Activity Interface for Physical Activity Motivating Games

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ABSTRACT
Contemporary lifestyle is becoming increasingly sedentary with no or little physical activity. We propose a novel design for physical activity motivating games that leverages engagement with games in order to motivate users to perform physical activity as part of traditionally sedentary playing. This paper focuses on the wearable activity interface for physical activity motivating games. We discuss the activity interface design considerations, present physical activity processing details, and analyse some observations of user interaction with the activity interface.

Author Keywords
Serious games, wearable interface, physical activity.

ACM Classification Keywords
H.5.2: User Interfaces, Interaction Styles, I.2.1: Applications and Expert Systems, Games.

General Terms
Design, experimentation, human factors.

INTRODUCTION

According to the World Health Organization, obesity affects over 1.6 billion adults worldwide [5]. One of the reasons for this phenomenon is an increasingly inactive contemporary lifestyle: low amounts of physical activity (sports, exercises) and high amounts of sedentary activity (TV, computer). Since the nature of the sedentary activity is often addictive and self-reinforcing, improving lifestyle by increasing the amount of physical and decreasing the amount of sedentary activity cannot be achieved easily.

Our research of physical activity motivating games presents a novel approach aimed at combating this problem. The activity motivating games leverage engagement of users with games to motivate them to perform physical activity as part of the sedentary playing [1] by adapting the game design such that users gain virtual game related rewards in return for real physical activity they perform. The motivation to perform physical activity is achieved by modifying the following components of the game and aspects of user interaction with the game:

- *Game motivator*. Users are made aware of the possibility of gaining rewards in return for performing physical activity. Also, the game is modified, such that certain game functionalities are reinforced by the rewards.
- *Activity interface*. Users are provided with an external interface capturing their physical activity. This activity is processed, and converted into virtual game rewards.

These modifications are intended to motivate users as follows. On one hand, the game is modified such that certain features are disabled/diminished. On the other hand, users are made aware of the possibility to perform physical activity and gain game rewards, i.e., enable/reinforce the disabled/diminished features. A composition of these factors combined with existing engagement with the game motivates users to perform physical activity. When performed, the activity is captured by the activity interface and converted into game rewards that enable/reinforce the features. The rewards are visualised by the game interface, such that users remain in control of the amount and timing of the physical activity performed.

We applied the above modifications to a publicly available Neverball game (www.neverball.org). Neverball consists of multiple levels, in which users navigate a ball through a maze-shaped surface and collect coins (see Figure 1) in a limited time. We adapted Neverball by reducing the time allocated to accomplish the levels and motivated users to perform physical activity by offering time based rewards. When the time was perceived to be insufficient, users could pause the game and perform some physical activity. We developed a wearable accelerometer based activity interface, which was configured to recognise jump events, such that for every jump captured, users gained one additional second to accomplish Neverball levels. We conducted an empirical evaluation, which ascertained that activity motivating games can significantly increase the amount of physical activity performed while playing [1].

This paper focuses design and development of the wearable activity interface. The contributions of this paper are three-fold. Firstly, we discuss the design considerations pertaining to the activity interface. Secondly, we present the technical aspects of the conversion of physical activity into game rewards. Thirdly, we present some observations referring to users interaction with the activity interface.

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Figure 1. Neverball user interface.

RELATED WORK

Game technologies involving users' physical activity were developed and disseminated in commercial products, like Dance-Dance Revolution developed by Konami, Wii by Nintendo, and PCGamerBike by 3D-Innovations. Dance-Dance Revolution is a dance pad on which users step to control the game. Wii uses an accelerometer-based device, allowing users to control the game by movement. PCGamerBike is a programmable controller using bicycle pedalling motion to control the game. However, these are commercial products providing bodily interfaces to interact with games rather than motivators of physical activity.

The only practical integration of physical activity into computer games was presented by Fujiki *et. al*. [2]. User's physical activity captured by an accelerometer was visualised using a simple race-like game interface. The amount of activity affected the speed of the game character, its standing comparing to others, and the facial expression of the user's avatar. Rather than designing new interfaces and games, physical activity motivating games provide a conceptually new paradigm. If integrated into a variety of existing and future games, it will motivate users to perform physical activity as an integral part of playing [1].

DESIGN AND DEVELOPMENT OF ACTIVITY INTERFACE

There are several factors that need to be considered when designing and developing the wearable activity interface. This section discusses the design considerations and elaborates on the activity processing and conversion details.

Design Considerations

The first consideration refers to the technology used to capture users' physical activity. This can be done using a variety of physical or physiological sensing technologies. For example, consider an accelerometer that measures acceleration, a pedometer that counts steps, or a gyroscope that measures inclination as examples of physical technologies and a heart rate monitor, an ECG reader, or a respiration rate monitor as examples of physiological technologies. To increase accuracy and reliability, activity interfaces can combine several technologies. The selection of the technology determines both the type of activity users perform and location where the activity is measured.

The second consideration refers to the position of the activity interface on the body. In most sensing technologies (mainly physical), the location impacts the accuracy of the activity data. For example, an accelerometer based activity interfaces should be positioned as close as possible to the user's centre of mass to accurately capture the activity.

The third set of considerations refers to the characteristics of the activity interface, which are as follows:

- *Unobtrusive*. Data transfer from the activity interface to the game should be independent of the user. That is, activity data should not be manually fed in, but rather uploaded automatically upon capture.
- *Wireless*. Users should not be physically connected to the computer on which the game runs, as to not restrict their motion. As such, a wireless transmission of the activity data should be used.
- *Instantaneous*. Activity data should be transferred in real time, i.e., immediately or as soon the connection between the activity interface and the game is established.
- *Compact and wearable*. The activity monitor itself should be compact and lightweight, so as not to interfere with a users' motion. Also, it should be wearable or alternatively attachable to a users' garment.

Activity Monitoring Device

We considered several commercial products when deciding which activity monitors to use. The GT3X developed by Actigraph is an accelerometer based pedometer that requires a cable connection for data upload, thus, restricting users' motion. ForeRunner by Garmin is a wireless exercise monitor that requires users to press a button for data upload, thus, being obtrusive. Pi-Node by Philips is an accurate accelerometer, gyroscope, and magnetometer based motion detector supporting immediate wireless data upload. However, it requires applying complex signal processing techniques and price wise cannot be integrated with physical activity motivating games.

To comply with the design considerations, we use an in-house developed tri-axial accelerometer to capture user's physical activity [3]. The accelerometer is compact (*42x42x10* millimetres) and lightweight (*15* grams). It can be clipped to an elastic band and attached to a user's waist. This way, the activity interface can be easily attached to any garment, does not interfere much with a user's motion, and can be positioned closely to the centre of mass. The three dimensional acceleration signals are wirelessly transmitted *500* times per second using an RF technology to a USB receiver attached to the computer. Figure 2a shows the elastic band, accelerometer, and USB receiver compared to a standard-size magnetic card. Figure 2b shows the activity monitor attached to the user's waist.

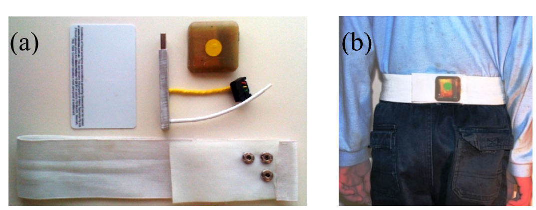

Figure 2. Wearable accelerometer unit used as activity interface: (a) system, (b) on subject.

Physical Activity Data Processing

We process the received acceleration signal to identify users' activity bursts (further referred to as *jumps*). 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 is still. We approximate the magnitude of the acceleration as follows:

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

The acceleration signal can be noisy, as every user's motion is captured. Hence, we use magnitude and time thresholds to identify jumps. If $AM(t)$ exceeds A_{min} for a period of time Δt longer than T_{min}, we identify this as a jump event[1]. The threshold values are calibrated to minimize the number of false positive jumps identified. Figure 3 shows sample acceleration signals captured and respective jump events identified for both low intensity (a) and high intensity (b) activity. The horizontal axis stands for time (in seconds) and vertical for the acceleration.

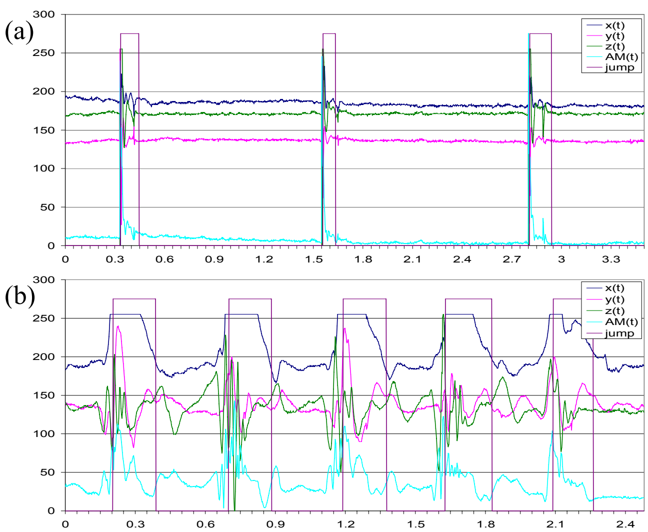

Figure 3. Acceleration processing and jump identification.

Note the differences between low intensity (Figure 3a: *3* jumps in *3.5* seconds) and high intensity (Figure 3b: *5* jumps in *2.5* seconds) activities. The high intensity activity signal is considerably noisier and harder to process than the low intensity activity signal. Hence, the values of the A_{min} and T_{min} thresholds need to be calibrated accordingly.

Finally, the identified jumps are converted into virtual rewards in Neverball. We implement a uniform time based reward mechanism, such that for every jump identified by the activity interface, users gain one additional second to accomplish Neverball levels.

USER INTERACTION WITH ACTIVITY INTERFACE

Prior to evaluating the impact of the activity motivating games, we conducted a trial run assessing the accuracy of the activity interface. Two adults and two children were equipped with the activity monitors and requested to jump at various degrees of intensity for the same amount of time. Table 1 presents the number of jumps performed, the number of jumps identified, and the error rate.

	low intensity			*high intensity*		
	jumps	*counted*	*error*	*jumps*	*counted*	*error*
adults	*116*	*114*	*1.72%*	*243*	*235*	*3.29%*
children	*151*	*148*	*1.99%*	*375*	*362*	*3.47%*

Table 1. Accuracy of activity identification.

As can be seen, activity identification is reasonably accurate both for adults and children at both degrees of intensity. For the low intensity activity, the error rate was less than *2%*. Although the error rate does increase for the high intensity activity, it remains less than *3.5%*. We presume that using state of the art signal processing techniques would further decrease the error rate.

We conducted an experimental evaluation of physical activity motivating games involving *180* users aged *9* to *12* unfamiliar with Neverball. They were divided into two groups: *90* played the normal *sedentary* version of Neverball and *90* played the *active* version of Neverball having the reduced level times. The duration of the playing session in both cases was *20* minutes. Note that the users of both groups used the activity interfaces and were aware of the possibility of gaining one second in return for every jump identified. However, the level times of the *sedentary* users were long enough, such that they had no real motivation to jump.

The results show that activity motivating game increased the amount of activity performed while playing (see Table 2). The *sedentary* group users jumped on average *41.9* times during the playing session, whereas the *active* group users jumped *257.5* times. Similarly, the *sedentary* group users spent on average *95.4%* of time playing and *4.6%* jumping, whereas the *active* group users spent only *76.0%* of time playing and *24.0%* jumping. The differences between the groups were statistically significant.

	sedentary	*active*
jumps	*41.9*	*257.5*
T_{sed}	*95.4%*	*76.0%*
T_{act}	*4.6%*	*24.0%*

Table 2. Amount of activity performed

In addition to the amount of physical activity performed, it is important to evaluate users' perception of enjoyment of playing the active. No statistically significant difference in the perceived enjoyment of playing (measured on a 6-Likert scale) was observed. Users of the sedentary game reported average enjoyment of *5.52*, whereas users of the active game were very close and reported *5.48*.

The activity interface had a mixed influence on the enjoyment of playing [4]. On one hand, the need to jump interrupted the flow of playing and could have decreased the enjoyment of playing. On the other hand, the activity

[1] More accurate signal processing techniques can be applied instead. This one is used as the acceleration approximation.

interface provided users with more control over the game and could have increased the enjoyment. The results might indicate that these factors balanced each other, such that the reported perceived enjoyment did not change considerably.

The post-experiment questionnaire supports this. Users were asked to reflect on the factors that made the playing enjoyable. They were presented with a list of factors and asked to tick those with which they agree. Table 3 shows the number of participants that agreed with two factors of a particular relevance. The first refers to the sedentary playing and the agreement slightly decreases for the *active* group users. The second refers to gaining additional time by jumping and the agreement level increases considerably for the *active* group users. These results indicate that users liked the interaction mode through the activity interface.

I liked to ...	*sedentary*	*active*
... control the ball in the maze	*65*	*55*
... get more time by jumping	*35*	*60*

Table 3. Enjoyment factors.

Another observation refers to the timing of jumping. Figure 4 shows two typical interactions with the activity interface observed for two users playing the same level of Neverball. The horizontal axis stands for the time elapsed from starting the level and vertical for the remaining time. Lines having a negative slope refer to the sedentary playing, whereas lines having a positive slope refer to jumping (the slope depends on the intensity of jumping).

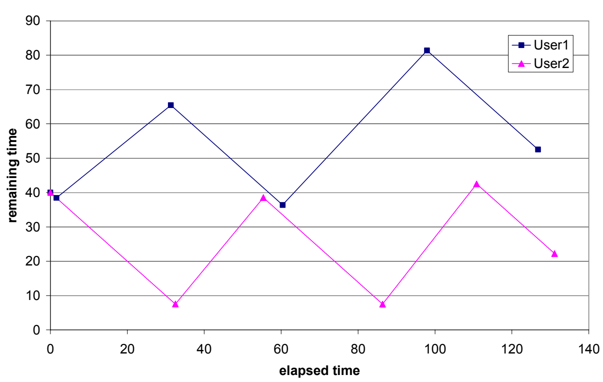

Figure 4. Time-based sedentary/active interaction.

Both users initially had *40* seconds to accomplish the level. The policy of *user1* is referred to as *banking* as the user performs physical activity to gain time in advance of this time being required. We see *user1* jumping after only *1.6* seconds of game play to gain *27* seconds of game time. The second jumping occurs *29.0* seconds later when *user1* still has *36.4* seconds to spare. Then, *user1* gains additional *45* seconds of game playing. Finally, *user1* plays for *28.9* seconds and accomplishes the level at elapsed time of *126.8* seconds still having *52.5* seconds to spare.

The behaviour of *user2* differs considerably as is referred to as an *as needed* policy, since users jump to gain additional time only when the time remaining is low. We see *user2* playing the game for *32.5* seconds until only *7.5* seconds remain. At this point *user2* jumped to gain additional *31* seconds of game playing before continuing to play with *38.5* seconds to spare. Then, *user2* continued to play until only *7.5* seconds remain before jumping again to gain *35* seconds. Finally, *user2* accomplished the level at elapsed time of *131.1* seconds still having *22.2* seconds to spare.

Comparison between the users shows that *user1* banked the time and jumped even though they had around *40* seconds remaining. Conversely, *user2* exhausted the time and jumped only when *7* seconds remained. Interestingly, the vast majority of users preferred the *as needed* policy and jumped when the remaining time was under *10* seconds.

CONCLUSION AND FUTURE RESEARCH

In this work we present the wearable activity interface for physical activity motivating games. An accelerometer based interface was used to convert the captured user jumps into additional time in Neverball. The evaluation showed that users performed significantly more physical activity and did not report a decrease in the perceived enjoyment of playing the activity motivating version of Neverball.

In the future, we will combine physical and physiological sensing technologies to increase the accuracy of the activity monitor. Also, we will investigate the use of wearable activity interfaces, which will allow users to control the game simultaneously while performing physical activity.

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