Heart Rate Control of Exercise Video Games

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ABSTRACT

Exercise video games combine entertainment and physical movement in an effort to encourage people to be more physically active. *Multiplayer* exercise games take advantage of the motivating aspects of group activity by allowing people to exercise together. However, people of significantly different fitness levels can have a hard time playing together, as large differences in performance can be demotivating. To address this problem, we present heart rate scaling, a mechanism where players' in-game performance is based on their effort relative to their fitness level. Specifically, heart rate monitoring is used to scale performance relative to how closely a person adheres to his/her target heart rate zone. We demonstrate that heart rate scaling reduces the performance gap between people of different fitness levels, and that the scaling mechanism does not significantly affect engagement during gameplay.

KEYWORDS: Heart rate input, multiplayer exercise video games, exertion interfaces, kinetic interfaces, active games.

INDEX TERMS: H.5.2 [User Interface]: Input devices and strategies, Interaction styles;

1 INTRODUCTION

Exercise video games have been proposed as a way of motivating sedentary people to perform physical activity [5, 19, 26]. The popularity of games such as *Wii Sports, Wii Fit* and *Dance Dance Revolution* point to a broad interest in the form of exercise that video games can provide. Exercise video games can improve adherence over standard exercise [31] and can provide positive health benefits [10, 31].

Peer support has been shown to be a primary factor in motivating people to participate in exercise [2, 15]. However, performance can vary drastically among people with significantly different fitness levels, making it hard for peers to exercise together. Given that less physically active people tend not to enjoy exercise [27] and have a greater risk of returning to sedentary behaviour when their performance is limited by their physical capabilities [8], it is important to reduce the barrier that differing physical abilities can impose on fun competition.

In exercise video games, a computer mediates players' interactions, making it possible to scale game difficulty to allow people with different abilities to compete. The challenge lies in finding ways of automatically scaling difficulty so that it does not intrude on gameplay or take away from the sense of accomplishment of the player receiving its benefit.

In this paper, we introduce *heart rate scaling,* a novel mechanism allowing peoples' performance in exercise video games to be based on their effort relative to their fitness level. This allows people to compete despite radical differences in fitness level. The technique is based on monitoring players' heart rate, and scaling their performance relative to how closely they meet their target heart rate. We have implemented heart rate scaling in our *Heart Burn* racing game. We discovered that our technique significantly reduces the gap between people of disparate fitness levels while slightly worsening the gap between people of similar fitness levels.

Heart rate scaling has some unintuitive properties; e.g., maintaining the same pace may yield different speeds at different times in the race. However, our experiments showed that the use of heart rate scaling did not negatively impact players' engagement with the game. Over all, these results indicate that heart rate scaling is a promising approach to reducing the barriers to playing together due to differing fitness levels.

The paper is organized as follows. We first review existing multiplayer exercise video games and examine other approaches allowing people of differing abilities to play together. We then give an overview of our heart rate scaling approach, and motivate its design. Finally, we present the results of an experiment in which the approach was evaluated in the context of the *Heart Burn* racing game.

2 RELATED WORK

To provide context for this work, we review previous exercise video games, look at existing techniques for balancing games for people of different abilities, and then consider previous approaches to using heart rate as an input technique to interactive systems.

2.1 Multiplayer Exercise Video Games

Much of the research in multiplayer exercise games has focused on co-located games in which players interact in the same physical space. For example, *Paranoia Syndrome* [14], *Nautilus* [30], *Kick-Ass Kung Fu* [12] and *Human Pacman* [7] combine physical actions in the real-world with a virtual game environment. These games allow several people to cooperate or compete together while performing some form of physical activity. None of these games address the problem of players' potentially having significantly different fitness levels.

Several researchers have focused on distributed games which allow people in different locations to interact. In *Breakout for Two* [21], two distributed players kick a soccer ball at a projected wall of virtual bricks. The player who is able to destroy more bricks is considered the winner. *Breakout for Two* is a competitive game in which players with greater physical stamina or soccer skills may have an advantage.

The *Push'N'Pull* game [21] uses two *Powergrid* resistance training devices, connected to a computer, to allow a pair of players to manipulate onscreen objects. Moving virtual objects requires less physical effort if both players apply force to their individual training devices. Since *Push'N'Pull* is a cooperative game, players of different physical strengths and fitness levels can work together to complete the game tasks.

Figure 1. Playing the Heat Burn Game; Inset: player controls using bike and game pad.

2.2 Approaches to Game Scaling and Balancing

There exist a number of techniques for balancing game play between people of disparate abilities. Some of these have been used in traditional sports; some have been developed specifically for video game play.

2.2.1 Sports and Traditional Games

In order to allow players or teams of differing skill levels to compete, the more experienced opponent is often given some form of disadvantage. For example, it is common for amateur golfers to have a calculated handicap in order to adjust their score based on previous win-loss records. Handicapping may lead to a sense of hollow victory, as both players are aware of the "real" score.

Ladders are used in other sports (e.g., bowling, squash) and games (e.g., chess, Go) to adjust competition. This allows players to participate in games at their level, but segregates the player base, possibly making it difficult for friends to play together.

2.2.2 Balancing in Video Games

Balancing is an important feature of competitive multiplayer video games. It may impact the fun of a game if a particular character or team has an unassailable advantage. Because of this, game designers attempt to balance the effectiveness of character types, power-ups, and weapons. Hanson [13] suggests using combat simulations and player monitoring during testing to avoid any possible unintentional advantages or disadvantages. Habgood and Overmars [11] explain how many competitive multiplayer games have settings to adjust a handicap for more experienced players, or include a catch-up system which automatically gives a losing player additional advantages.

Other innovative techniques have been proposed to balance experienced and inexperienced players in networked games. For example, the "fat-boy" mode in *Unreal Tournament* increases the width of a player's avatar every time he or she scores a kill. In this case, a player who has scored a large number of kills becomes an easier target, therefore handicapping better players.

2.2.3 Asymmetric Roles

Assigning different tasks to players in games and sports is another way of helping people with different capabilities to play together. Many team sports have different positions requiring different skill sets. For example, soccer requires players for offence, defense, as well as a goalie. Asymmetric roles have been implemented into several multiplayer video games; for example, Nintendo's *Mario Kart: Double Dash* requires a driver and a gunner.

Asymmetric roles are also used in exercise video games. *Age Invaders* [18] can be played in both a co-located and distributed setting. Co-located players run around and shoot virtual rockets at their opponents using a hand-held trigger. Distributed players can also participate in the game by using an online interface to drop power-up items for their teammates. This combination of co-located and distributed interaction allows players of different ages (and presumably different physical capabilities) to play together.

The *Life is a Village* game [32] also includes asymmetric roles. Two players cooperate to gather quest items while avoiding missiles thrown by enemies. One player steers (using a recumbent bicycle for input), while the other defends, using a Wii remote to swat incoming snowballs. This asymmetry of roles allows players with different fitness levels to play (and exercise) together.

2.3 Heart Rate as a Form of Input

Several researchers have suggested the possibility of using heart rate for computer input [3, 16, 28]. Heart rate has also been used as a form of input for video games, in order to improve quality of exercise, or simply to add novelty to gameplay.

Heart rate monitoring can be used to encourage players to maintain their heart rate within its target zone. Buttussi et al. [5] designed a system that uses heart rate monitors and motion sensors as input mechanisms. A player's physical movement is used to control his/her onscreen avatar, while game difficulty is based on the player's heart rate. The authors built two games in which the level of difficult is automatically adjusted if the system determines that the player should exert more or less physical effort. Similarly, Masuko and Hoshino [20] built a single player exercise video game designed to help players maintain effective exercise intensity. In the game, players perform different boxing maneuvers to fight against virtual opponents. The system monitors heart rate in real time and adjusts the content of the game in order to encourage more vigorous movement if the player's heart rate falls below their target heart rate zone, or less vigorous movement if heart rate is too high.

TripleBeat [25] is a mobile phone-based system that uses heart rate to encourage joggers and runners to perform high quality exercise. TripleBeat includes a scoring mechanism based on the runner's target heart rate zone. The authors found that awareness of both heart rate and the scores of other runners led to better performance and enjoyment. TripleBeat does not allow players to compete in real time, and the ability of the scoring mechanism to reduce performance gaps among competitors was not investigated.

Heart rate monitoring can also be used to provide a novel game experience. *Tetris 64* was a commercially released game for the Nintendo 64 which included a "Bio Sensor" that clips onto the player's ear. In the Bio Tetris mode, the game is sped up when the player's heart rate increases, and slowed down when the player's heart rate decreases.

Nenonen et al. [22] created a single player virtual biathlon game which includes heart rate input controls. During the skiing portion of the game, players perform an exercise of their choice. The player's heart rate determines the speed of his/her avatar. During the shooting portion of the game, the steadiness of the scope is adjusted based on the player's heart rate; the faster the player's heart rate, the faster the scope swings. The authors conclude that heart rate input can be used for a variety of physical activities.

Although various scaling techniques address variations in skill level, none of the existing approaches directly address differences in player fitness levels. In the next section, we show how heart rate can be used as a measure of physical effort suitable for scaling performance in multiplayer exercise games.

3 HEART RATE CONTROL

Players' performance in games normally is determined by the strategic and tactical decisions they make while playing. For example, in a racing game like Nintendo's *Mario Kart,* players must dodge obstacles, drive over "power ups", and use defensive and offensive skills to compete with other players. The player who best manages these tasks wins the race.

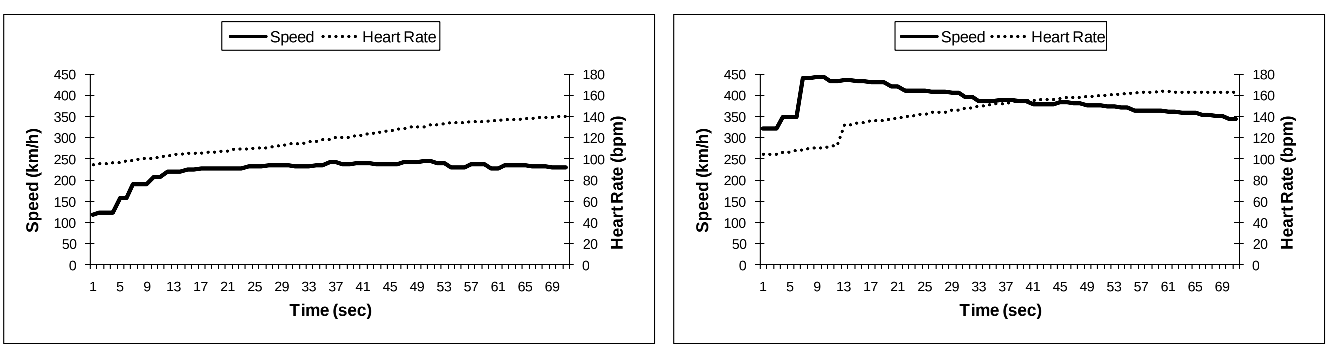
As seen in the previous section, exercise video games add the additional component of physical fitness to determining the likelihood of winning. In *Game Bike,* for example, races are determined primarily by how fast the players can pedal a stationary bike [31]. This can lead to a disheartening experience for unfit players, who will lose game after game to more fit competitors.

Our goal is to narrow the difference between players with different fitness levels. While we do not believe that the gap can be completely removed, our aim is to reduce it to the point that skill at the game itself is more important than fitness level. One way of achieving this goal is to base players' performance on their effort relative to their fitness level rather than their raw power. Doing so allows players of varying fitness levels to compete more effectively since success is based more on skill and effort than on physical fitness.

To help address this goal, we have created the *Heart Burn* game. In *Heart Burn*, players race a truck along a twisting track. The first player to reach the end of the track is declared the winner. A stationary bicycle and wireless game pad are connected to a computer running the game. Players control their onscreen truck by pedaling the bike and steering with the game pad. In the "standard" case, the power of the player's cycling determines the truck's speed (where power is a function of gear and pedaling cadence). If a player strays off the track, her truck slows down, so precision of steering influences game performance. Figure 1 shows *Heart Burn* in action.

One indication of a player's physical effort is her heart rate. As a person's level of physical exertion increases, her heart rate will also increase. Heart rate can be accurately measured using inexpensive devices, such as consumer grade GPS wristwatches or stationary bicycles. A racing game like *Heart Burn* can use heart rate to determine the player's speed in the game, rather than basing speed directly on how fast the player is pedaling.

Heart rate on its own is an imperfect measure of effort. Figure 2 shows data from the first 71 seconds of two example games of *Heart Burn*. The dark line shows the player's "standard" game speed. Standard speed is a function of gear and cadence (pedal revolutions per minute), and is reported in game units of km/h.



(a) Player 1: speed and heart rate **(b) Player 2: speed and heart rate**

Figure 2. Graphs comparing the speed and heart rate of two players of different fitness levels.

That is, standard speed is based on the player's pedaling power, not her heart rate.

The light line shows the player's heart rate. Figure 2(a) shows example data for a 66 year old woman, and figure 2(b) shows example data for a 29 year old man. These examples illustrate two well-established properties of heart rate during exercise [23]:

- There is a lag between performing exercise and heart rate increasing. For example, player 2 increases his speed substantially at the seven second mark of the game, but this increase is not reflected in his heart rate until the 13 second point. In both players' cases, their heart rate continues to climb after their effort has stabilized, and in player 2's case, in fact climbs during the latter 60 seconds of the race, despite the fact that he has reduced his pedaling speed. Similarly, when the player's effort is reduced, there is a lag before heart rate decreases.
- This lag varies from person to person. Typically, fitter people require more time to increase their heart rate, and less time to have their heart rate return to normal.

From these examples, we derive three principles to be applied when using heart rate as an input mechanism for exercise video games: base performance relative to target heart rate; scale speed non-linearly, and apply a nimbleness factor. From these principles, we have created a formula to be used in mapping heart rate to in-game speed, and have experimentally determined the properties of this formula. As will be discussed in detail, figure 3 shows the effect of applying this formula to derive speed from players' heart rate.

3.1 Target Heart Rate

To use heart rate as an input mechanism, we must somehow convert heart rate values to players' speed in the game. This conversion should reward players for their effort relative to their fitness level. Health guidelines suggest that people should carry out exercise within a target heart range appropriate for their age.

According to the ACSM [1], in order to maintain or improve cardio respiratory fitness, exercise must be performed in the range of 65% to 90% of a person's maximum heart rate. The range of 70% to 80% of maximum heart rate is generally considered the best for improving cardiovascular fitness (referred to as the "aerobic zone") [4]. Using a standard formula [17], we calculate the player's target heart rate based on her *heart rate reserve*, the difference between a player's maximum heart rate and resting heart rate. (Maximum heart rate is determined by the player's age [9]). The Karvonen formula [17] calculates target heart rate as follows:

$$hr_{target} = (intesity \times hr_{reserve}) + hr_{resting}$$

In *Heart Burn,* we use the lower bound of the aerobic zone of 70% for *intensity* when calculating a player's target heart rate. Different intensity values can be chosen by game designers wishing to promote more or less vigorous exercise.

Our approach is to scale the heart rate value based on the player's target heart rate. The normalized heart rate h takes on the value 0 when the player is at her resting heart rate (i.e., not exerting herself at all), and the value 1 when she has achieved her target heart rate:

$$h = \frac{hr - hr_{resting}}{hr_{target} - hr_{resting}}$$

In a game, the player's speed can be computed by multiplying a maximum speed by the normalized heart rate h. This helps put players on an even footing, as each player's speed is based on attaining a heart rate appropriate to her fitness level.

3.2 Logarithmic Scaling

The formula for h reported above has two short-comings. First, players continue to be rewarded with speed increases once they have surpassed their target heart rate. Second, players whose hearts are slower to respond to physical exertion (typically fitter people) will be disadvantaged. Both of these problems can be ameliorated by scaling h. In our experience, a logarithmic scale works well:

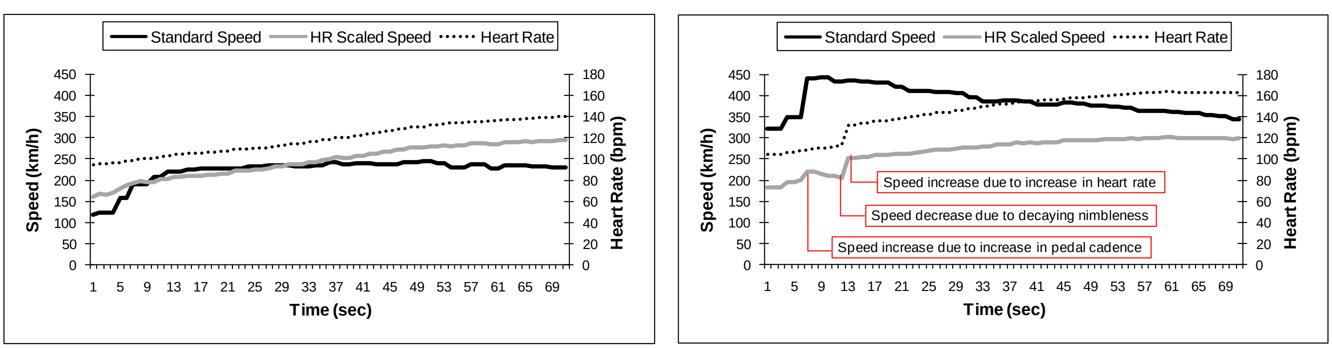
$$h' = \log_{10}((10-1)h + 1)$$

This scaling preserves the properties that when the player is at rest, h' (the scaled, normalized heart rate) is reported as 0, and when the player achieves her target heart rate, h' is reported as 1. However, the logarithmic scaling lowers return on additional effort beyond target heart rate so that there is little advantage in over-exertion. Additionally, speed is increased at lower heart rates, reducing the disadvantage of those requiring more time to achieve their target heart rate.

3.3 Nimbleness

A further key problem with heart rate control is the lag between a player's change in pedal speed and the corresponding change in heart rate. For controls to feel natural, players will expect, for example, a sprint to lead to an immediately visible speed increase. Similarly, pedaling slower (e.g., just before a sharp turn) should lead to an immediate speed decrease.

We therefore blend heart rate input with a speed change based on the player's acceleration. If the player accelerates, she will see an immediate speed increase. The increase is not permanent, however; if the player's heart rate remains constant, her speed



(a) Player 1: standard speed and HR scaled speed

(b) Player 2: standard speed and HR scaled speed

Figure 3. Graphs comparing the standard speed and the heart rate scaled speed of the two players from Figure 2.

drifts back to the original speed based purely on heart rate. This provides players with immediate feedback on acceleration, while having little impact on who wins the race.

We accomplish this behaviour by adding a nimbleness component to the speed factor. Nimbleness is defined as a weighted average of acceleration over a time window of w seconds. Therefore a change in pedaling speed will result in an immediate speed effect, but over the following w seconds, speed will return to being based purely on heart rate. Nimbleness is based on acceleration. On an exercise bike, we calculate acceleration as the change in the player's cadence (measured in pedal revolutions per second). Specifically, acceleration at time t is calculated by comparing current cadence with the cadence from the previous second:

$$a_t = c_t - c_{t-1}$$

We then calculate the acceleration A_t over a window of w seconds ending at time t as a weighted average of the acceleration values over that window. Weight decays over time and this is achieved by subtracting i from w:

$$A_t = \frac{\sum_{i=0}^{w-1}(w-i)a_{t-i}}{\sum_{i=1}^{w} i}$$

Nimbleness falls in the range [–1,1]. Since acceleration can be an arbitrarily large number, it is clamped to some maximum m (or $-m$ in the negative case). Nimbleness at time t is:

$$n = \frac{clamp(A_t, -m, m)}{m}$$

A pedal cadence of 50 to 60 rpm is reported as the most economical and efficient [19], especially for recreational cyclists. Therefore, we used a maximum bicycle acceleration of 50 rpm (adjusted to 0.833 rotations per second). During pilot testing of the formula, we found that a window of 5 seconds to be natural for players. These numbers can be adjusted to suit different player or game types.

3.4 Formula

The formula can then be summarized as follows, where s_{max} is the in-game speed that should be attained when the player is at his target heart rate. A constant factor f (where, $0 < f < 1$) is applied to nimbleness to allow short bursts of speed or slowdowns. From our pilot studies, we determine a factor of 0.3 to be effective.

$$s = s_{max} \times (h' + (f \times n))$$

The formula is applied only when the player is moving ($cadence > 0$) in order to avoid the unintuitive situation of a player sprinting at the beginning, and then coasting through the remainder of a race.

Figure 3 shows the results of applying the formula to the heart rate data from figure 2. For comparison, standard speed data is also provided. We see that the players' speed increases as the race progresses, due to the time required to increase heart rate. The logarithmic scaling helps players move non-linearly to the maximum speed as the race proceeds. Again due to logarithmic scaling, speed increases more gradually once target heart rate is exceeded. The nimbleness factor allows players' acceleration to be reflected in the final speed, helping to give a more natural feedback.

4 EVALUATION: HEART BURN GAME

To experiment with our method for using heart rate to control exercise video games, we have developed the *Heart Burn* game. Two players compete to drive their trucks over a twisting course. Players must follow the course (straying off results in a speed penalty), requiring them to balance speed and accuracy of steering. The first player to reach the end of the course wins. Players pedal a recumbent bicycle and use a joystick on a wireless game pad to control their trucks.

We have created two versions of *Heart Burn,* one using a standard speed control (where pedaling speed and gear control in-game speed), and the other using our scaled heart rate control (henceforth, "HR scaling"). We have performed dozens of informal experiments with the game which helped identify the issues in heart rate control of exercise games, and led to the three core design principles described in the section 3. *Heart Burn* is an engaging game, and has allowed for numerous enjoyable play sessions and tournaments in our lab.

More formally, we used *Heart Burn* to investigate the following hypotheses:

- Heart rate scaling leads to closer races than standard speed computation. Specifically, the difference in average speed between competitors is lower for the HR scaling case.
- The heart rate scaling version of the game is at least as engaging as the standard case; that is, players will not find the HR scaling algorithm so unnatural as to reduce enjoyment of the game.

4.1 Experimental Design

We carried out a study to investigate these hypotheses.

4.1.1 Participants

Participants were selected on their ability to play 3D computer games and operate a recumbent bicycle. Additionally, the PAR-Q [6, 29] physical activity readiness questionnaire was used to screen participants whose health might make exercise inadvisable. Prior to participating in the study, participants were asked to report their perceived fitness level. Based on this information, we attempted to pair participants of different fitness levels.

A total of 30 participants were recruited from the university community. From this initial set, four participants (two pairs) did not participate after being screened by the PAR-Q. Of those who completed the experiment, the results of one pair were excluded because one participant was physically too small to effectively use the recumbent bicycle. In total, the results of 24 participants were used. Participants' ages ranged from 17 to 30 with a mean age of 21. There were 19 males and five females. Five participants reported their fitness level as poor (no aerobic activity in eight weeks), 13 reported as average (regular aerobic activity of 20 minutes, three times a week), and six excellent (regular training of more than an hour several times a week).

4.1.2 Equipment

The physical set up of the experiment is shown in Figure 4. The participants played in separate rooms. Participants used a Tunturi E6R recumbent bicycle, attached via a serial cable to a PC running the game. A wireless PS2-style controller was used for steering. The race track, truck and opponent's truck were projected onto a large (6' x 8') screen. Four speakers played up-beat music during gameplay.

Each participant wore a Polar heart rate strap around his/her torso. The strap wirelessly transmitted heart rate to the recumbent bicycle. The bicycle transmitted heart rate and the player's cadence (pedaling revolutions per minute) to the PC running the game.

Each second, the game logged the player's heart rate, cadence, in-game speed (based on the standard algorithm), and in-game speed (based on the HR scaling algorithm.)

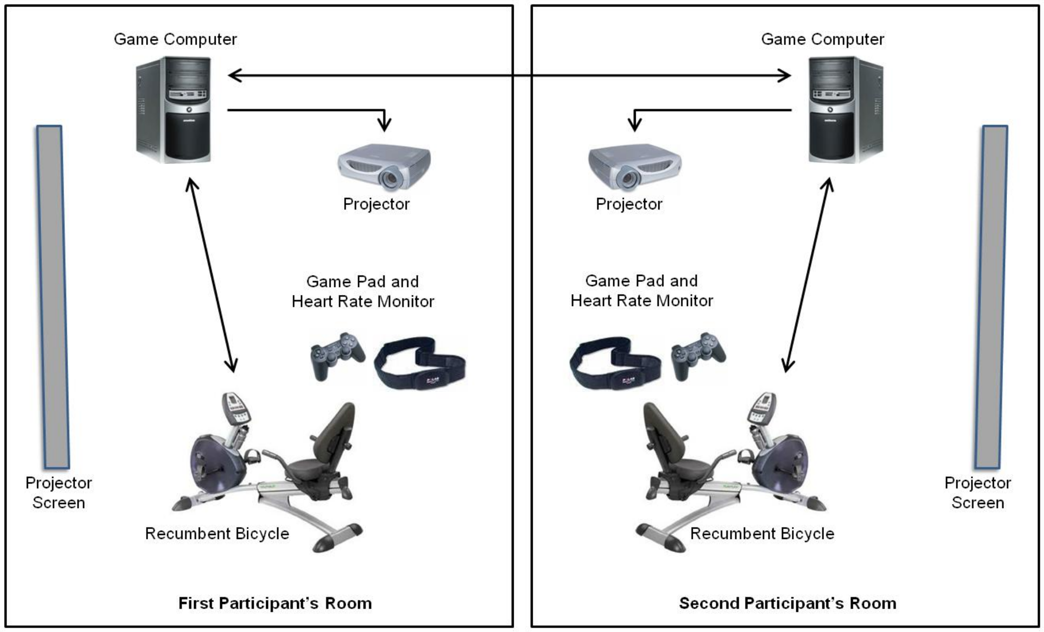


Figure 4. Experiment set up. Recumbent bicycle transmits pedal speed and heart rate (from wireless Polar monitor) to the game computer through a serial port connection. Game pad is wirelessly connected to the computer.

4.1.3 Experimental Method

Participants performed two training races. First, their truck traversed the track using computer control (i.e., players steered but did not pedal), allowing them to gain familiarity with using the PS2-style controller to steer. Then, they were given a practice run using the bicycle. This second run served as a warm-up, and also allowed the participant to select a comfortable gear. Once a gear was selected, it remained constant throughout the experiment.

Participants played a total of four games versus their opponent, two under each of the standard and heart rate scaling conditions. Six groups played the standard condition first, and six played the heart rate scaling condition first. Within-person biases were equalized by random order. Participants were given a three minute rest between races.

Following the first condition, players completed a questionnaire [24] to measure their level of engagement with the game. This scale included 31 questions on a seven point Likert scale.

Following the second condition, participants again completed the engagement questionnaire, demographic data was collected, and a semi-structured interview was carried out with both participants to gather qualitative comparisons of the two conditions.

The experiment was designed to investigate the effectiveness of the scaling mechanism, and not the exercise benefit of the game. Therefore, races were short in order to not exhaust the participants. On average, each race took the participants about 1.5 minutes to complete.

4.2 Results

Our results address the two hypotheses listed above.

4.2.1 Hypothesis 1

We hypothesized that heart rate scaling leads to closer races than standard speed computation. If two participants have average speeds over a race of s_1 and s_2, we calculate the speed difference in that race as the percentage:

$$\frac{|s_1 - s_2|}{\min\,(s_1, s_2)}$$

Based on 24 races in each condition, we compared speed difference between standard and HR scaled races using a paired samples t-test. The difference in average speed was lower in the HR scaled case (7.9% vs 13.3%), but this difference was not significant at the alpha=0.05 level: $t(23) = 1.707$, $p = .101$, $d = 0.349$.

	Standard case	**HR scaled case**
All races	13.3%	7.9%
"Blowout" races	28.8%	7.8%
Close races	2.2%	8.0%

Table 1. Mean speed differences between standard and HR scaled races.

The races clustered into two groups, with 14 close races in the standard case (speed difference ranging from 0% to 4%) and 10 "blowout" races (speed difference ranging from 15% to 53%). In these "blowout" races, the losing player spends the majority of the race so far behind the winning player that they do not even see his/her truck. No races had average speed differences between these clusters. Again using paired samples t-tests, we compared the differences in average speed between the standard and HR scaled conditions, within these two groups.

In "blowout" races, the average difference in the standard case was 28.8%, versus 7.8% in the HR scaled case; this difference was significant: $t(9) = 7.35$, $p = .001$, $d = 2.325$.

In close races, the average difference was 2.2% (standard) versus 8.0% (HR scaled); this difference was significant: $t(13) = -3.206$, $p = .007$, $d = 0.857$.

4.2.2 Hypothesis 2

To determine whether heart rate scaling is at least as engaging as the standard case, we compared players' engagement scores for each condition using a paired-samples t-test. The mean engagement in the standard case (M=173.8) was slightly higher than in the HR scaling case (M=169.6), but this difference was not significant at the alpha=.05 level, t(23)=1.886, p=.072, d = 0.385. Post hoc analysis reveals that power was low (0.27).

4.3 Analysis

Heart rate scaling should increase competitiveness of players with radically different fitness levels while not negatively impacting the competitiveness of players of similar fitness levels. When examining the results of all races, we saw no significant difference between the conditions. When we separately analyze close versus "blowout" races, however, a more interesting picture emerges. In blowout races, HR scaling enormously improves competitiveness, while in close races, it actually worsens competitiveness. This implies that HR scaling might be applicable when there is a large difference in players' ability, but should perhaps be avoided in cases where abilities are similar. Interestingly, the speed difference for the HR scaling condition is similar in both the close race and blowout race clusters (7.8% versus 8.0%).

Together, these results suggest that HR scaling is limited in how close it can bring players together, but is a highly promising technique when players' capabilities are significantly different.

It is interesting to note that races fell into either close (up to 4% speed difference) or "blowout" (over 15% difference) categories with no races in-between. We conjecture that when races are close, players are motivated to try harder to close the gap. This is shown by the statements made by some of the participants. For example, "it (the game) was demanding but it depends on the person and how much they want to win" and "it (the game) is powered by competition, so there is no limit. It depends on your competitor, because if they are more competitive than you, then you are going to go and try to get above him." It is possible than when the speed differences are higher, players perceive the situation as hopeless, and therefore do not make an extra effort to catch up.

Engagement scores were similar between the two cases. No significant difference was found. (Power was low, indicating the possibility of a type 2 error; however, the difference observed between the two cases is very small.) This suggests that participants did not find HR scaling to be jarringly unnatural. This is a positive result, given that (as is suggested in figure 3) HR scaling does behave quite differently from speed computations based on pure player power. This is reflected by player comments, such as "I didn't really notice a difference," "I didn't really see a difference," and "they were both ok, no difference."

However, in some instances of "blowout" races, where a player lost by a significant amount in the standard case, the losing player identified a preference for the HR scaled condition. For example "I like the second one (the HR scaled condition) better, because it was more competitive so I had a better work out" and "I think the second one (the HR scaled condition). I'm not entirely sure what the difference is; it seemed to be responding a bit more."

4.3.1 Limitations

Our subjects were largely drawn from the university population. They were for the most part young and fit. Our recruiting poster and mailings indicated that the experiment would involve performing exercise, which likely biased the sample towards people who are more active. We suspect that this accounted for the large number of close races that we saw in the standard condition (14 of 24), and that if we drew from a more heterogeneous population, we would have seen greater diversity in race speed. We experienced difficulty in recruiting older participants who were comfortable steering a virtual car using a joystick.

We are interested in whether the closer races enabled by HR scaling reduce the disheartening effect of repeatedly losing. Since players only performed two races under each condition (and therefore did not suffer long strings of losses), we cannot conclude whether this was achieved.

In our experiment, we calculated target heart rate based on a person's resting heart rate and a predicted maximum heart rate. Traditionally, maximum heart rate has been estimated using the formula *220 – age*. It is known that this formula can be inaccurate by as much as 10 to 12 bpm [1]. Therefore, we used the recently proposed linear formula of *207 – (0.7 * age)*, which has been shown by Gellish et al. [9] to provide a more accurate estimate. Additionally, the resting heart rate of a participant was taken at the beginning of the experiment. Ideally, resting heart rate should be measured in the morning when a person has just woken up. Thus, our measures of resting rates did not take into account variations based on what a participant had done prior to the experiment (e.g., previous physical activity, consuming caffeine). However, despite the potential for inaccuracies in our measured resting heart rates and predicted maximum heart rates, our heart rate scaling mechanism was still effective at improving competition.

5 DISCUSSION

The experiment described above shows that, at least in the context of the *Heart Burn* bicycle racing game, heart rate scaling can make competition between people of different physical fitness levels significantly more competitive. In "blowout" races, speed differences between participants dropped from an average of 29% to an average of 8%. Meanwhile, participants reported no difference in engagement between the standard and HR scaling conditions, indicating that despite its manipulation of input, HR scaling is intuitive enough to satisfy players.

The goal of HR scaling is to make the physical aspects of competition close enough that the results are decided on the basis of effort and gameplay rather than players' underlying fitness level. HR scaling takes us a significant distance in this direction. For example, a more complex racing game than *Heart Burn* might involve the use of powerups and obstacles that introduce a more tactical element. Players would still need to put effort into pedaling, but the differences in speed from HR scaling might become less important than other gameplay aspects. Further experiments are required to determine whether this is, in fact, the case.

The approach has nevertheless significant shortcomings that we hope can be addressed by further research. Much of the speed difference in HR scaling comes from differences in how players' hearts respond to exercise. We observed people with outstanding cardiovascular fitness who took the entirety of a 90 second race to achieve their target heart rate, making for them the race effectively unwinnable. One solution to this problem might be to build a profile of players over time, allowing a customized formula to be developed for each player based on knowledge of his/her individual physiology. The challenge here is that it may be difficult to distinguish between a person whose heart is slow to respond to activity and a person who simply isn't making much effort.

A second limitation is that for players who are of similar abilities, HR scaling may provide worse results than standard speed computation. One approach to addressing this might be to dynamically switch between the two approaches depending on how close the race is. It might even be reasonable under some circumstances for one player to use standard speed computation while the other uses HR scaling. Challenges here involve seamlessly changing between methods so that players aren't aware of or annoyed by the change.

Over all, we discovered that *Heart Burn* requires gameplay decisions not found in traditional racing games. For example, when players are out of breath, they find it more difficult to steer. Players must find a balance between speed and ability to control their vehicle. Such novel aspects of gameplay lead to new and enjoyable challenges.

6 CONCLUSION

Multiplayer exercise video games allow people to exercise together. An advantage of using games for exercise is that they can allow people of disparate ability to compete. To this end, we have introduced a mechanism designed to base players' game performance on their effort relative to their fitness level rather than on pure power. This novel approach uses real-time heart rate data to scale game performance. We proposed that game speed should be based on players' target heart rate, should be scaled logarithmically, and should include a "nimbleness" component.

We implemented heart rate scaling within the new *Heart Burn* game, and used it to investigate the effectiveness of the technique. We found that HR scaling was effective in cases where participants were significantly mismatched, but reduced competitiveness when participants were closely matched. Participants were equally engaged by both standard and HR-scaled versions of the game, indicating that HR scaling is sufficiently natural. Over all, our results suggest that heart rate based scaling mechanisms should be considered by designers of exercise video games as a way of supporting competition among people of varying fitness levels.

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