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Raising Heart Rate with Dance Pad Based Computer Games

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Abstract

Floor-positioned computer game controllers that require movement of large muscles are well known, most commonly in the form used in the rhythm-based game Dance Dance Revolution. Studies of the health benefits of such devices are often reported in the context of using the controller to play a particular game. In this paper we take a different approach, analyzing the controller as an exercise device in its own right, and using the findings to implement an appropriate game prototype. Trials show that the game increases the heart rate of the players to the level recommended for health and physical fitness.

Keywords

Exergaming, game design, exercise.

1. Introduction

Developed countries are faced with a growing obesity problem. Childhood obesity is of particular concern, with childhood obesity rates rising greatly over the last 30 years [1] . In Australia, the number of overweight 7 to 15 year olds almost doubled and the number of obese children tripled in the years between 1985 and 1997 [2] . Whilst poor diet is a major factor in increasing obesity, so is lack of physical activity. Often cited as a factor in increasing obesity is the lifestyle change from a decrease in children playing physically active games and an increase in physically passive pastimes such as TV watching and the playing of computer games. In order to reverse this trend, the combination of exercise with computer-based games has garnered increased attention. Such a combination seeks to rebalance lifestyle towards more physically active pastimes whilst employing the attractiveness technology brings to such entertainment. The term exergaming has been coined to refer to such systems.

A variety of exergames have been implemented over the years with various styles of equipment [3] . The game Dance Dance Revolution, widely known by its acronym, DDR, is one of the most studied. DDR, released in 1998, is a game based around an input device known as a dance pad. An example of a pad produced by Cobalt Flux is shown in Figure 1. The dance pad consists of a square pad that rests on the floor that the player stands on. The pad includes several switches that the player activates. The game shows a series of ‘dance steps’ – in time to music, with each step corresponding to a switch on the dance pad. The player scores by hitting the right switch at the right time. Since the original DDR, a number of arcade and home games have been produced using the same gameplay mechanic of following 'dance steps', one exception being The Winds of Orbis, an action-adventure game played with a combination of DDR pad and Nintendo Wii input controllers [4] .

Figure 1: A dance pad produced by Cobalt Flux.

Several studies of the DDR game point to its potential as an effective form of exercise. Lanningham-Foster et al. [1] have reported from experiments with 25 children that playing Dance Dance Revolution increases energy expenditure by 172 +/- 68% above resting values, compared to a 138 +/- 40% increase when walking on a treadmill at 1.5 miles per hour (2.41 kilometers per hour). Comparing the exercise outcomes of Dance Dance Revolution with the guidelines for exercise set by the American College of Sports Medicine [5] , Tan et al. [6] found the game met the minimum recommendation for intensity (e.g. 60% of maximum heart rate), but did not meet the recommendation for exercise duration.

Current research into the effectiveness of exergames is skewed heavily into evaluating existing commercial systems with respect to their health benefits. This limits the relevance of the findings to one particular combination of hardware and game mechanics rather than just the exercise potential of the hardware. For example Graves et al. [7] have documented that the game Wii Sports is not of sufficient intensity to meet the exercise requirements of children, however this is not an evaluation of the potential of the Wii's motion controller in its own right. In the same vein, results reported for Dance Dance Revolution are indicative of the particular style of game play, hitting buttons to a beat, rather than an evaluation of the input pad as exercise equipment.

In this paper we investigate the dance pad in terms of its exercise potential and introduce games with this in mind.

2. Dance Pads and Exercise Intensity

A basic measure of the effectiveness of an exercise is its intensity and the most common measure of exercise intensity is heart rate. Although heart rate is not the most accurate measure of intensity, influenced by many factors such as tiredness, hydration, and ambient temperature, and drifting upwards over and exercise session, it is generally used as a marker of exercise intensity since it is relatively easy to measure with inexpensive off-the-shelf heart rate monitors. Heart rate responds to the increase in exercise intensity in order to supply oxygen and nutrition to the body (e.g. heart muscle, skeletal muscles, and brain).

Games based on the dance pad require movement of legs. This movement activates muscles in the legs and hip, along with activations of other muscle groups involved in the movements and balance. The exercise intensity depends on the speed of this movement (i.e. step frequency), the extent to which the muscles are moved and the resistance opposing the movement.

The effect of speed on the DDR pad is illustrated in the graph of Figure 2. The graph shows three heart rate traces taken on separate days (to avoid residual effects) from the same subject performing the same sequence of button presses with each exercise session requiring a different speed (120 and 200 steps per minute, and a fastest step frequency possible). The button sequence was a constant repetition of 'left arrow' and 'right arrow' with the left arrow activated with the left foot and right arrow with the right foot, limiting body movement across the pad. The protocol for these exercise sessions involved reading the heart rate for one minute prior to exercise (with the player standing on the dance pad), as the subjects heart rate would rise immediately upon the player stepping onto the pad due to anticipation. After this minute, the subject was required to perform the sequence for 10 minutes using a metronome to time their steps, after which they were required to remain on the pad for five more minutes to monitor the decrease in heart rate post-exercise.

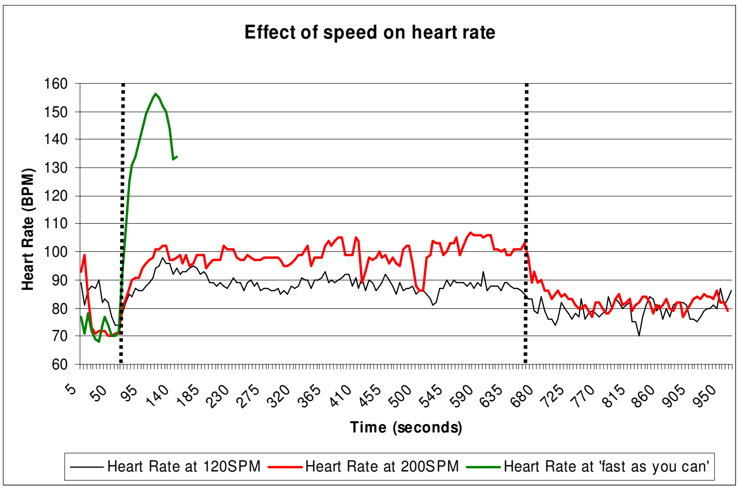

Figure 2: Effect of speed on heart rate (speed measured in steps per minute (SPM)) – heart rate was measured for one minute prior to exercise to overcome initial rise due to anticipation and for five minutes after the exercise. The exercise boundaries are indicated by the horizontal lines.

For a DDR pad, the speed of button activations is the easier method to control exercise intensity as it can be obtained by measuring the time between successive button presses. In rhythm-based games, such as DDR, the goal is to hit the buttons when indicated on screen and penalizing the player for not responding at the correct time – thus controlling game intensity. If the DDR pad was instead utilized in a game where success was proportional to speed, the player may tire quickly, not exercising for the required duration and their heart rate may rise above recommended levels, as the 'fast as you can' results show in Figure 2, where the subject did not continue for the full 10 minute duration due to exhaustion.

The extent of muscle movement, in terms of distance the muscles move for each step, is another factor that can be controlled by stipulating different successive button combinations. The sequence pattern has a significant effect on exercise intensity. Figure 3 shows the heart rate for three different sequences repeated for the duration of the exercise session. Each session was performed at a constant speed of 120 steps per minute, performed on a different day with the same subject, using 10 minutes of exercise with one minute pre-exercise to determine resting heart rate and five minutes post-exercise to monitor heart rate recovery.

Sequence 1 was identical to that used in the previous example of the effect of speed on heart rate, involving pressing the left and right arrows on the pad. In sequence 2, the player started with the left foot on the triangle button and the right on the square button (see Figure 1). The sequence required the top-left diagonal arrow to be pressed with the left foot, followed by returning the left foot to the triangle pad, then pressing the top-right diagonal arrow with the right foot, followed by returning that foot to the square pad after which the sequence repeated. This sequence arrangement kept the player standing towards the back of the pad reaching each foot to a front arrow and then bringing the foot back.

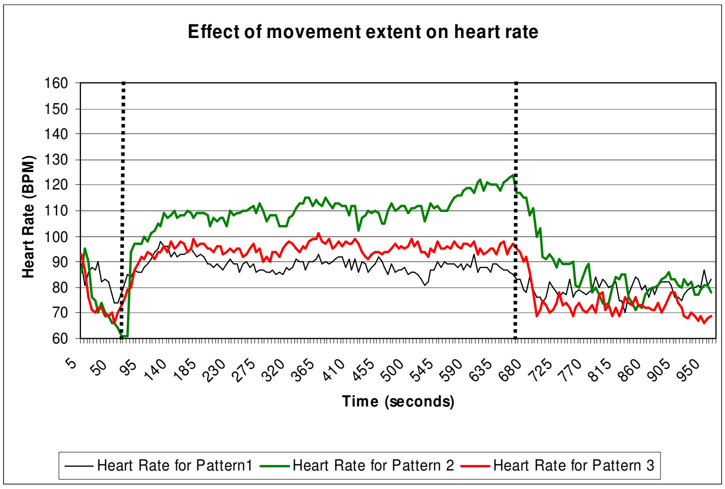

Figure 3: The effect of different movement patterns on heart rate. For each movement pattern, a constant speed of 120 steps per minute was maintained.

Sequence 3 used the same buttons as sequence 2 with a modified order. First, the left foot activated the top-left diagonal button, the right foot then activated the top-right diagonal button – leaving the player standing at the front of the pad on the diagonal arrows. The player then had to step back, first with the left foot onto the triangle button, then with the right foot onto the square button – moving the player to the back of the pad.

The effect on heart rate shows that sequence 1 was the least intense. This sequence allows the players to keep their body stationary and merely step in place to activate the buttons. Sequences 2 and 3, which require the players to move their body more resulted in higher heart rate response. Interestingly, the magnitude of increase in heart rate in sequence 2 was greater than that in sequence 3. Although sequence 3 required the players to move their entire body more, sequence 2 resulted in more pronounced stretching of the leg muscles.

The third factor contributing to exercise intensity, the resistance (loading) to movement, is the most difficult to achieve. To simulate this, the player carried a weight on their back, introducing a force against upward motion, rather than against the movement of the exercise. Figure 4 compares heart rate responses between unloaded and loaded (15 kg) conditions for sequence pattern 2 at 120 steps per minute. The heart rate increased with the load, but the effect was minor, and a more pronounced effect on heart rate was obtained by having the player move in a different step pattern, as seen in Figure 3, which can be achieved in a less obtrusive way than having the player wear weights.

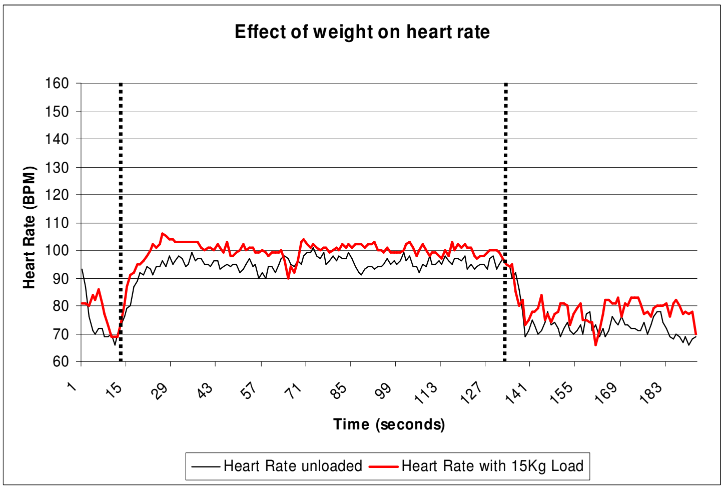

Figure 4: Effect of weight on heart rate when performing pattern 2 at 120 steps per minute.

3. The Game Design

The game that was designed for the DDR pad, iAthlete, was themed around an athletics competition consisting of three events, sprint, hurdles, and long jump each with different gameplay mechanics. In the sprint, the player's avatar runs down a short straight track. The avatar's speed is controlled by the player pressing the left and right arrows keys, as in pattern 1 on the pad in succession, illustrated in Figure 5 (a). The sprint event was designed to increase the heart rate as fast as possible from the resting state. As player's speed directly affects avatar's speed, the event was made short in order to prevent overexertion of the player fatigue, such as was illustrated in the 'as fast as you can' condition shown in Figure 2. Competitive players can complete this event in just under a minute.

The second event was themed around a hurdles race. This longer event was designed around a gameplay mechanic that was used to control the exercise intensity through a mixture of speed and precision requirements that could adjust with player fatigue. The player 'runs' between hurdles using the left-right arrow combination of pattern 1, as in the sprint, with two triggers placed in front of each hurdle. Once the player's avatar reaches the first trigger, the avatar keeps moving at the current speed and the player no longer has to perform the running action on the dance pad – the player can momentarily rest. Upon reaching the second trigger, a random combination of between 3 and 7 arrows is shown. The objective is for the player to enter the arrow combination in the correct sequence before the avatar reaches the hurdle, as illustrated in Figure 5 (b). In doing so the players move their body across the pad more like in movement patterns 2 and 3. If the player presses the incorrect arrow, or an arrow out of sequence they must begin the combination again from the first arrow. Once the complete combination is entered correctly, the player does not need to do anything until the avatar reaches the hurdle. On reaching the hurdle the avatar is shown jumping over if the combination was entered successfully or running through and experiencing pain if the combination was not entered. After the hurdle the player must then 'run' again to move the avatar to the next hurdle.

The game mechanic, switching between speed-based gameplay (running between hurdles) and accuracy (inputting arrow combination) acts to modulate exercise intensity depending on player fatigue. For the accuracy-based gameplay, the avatar's speed is constant and equal to the speed it was traveling at the end of the speed-based section of gameplay. This means that a tired player, whose avatar was running slowly in the sprint, has more time to rest and enter the arrow combination before clearing the hurdle and having to sprint again.

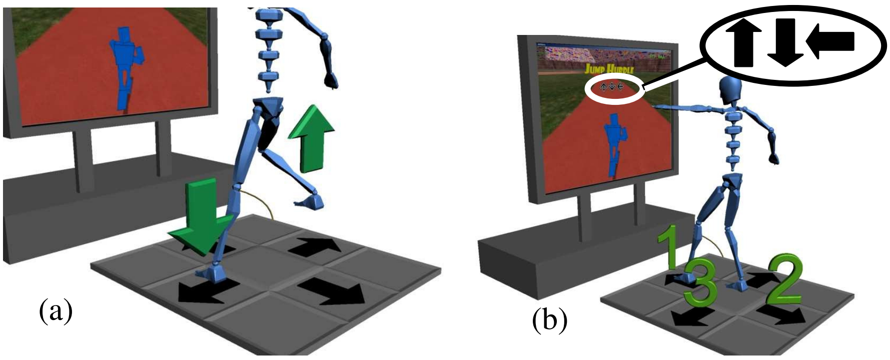

Figure 5: In the Sprint event (a) the player alternates between stepping on the left and right arrows. The frequency of this action affects the speed of the player's avatar in the game. In the Hurdles event (b), the player uses the Sprint action (as in (a)) to run between hurdles and when within the hurdles trigger area can stop sprinting to activate a random series of between 3 and 7 arrows in the displayed sequence.

The third event is the long jump. This is a short event aimed to introduce some variety into the gameplay. At the start the player performs a sprint to increase speed. Once the avatar reaches a trigger the speed stays constant and the player is prompted to enter a combination of arrows, as in the hurdles event. Once a player enters the combination, they are prompted to enter another. This continues until the avatar reaches the long jump pit at which the player must press the left and right arrows simultaneously to perform the jump. The length of the jump depends on the speed of the initial run-up, the number of combinations successfully entered, and the distance from the pit that the player performs the final jump at.

4. Experimental Setup

Fifteen participants were recruited to play the game while their heart rate was logged. There were 13 men and two women in the group. The age of the participants ranged from 18 to 56 with median age 23. From the body mass index (BMI) of the participants, two were classed as underweight, six as normal, five as overweight and two as obese.

For the session, the game was set up to run the three gameplay types in succession – first the sprint, then the hurdles and finally the long jump. This sequence was then repeated twice, the total exercise time being approximately 10 minutes.

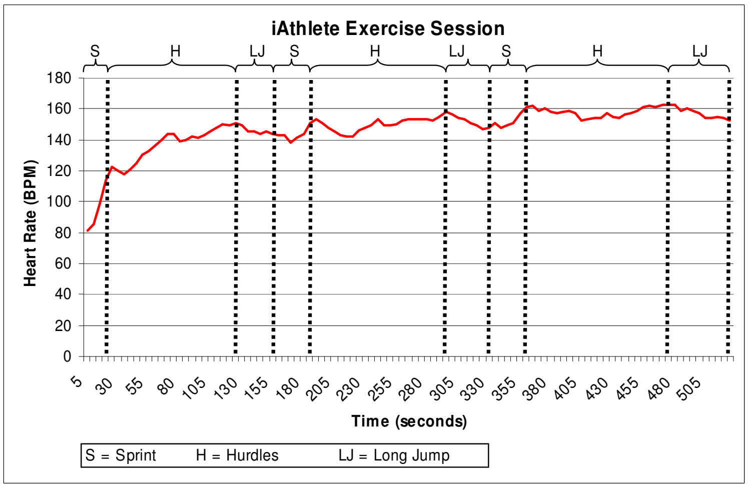

Figure 6: A heart rate trace for three successive repetitions of sprint, hurdles, and long jump.

5. Results

All subjects experienced a rise in heart rate during their play session. A graph of heart rate for one subject is shown in Figure 6. The trials showed that the game increased the heart rate, but the heart rate responses depended on the game play type. The sprint and hurdles led to an increase in heart rate, whilst the long jump event was short and during it the heart rate decreased slightly in some subjects. The maximal heart rate (HR Max) for each player was calculated as 220 minus age [6] . The average heart rate and maximum heart rate from the gameplay was then converted into a percentage of HR Max, with players classified into zones recommended by the ACSM (Pollock Et al. 1998) as shown in **Error! Reference source not found.**. The lowest percentage of HR Max for an average heart rate was 58.7% and for maximum heart rate 67%, both from the same subject, a 24 year old man with BMI of 23.3 (normal) who exercises regularly.

In all cases the average intensity, based on average heart rate, constituted moderate to hard exercise. The ACSM guidelines state that the minimum heart rate for exercise to maintain and improve fitness is approximately 55 to 65% of maximal heart rate, with recommended exercise intensity at a heart rate between the minimum and 90% of maximal heart rate [5] . This was met by the average heart rate of all participants, and the maximum heart rate achieved during the session exceeded 90% of maximal heart rate for five participants.

Table 1: Distribution of players into exercise zones based on their average heart rate over the game and their maximum heart rate achieved during the game.

Intensity	Percentage of HR Max	Number of subjects whose average heart rate for the session fell into the category	Number of subjects whose maximum heart rate for the session fell into the category
Very light	<35	0	0
Light	35-54	0	0
Moderate	55-69	6	1
Hard	70-89	9	9
Very hard	≥90	0	5
Maximal	100	0	0

Duration of exercise is another factor determining the exercise effects, and the ACSM guidelines recommend a minimum duration of 10 minutes for an exercise bout [5] . The average duration for a session was 9 minutes and 38 seconds, with standard deviation of 51.4 seconds. The fastest session was 8 minutes and 24 seconds (Average HR: 85% HR Max, Maximum HR: 97% HR Max) and the longest session was 11 minutes and 17 seconds (Average HR: 82% HR Max, Maximum HR: 89% HR Max). Due to the nature of the game, its duration depended on the speed of the player, thus players that finished the session faster generally played at higher intensity. Duration of the game can however be changed by modifying the program. The ACSM guidelines recommend a 30 minute or longer accumulation of exercise bouts. Repeating the game would increase the duration, but it may be necessary to make the game more interesting to motivate the players to perform the game repeatedly.

Conclusion

The DDR dance pad can make players exercise intensely enough to benefit their health, with exercise intensity governed by the speed of play, the sequence of steps taken, and to a lesser extent by introducing a weight handicap for the player. The game we have designed with these factors in mind successfully increased player's heart rate to meet the recommendation of physical activity for health and improvement of physical fitness. It may be that the game can be used to make people, especially children more physically active, which could help prevent childhood obesity.

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