, potentially decreasing the enjoyment of playing, and discouraging players from playing activity motivating games. Hence, the activity should be related as much as possible to player's actions and be treated as integral part of playing [3]. For example, in arcade style games jumping would improve jumping skills, while stretching would increase the stamina of the game character.

Variety of activities. Ultimately, the physical activity should be introduced as part of the game in a player dependent manner. For example, in role playing games, a player can choose to act as a magician or a fighter character. Hence, the physical activity should match the game character selected by the player and the rewards gained. Moreover, the physical activity can reinforce specific features tailored to the game character, e.g., either defensive or attacking skills of a fighter character [15]. This can be determined by monitoring player's strategy and previous interactions with the game.

Monitoring technology. Monitoring of physical activity can exploit various sensing technologies. An accelerometer and a gyroscope are examples of physical technologies, whereas a heart rate monitor and a respiration monitor are examples of physiological technologies. The selection of the monitoring technology determines the type of physical activity players will perform and the positioning of the activity monitor.

Activity monitor. The activity monitor should answer several requirements. Firstly, it should be compact and preferably wearable, so as not to interfere with a player's motion. Secondly is should support an instantaneous and real time data transfer from the activity monitor to the game. Thirdly, the data transfer should be unobtrusive and independent of the player, i.e., the data should be uploaded automatically upon capture. Finally, data transfer should preferably use wireless communication technologies, not to restrict a player's motion.

Activity banking. In Neverball, players were rewarded only for the physical activity they performed while playing. However, to achieve a long term behavioural change, players need to be rewarded for any activity performed as part of their routine lifestyle. For this, the activity monitors should be modified to bank player's activity performed over a considerably longer period of time and then convert it into game rewards at game time. This will essentially upgrade the *PLAY, MATE!* design into a ubiquitous physical activity motivator.

Enhanced game control. In most contemporary computer games players would struggle to perform physical activity and control the game character simultaneously. Hence, players should be provided with enhanced game control that allows them to perform physical activity while playing. In Neverball this was done by enabling players to pause the game at any point in time, which could have potentially decreased the enjoyment of playing (this did not happen in practice). To overcome this concern, more sophisticated game control interfaces should be exploited.

CONCLUSIONS AND FUTURE WORK

In this work we presented the *PLAY, MATE!* design for physical activity motivating computer games. The main idea underpinning the design is that players' engagement with computer games can motivate them to perform physical activity while playing. In the design, performing out of game physical activity enables players to gain virtual game rewards. We presented the main components of the design and exemplified its application to a publicly available Neverball game.

We discussed the results of a user study involving *180* participants. The study allowed us to draw several important conclusions. Firstly, it ascertained the main idea of the design and practically showed that engagement with games can be leveraged to motivate players to perform physical activity while playing. Secondly, it showed that despite performing more physical activity and realistically perceiving the amount of activity performed, players did not report a decrease in perceived enjoyment of playing. Thirdly, it compared two game related motivators and showed that a direct game related motivator compelled players to perform considerably more physical activity than an indirect motivator. Fourthly, segmentation of players according to two criteria (gender and observed gaming skills) showed that the amount of physical activity decreases with the increase in player's gaming skills.

The combination of the first and third conclusions is of a particular importance. Essentially, it shows that physical activity can be successfully integrated into games without changing the perception and enjoyment of playing. This demonstrates the potential of physical activity motivating games. Also, it raises several open issues that we will investigate in the future:

- Increasing the amount of physical activity. The *PLAY, MATE!* design is aimed at motivating users to perform physical activity. As the evaluation showed, the amount of physical activity performed is player dependent. We will investigate ways of adaptively increasing the amount of physical activity players perform (tailored goal setting and personalised rewards), while preserving the challenge of the game and enjoyment of playing.
- Application to various types of games. The indirect motivator of virtual competitor did not compel players to perform physical activity as much as the direct motivator. This could be explained by inappropriateness of the competitor motivator in Neverball. We will develop other game related motivators and strategies for applying the *PLAY, MATE!* design to various types of games.

- Adhering to behavioural theories. Currently, the *PLAY, MATE!* design is aligned with Premack's principle, which conditions a high probability activity (playing) on a low probability activity (physical activity) [14]. Premack's principle is an obsolete theory having a simplistic view of behavioural modification procedures, and insensitive to individuals' cognitive processes. We will investigate the application of modern behavioural theories.
- Longitudinal user study. We will conduct a user study, in which players will interact with activity motivating games in their natural environment for an extensive period of time. This will help us to understand whether the *PLAY, MATE!* design leads to the desired long term behavioural change and to a healthier lifestyle, providing an alternative way to combat the obesity problem.

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