Designing for Exertion: How Heart-Rate Power-ups Increase Physical Activity in Exergames

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ABSTRACT
Exergames have proven to be a fun way of engaging in physical activity, but most exergame play is not sufficiently vigorous to replace traditional physical activity. We argue the importance of designing for exertion in exergames. To illustrate this, we present the heart rate power-up, a novel game mechanic which can be applied to a wide range of exergame styles. A study of 20 participants found that heart-rate power-ups increase exertion levels in games, sometimes dramatically, while also increasing players' level of enjoyment.

Author Keywords
Exergame; video game design; active video game

ACM Classification Keywords
K.8 [Personal Computing]: Games

INTRODUCTION
Exergames – video games with a physical activity component – have received increasing attention as a way of motivating participation in physical activity. Examples include Dance Dance Revolution, where players gain points dancing in time to music [13], Liberi, a cycling-based game for children with cerebral palsy [15], and Swan Boat, where players control a virtual boat by running on a treadmill and flapping their arms [2].

Exergames have been shown to elevate players' heart rates compared to traditional digital games, but for the most part fail to motivate the moderate to vigorous activity levels associated with improved cardio-vascular health [3,27]. This has led to hesitation among public health organizations in recommending exergames as a replacement for traditional physical activity [1].

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Many exergames have been designed with a focus on entertainment. While games like Wii Sports Tennis [23] or Dance Dance Revolution incorporate physical motion [13], their design has not included a conscious focus on achieving and sustaining moderate to vigorous levels of exertion. We argue that to elevate exergames to the point of being effective replacements for traditional physical activity, such a focus is required – i.e., we must *design for exertion*.

As a first step toward this goal, we introduce and evaluate a novel game mechanic, Heart-Rate (HR) Power-ups, which can be applied to an exergame to encourage more vigorous play. HR power-ups encourage players to elevate their heart rate to a target zone by providing rewards in the game for doing so. For example, in our *Gekku Race* racing game, players who have attained their target heart rate are given a powerful weapon that slows down other players; in our *Biri Brawl* fighting game, players regenerate their health more quickly. In a study of 20 people, we found that HR power-ups increase players' time above target heart rate, and at the same time increase their enjoyment of the game. We further found that HR power-ups are particularly effective for games in which player's *average exertion* is low, elevating players' activity to levels close to those recommended for exercise.

To illustrate HR power-ups, we have developed three games incorporating the mechanic, ranging over three different game genres, and three different average exertion levels. All of the games require players to pedal a stationary bicycle to move their avatar, while using a gamepad for other game input. A heart rate monitor is used to determine when a player activates the power-up by reaching her target heart rate zone. Figure 1 shows a typical game-play set-up.

This paper makes two contributions. First, we demonstrate the need for designing for exertion and the lack of techniques currently available to designers. Second, we introduce the HR power-up technique, a broadly applicable game mechanic, and demonstrate its positive effect on both exertion levels and player enjoyment.

The paper is structured as follows. First, we discuss background work on exergames, reviewing techniques used to increase exertion. We then describe our HR power-up

Figure 1. Play of an exergame using a heart-rate power-up. The player's avatar is controlled by pedaling. Heart rate is measured via a wrist-mounted monitor.

technique, illustrating it through three games. We then report our study and discuss implications for design.

BACKGROUND: EXERGAMES AND EXERTION

Exergames are digital games whose gameplay involves physical activity. Examples of exergames include *Just Dance*, where players mimic the dance moves of an on-screen avatar and gain points for correct timing and performance [31], *Pulse Masters Biathlon* in which players aim to complete a biathlon as quickly as possible, with the twist that their heart rate increases their speed but decreases their ability to aim [22], and *Growl Patrol*, a ubiquitous game where players run around outside to round up virtual animals that have escaped from a zoo [16].

The main focus in the design of exergames has been to motivate people to engage in physical activity [10,15,20] or to comply with rehabilitation programs [4,11]. For example, *Grab Apple* uses innovative techniques to integrate short bursts of activity into the work day [10], and *Swan Boat* uses an ensemble of custom-designed equipment to provide an engaging full-body exercise experience [2]. This has led to a far greater emphasis on players' enjoyment and sustained play of the game than on the quality of the exercise itself.

Mueller and Isbister have proposed guidelines for the design of enjoyable exergames [19]. These address how to map player movements to controls, deal with the ambiguity of movement, facilitate a social experience and highlight personal expression, but do not provide advice on how to increase exertion. Sinclair does highlight one difficulty of designing for exertion, that the pace of games and exercise may not be aligned, making it difficult to attain target heart rate levels with a particular game design [29]. But in general, there is little help for designers in how to reach levels of exertion in games consistent with health benefits.

This focus on player experience over exertion has led recent meta-analyses to conclude that currently available exergames are not a suitable substitute for traditional physical activity. As a baseline, the American College of Sports Medicine (ACSM) recommends a minimum of 30 minutes of exercise five days per week at moderate intensity, or 20 minutes 3-times a week at vigorous intensity [28,33]. In a meta-analysis of 16 studies of energy expenditure in exergames, Peng et al. found that exergames increase players' heart rates significantly, but that playing them is not enough to meet ACSM recommendations [27]. Similarly, in a meta-analysis of 18 studies, Biddiss and Irwin concluded that exergames elicit moderate activity levels during play but should not be used as a replacement for vigorous physical activity [3].

The 24 studies reviewed by these meta-analyses performed 53 evaluations of games. 17 of these evaluations were of Wii Sports, and 10 were of Dance Dance Revolution, both of which were designed for entertainment, not as a form of physical exercise. To illustrate this, Pash et al. showed that in Wii Sports, small wrist movements often lead to better scores than large, more realistic movements [26]. Thus, the game's design penalizes rather than rewards exertion.

Despite these results, it is possible for digital activities to lead to higher intensity of physical activity. For example, the free run program included in Nintendo's Wii Fit can prompt exertion equivalent to traditional moderate-intensity aerobic exercise [8]. It should be noted, however, that this program is a running simulator rather than a game.

Designing for Exertion

At their core, all exergames promote exertion by requiring physical movement to play. Increased exertion typically rewards improved game performance: in *Growl Patrol*, players must run as fast as the animals they are chasing [16]. In *Frozen Treasure Hunter* [35], pedaling a stationary bicycle faster increases the speed of the player's avatar. While the movement inherent in the play of such games is a form of physical activity, this activity is, as we have seen, often insufficient to sustain elevated heart rate.

A small number of techniques have been proposed for raising the level of exertion in exergames. The most basic approach is to increase the game's pace: in the Interaction Tempo balloon-bursting game [17], Landry and Parés demonstrate how increasing the rate of appearance of balloons leads to increase in players' heart rate.

Another technique involves requiring more exaggerated movement patterns of players during game. Mondero et al. modified the movement pattern of players of Wii Sports Tennis and Wii Sports Boxing [18]. The games were augmented so that players were required to take large steps in addition to the upper body movements already required to, for example, swing a tennis racquet. This change led to an increase in energy expenditure from light to moderate intensity levels.

Another approach is to improve players' game experience when they attain target levels of exertion. Boyd et al. have created a mobile game in which the landscape of a virtual world is created as players walk around the real world. High exertion creates a lush environment, while low exertion creates an impoverished atmosphere [7]. In Wylie

and Coulton's Health Defender, a game based on Space Invaders, attaining an HR threshold rewards players with in-game bonuses. This game demonstrated a potential danger in designing for exertion, that the control scheme in a game that leads to the highest level of exertion may not be the scheme that leads to the highest player enjoyment [34]. Webz of War [21] also uses heart rate as an input to modify the player's game experience. As players' heart rates increase, they become more powerful in the game.

Inspiration from Interactive Fitness Systems

Numerous techniques have been designed to increase exertion in *interactive fitness systems,* digital systems supporting traditional exercise. Examples include *TripleBeat,* a mobile system that provides runners with personal awareness and virtual competition [25], and the *Strava* platform that uses GPS to track users' runs or bike rides, allowing them to check their progress against others and to join challenges [30].

Other techniques used by interactive fitness systems include *digital opponents* and *ghost guides*. For example, the Expresso stationary bicycle shows a digital rendering of a track [12]. A *pace bike* is displayed as another cyclist on the screen, showing users how well they are maintaining a goal speed. Similarly, the *ghost guide* shows an opponent whose speed matches one of the user's past workouts. This can help provide motivation to improve over earlier performance.

HEART-RATE POWER-UPS

Our central contribution is the introduction and study of the HR power-up game mechanic that aims to increase levels of exertion in exergames. Power-ups are a common mechanic in commercial video games, including, for example, the Super Star power in Nintendo's Super Mario Bros, which grants the player temporary invulnerability [24]. Fabricatore has described power-ups as a satellite mechanic that enhances existing activities [9]. HR power-ups provide in-game rewards to players who attain their target heart rate while playing. Whenever players' heart rate reaches a specified target zone, they receive a reward: for example, their avatar may have a stronger attack, may heal more quickly, or may simply take on an appealing appearance.

HR Power-ups derive from the use of heart rate to improve player experience in earlier games. But unlike earlier approaches, HR Power-ups are a generic technique that can be applied to a wide range of games.

We have implemented HR power-ups in three simple games representing a range of game genres and a range of average exertion levels. *Gekku Race i*s a racing game; *Dozo Quest* is a platformer game, and *Biri Brawl* is a fighting game. All three games are played on a recumbent bicycle (Figure 1). Pedalling the bicycle powers an in-game avatar; the faster the player pedals, the faster the avatar moves. Players wear a wrist-mounted heart rate monitor that connects wirelessly to the computer on which the game is running. A standard game controller is used to control the avatar's direction and to launch special abilities such as attacks. We introduce these games below, and describe how we have applied the HR power-up concept in each of them.

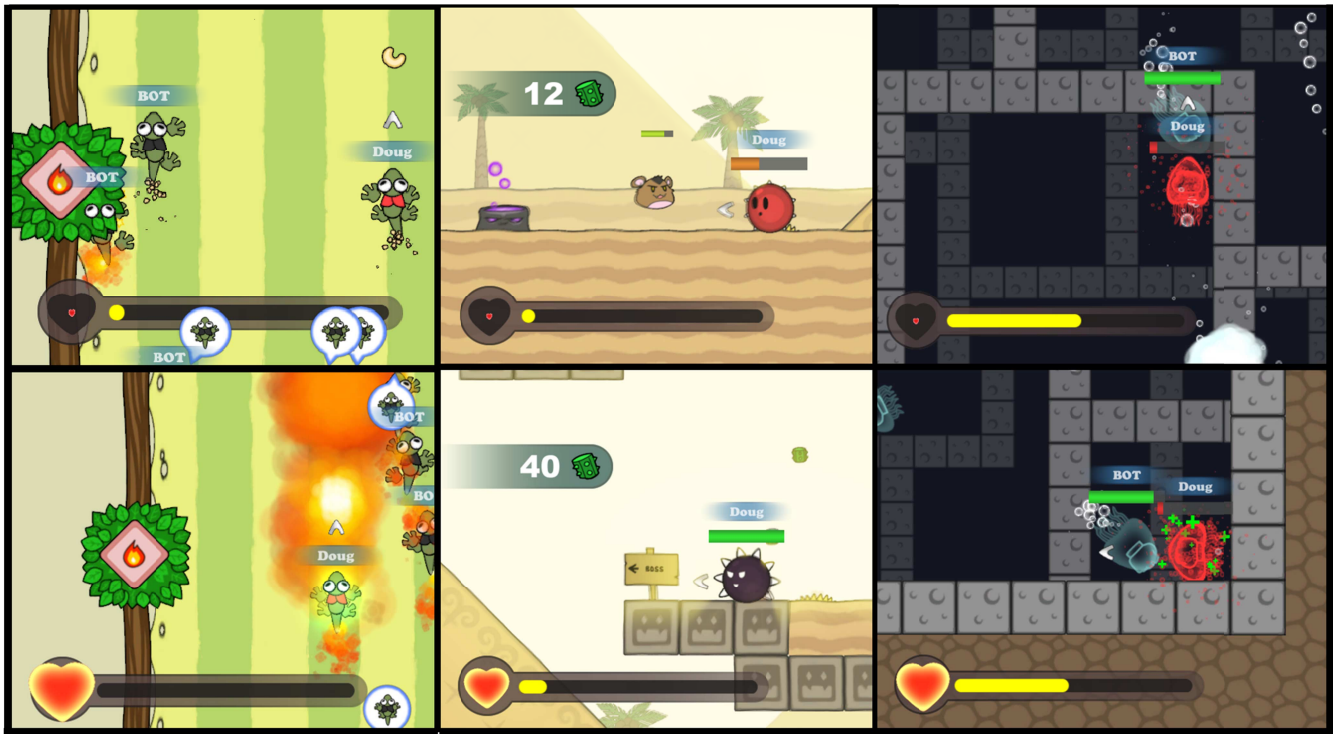

Figure 2. From left to right: Gekku Race and Dozo Quest, Biri Brawl. The bottom row shows the HR power-up: Dozo Quest has a more powerful avatar, Biri Brawl includes health-regeneration, and Gekku Race provides more powerful attacks.

Gekku Race

Gekku Race is a racing game in which players pedal to move their avatar along a track, steering with an analog stick on their game controller (Figure 2: left). The faster the player pedals, the faster their Gekku character moves. The objective is to be the first to reach the top of a track. As players pedal, a small energy bar at the bottom of the screen fills up. Once the bar is full, the player is able to shoot cashews or fireballs at other racers to stun them or knock them down the track.

Whenever a player's heart rate reaches the target range, the player's avatar becomes "powered up". The Gekku avatar glows a bright green, indicating that the power-up is active. Players' attacks become stronger: the cashew attack shoots three cashews rather than one, and the fire attack changes from a small ball to a long stream of fire. The powered-up attacks are visually and aurally satisfying, while providing a modest increase in avatar power. If the player's heart rate dips below the target range, the power-up is lost.

HR Power-ups in *Gekku Race* are designed to be visually obvious (through the green glow and the visual effects of the attacks), and desirable through the appealing visual and audio presentation of the attacks.

Dozo Quest

Dozo Quest is a platform game in which the player controls a red spiky ball in a desert maze (Figure 2: centre). As with *Gekku Race*, the speed of the ball is determined by the player's pedaling speed. The maze contains obstacles that must be jumped, climbed, or knocked down, and enemies that must be defeated or avoided. The objective is for the player to collect as many cactus pieces as they can. Players use a dash move to race up ramps, jump between platforms, break cacti, attack enemies, and smash walls in their path. As we shall see, *Dozo Quest* is typically played at a considerably lower level of exertion than *Gekku Race*, as players are not obliged to move quickly and may pause to decide how best to approach the next part of the platform maze.

When a player reaches her target heart rate, her powered-up avatar turns into a black ball with larger, more intimidating spikes. The avatar's health regenerates, allowing recovery from injuries. Attacks become stronger, aiding in combat and allowing walls to be destroyed more quickly.

Biri Brawl

Biri Brawl is a fighting game in which players control a "Biri" jellyfish underwater (Figure 2: right). As with the other games, players pedal to move their Biri, and steer with the analogue stick on their game controller. Players can knock out other Biris by punching them until their health runs out. Knocked out Biris respawn at full health. To increase their longevity, players can pick up floating booster packs that provide extra health or short bursts of extra speed.

The objective of the game is to knock out as many other Biris as possible in the time allotted. Performing well in the game involves good aim, successful timing of hits, and being able to disengage from fights that are going poorly. *Biri Brawl* encourages players to reach moderate levels of exertion. Players must pedal quickly to engage in combat or to escape if they are losing. However, there are opportunities for players to pause before engaging in the next combat.

As usual, a HR power-up is awarded when the player reaches his target heart rate. Green cross symbols float around the avatar visually indicating that the power-up is active. The benefit of the power-up is that the avatar's health regenerates, speeding recovery from combat.

Applicability of HR power-ups.

Gekku Race, Dozo Quest and *Biri Brawl* share characteristics that make them strong candidates for the application of HR power-ups. All three games are based on cycling exercise (a form of activity that can be performed vigorously), and all three games allow players to choose how hard they wish to exercise. Therefore, the games are well-suited to HR power-ups, in that it is possible for players to raise their heart rates if they are incented to do so.

Not all active games have these properties, however. We identify three properties required an active game to be suitable for the application of HR power-ups.

Agency over Exertion

A player's *agency over exertion* is the amount of freedom the player has to change their level of exertion in the game without penalty. For example, in Dance Dance Revolution (DDR), players perform dance moves at a pace dictated by the game [13]. If a player tries to increase his level of exertion by dancing faster, he loses points for failing to match the beat of the game. DDR therefore dictates the player's level of exertion, allowing the player little agency.

Agency over exertion may change at different points of a game. For example, a cut scene may require a player to stop moving. In a turn-based game, players may be inactive while waiting their turn.

Our three games all provide players with high agency over exertion. The games have no pauses that require the players to stop pedaling, and increasing pedaling rate does not penalize players' performance. HR power-ups are suitable in games that provide high agency over exertion: if players are discouraged or penalized for increased exertion during gameplay, they will be unable to respond to the incentive of exercising more vigorously in order to earn a HR power-up.

Motion controls support exertion

A game can facilitate exertion only to the degree that players can raise their heart rate by performing the game's physical motions. We define the *potential exertion* of a game as the maximum exertion level a player can reach through the use of the game's motion controls. For

example, the potential exertion of Wii Sports Bowling is limited by the game's core activity of slowly swinging one's arm to throw a virtual ball. The *Dozo Quest, Gekku Race* and *Biri Brawl* games are based on cycling input, which has been designated a vigorous activity by the ACSM [5], indicating high potential exertion. While the presence of high potential exertion does not guarantee that players will reach target heart rates during game play, it does ensure player's exertion is not limited by the game's motion controls.

Large gap between average and potential exertion

A game's *average exertion* level is that experienced during a standard gameplay session. Average exertion can be measured as the average of a representative set of players' exertion levels during gameplay. (Our Evaluation section reports average exertion in our three games.) The difference between a game's average and potential exertion indicates whether there is room for players to increase their level of activity. *Dozo Quest, Biri Brawl* and *Gekku Race* share a high potential exertion, but – as we shall see – differ in their average exertion. In our experience a game with a large difference in potential and average exertion is better suited for the implementation of HR power-ups.

Summing up, HR power-ups are suited to games that allow the player to modify their level of exertion, include motion controls that support high levels of exertion, and differ in players' average and potential levels of exertion. This implies that games such as those presented in the paper – platformer, racing and fighting games – as well as shooter and role-playing games – all have potential for application of the technique. Games that have rigid pace (like DDR) or whose controls do not significantly increase heart rate (like Wii Sports Bowling) are poor candidates for the technique.

DESIGN PRINCIPLES

Gekku Race, *Dozo Quest* and *Biri Brawl* illustrate that HR power-ups can be applied to three different genres of games (racing, platformer and fighting games) and three different levels of average exertion. While the power-ups provided in each game are different, they share approaches: all power-ups provide a change in the avatar's appearance and one or more improvements to the avatar's power.

The design of these power-ups followed three principles: (1) the effect of the power-up should be clear; (2) the impact of the power-up should be balanced, and (3) the player's activity should be coupled to the power-up's effect. These principles are described below.

Effect should be clear

It must be clear to the player when the power-up is in effect, how close they are to attaining their target heart rate, and what effect the power-up has on their avatar. For example, in *Biri Brawl,* the player's jellyfish is surrounded by green floating health symbols when it is powered-up, making it clear that the power-up is active and regenerating the avatar's health. In all games, a heart rate indicator is shown at the bottom left of the screen (Figure 2). This indicator gives players a way to compare their current HR to their target HR. As we shall see, participants commented that this indicator helped motivate them to push harder to obtain the power-up.

Clarity of effect is important for two reasons. First, if the player's heart rate is close to the target, the power-up may be activated and deactivated frequently. It should be clear when the effect is lost to help motivate the player to increase her exertion level to retrieve it. Second, the player must be convinced that the power-up is worth the (quite literal) effort required to activate it. It is therefore important that they see immediately what the effect does. For example, *Gekku Race*'s loud and visually exciting attacks clearly indicate the benefit of having the power-up. Similarly, the dangerous-looking avatar in *Dozo Quest* immediately conveys the idea that the power-up increases the player's power.

Impact should be balanced

It is tempting to make power-ups overwhelmingly powerful in order to increase players' desire to activate them. This should be avoided: overly powerful power-ups risk making the game too easy and ultimately boring for the player. Equally, the game must be playable without the power-up to avoid trying players who have not reached target heart rate.

For example, piloting of an early version of *Dozo Quest* indicated that both parts of this principle had been violated: without the power-up, it was difficult to complete the game without being killed by the enemies. Meanwhile, the power-up made the player effectively invincible, removing all challenge from the game. In the final version of the game, the difficulty was reduced in standard play, and the effect of the power-up was reduced to retain challenge in the game.

Activity should be coupled to effect

When players expend the necessary energy to meet their target heart rate, they should see the benefit of the power-up immediately and continuously as long as the target is maintained. Not only should it be clear that the power-up is active (our first principle), but the positive effect of the power-up should be immediately available.

For example, in *Gekku Race*, players need to pedal to charge up the Gekku's cashew and fire attacks. Game balance requires that these attacks not be available constantly. It was necessary to tune this recharge time so that the player did not need to wait overly long to receive the benefit of the power-up. In the final game, the charging time is six seconds.

Traditional power-ups often grant an ability that can be used in the future – e.g., in Mario Kart, players can obtain a banana that can be used later to slow down an opponent.

Our guidelines capture that power-ups must be tied to the player's present exercise level, so that obtaining a power-up for later use does not provide an excuse to slow down or reduce effort.

We applied these three principles through the iterative design and pilot testing of our three games. As we shall see in the next section, all three games were successful at increasing heart rate and time above target heart rate

EVALUATION

To evaluate the effectiveness of HR power-ups we performed a within-subjects study using the *Dozo Quest*, *Biri Brawl* and *Gekku Race* games described above. We wished to address the following four questions: Can power-ups assigned as a reward for reaching target heart rate encourage players to strive for and maintain their target heart rate? If so, does the effectiveness of HR power-ups depend on the difference between average and potential exertion levels of the game? Does the effectiveness of the HR power-up depend on player skill? And how does the presence of HR power-ups affect players' enjoyment of the game?

Participants

We recruited 20 participants from Queen's University (11 males, 9 females, 18-26 years old). 13 reported playing games daily and five of the remaining seven reported having been frequent gamers in the past. All participants were comfortable using a gamepad and operating a recumbent bicycle. We used the Physical Activity Readiness Questionnaire (PAR-Q) [6] to screen for health issues making physical exercise inadvisable. Roughly half of the participants were physically active, with 11 of 20 reporting physical activity at the recommended ACSM level. During the study, automated data collection failed for one participant, and so results are reported for 19.

Setup and Apparatus

As shown in Figure 1, players used a PCGamerBike Mini pedaling device as input to the games. This device provides cycling cadence information via a USB connection. Participants wore a Garmin heart rate monitor to provide real-time heart rate information to the game. Players used a Logitech gamepad to control their avatar. The games were displayed on a 55" wall-mounted television.

Measures

Data was collected through log files generated by the games. Once per second, the game recorded the player's heart rate and cadence, as well as game events such as the collection of a cactus in *Dozo Quest*. A custom log-file analysis tool was used to compute average heart rate, time spent within the target heart rate range and players' scores in each game. Players completed a custom questionnaire shown in Table 1.

Procedure

Participants first completed a demographic questionnaire. To obtain their resting heart rate, participants were asked to relax in a reclining chair for four minutes, after which their heart rate was measured. Using the participants' age and resting heart rates, the Karvonen formula [28] was used to calculate each participant's target heart rate. We chose a target heart rate of 65% of heart rate reserve, representing the moderate-to-hard intensity level recommended by the ACSM for people who regularly exercise at moderate-to-high intensity [28]. This target is significantly higher than that sought in the exergaming meta-reviews cited earlier; we chose this ambitious exertion level to convincingly assess the potential of game with HR power-ups as a viable substitute for traditional exercise.

Each participant ran trials in two separate sessions over two days. In one session, participants played all three games with the heart rate power ups; in the other, they played the control version of the same three games. Ten participants played the HR condition first and 10 played the control condition first. The three games were ordered according to a Latin square. At the beginning of each session, players pedaled for three minutes to warm up.

Under the control condition, players received the power-up in predetermined segments of the game. In *Dozo Quest* and *Gekku Race*, segments of the track were selected as regions in which the player automatically received the power-up. In *Biri Brawl*, the power-up was awarded during periods covering 50% of the playtime. Thus, in both conditions, players received the same power-ups; the conditions differed only in how the power-ups were awarded. In the experimental condition, the power-up was activated whenever the player met or exceeded their target heart rate.

Each game was described to participants immediately before it was played. The power-up and its effect in the game were explained. In both conditions, a heart rate indicator was shown in the bottom left of the screen to inform players how close they were to their target heart rate. Participants played each of the three games for seven minutes and rested between games to reduce cross-over of heart rate levels elevated from earlier play. The rest period was a minimum of five minutes, extended as necessary until the participant's heart rate fell below moderate intensity levels.

Participants responded to the statements shown in Table 1: they responded to statements S1-S5 after every trial, to S6-S7 following trials using HR power-ups, and to S8-S10 after completing both the control and HR power-up sessions.

The first two minutes of data from each game were considered to be warm-up, and were removed from analysis. Heart rate typically reaches a steady-state within one to two minutes following an increase in exercise intensity [14]. This left five minutes of data for analysis in each trial.

RESULTS

We present results around our four questions about the effectiveness of HR power-ups. The results are based on our gameplay logs and questionnaire responses. Questionnaire data is summarized in Table 1. We report significance at the alpha=.05 level, and "marginal significance" at the alpha=.07 level to highlight possible type 2 errors. We indicate effect size using Cohen's d [32], where a value of 0.2 is considered a small effect, 0.5 medium and 0.8 large. Data from one of the 20 participants is excluded because of a failure of that participant's heart rate sensor.

Q1: Can heart-rate power-ups encourage players to reach and maintain their target heart rate?

Figure 3 shows the average amount of time participants spent at or above their target heart rate during each game. For each game, we performed a one-way paired-samples *t*-test comparing time at or above target heart rate and applied Bonferroni correction to the results. Time was significantly higher in the HR power-up condition for *Dozo Quest* (t=3.22, p=.002) and *Biri Brawl* (t=2.82, p=.006). *Gekku Race* (t=3.215, p = .021) did not see significant changes. Figure 4 shows participants' average heart rate while playing the games. A one-way paired-samples *t*-test on player's average heart rate showed significant differences for *Dozo Quest* (t=4.39, p<.001) and *Biri Brawl* (t=2.88, p=.005), and no significance for *Gekku Race* (t=1.61, p=.062).

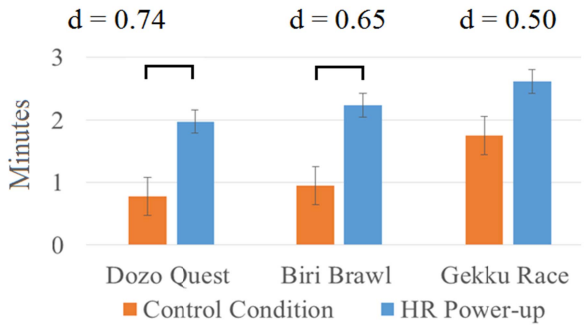

Figure 3. Average number of minutes that participants' heart rate was in their target heart rate range for each game. Hat symbols indicate significant differences.

Table 1 shows the results of questionnaires administered after each condition. When asked the question "I paid attention to the heart rate indicator during the game", A Wilcoxon Signed-Ranks test indicates significantly higher responses for *Biri Brawl* and *Dozo Quest*, but not for *Gekku Race*. When asked "I tried to reach and maintain my heart rate during gameplay", significant differences were found between the heart rate and control power-ups for *Biri Brawl* and *Dozo Quest*, but not for *Gekku Race*.

Q1: Interpretation of results

Our study reveals that players maintain a higher heart rate when games use an HR power-up. Player responses to S6 reveal that all participants felt encouraged to pedal harder

Wilcoxon Test Results			
Questions asked in each condition	Gekku Race	Biri Brawl	Dozo Quest
S1) The game was physically tiring	z=-1.933, p=.53	z=-1.134, p=.257	z=-3.035, p=.002
S2) I was good at achieving the game's objectives	z=-1.732, p=.83	z=-.212, p=0.832	z=-0.359, p=.719
S3) I paid attention to the heart rate indicator during the game	z=-2.359, p=.18	z=-3.361, p=.001	z=-3.572, p<.001
S4) I tried to reach and maintain my target heart rate during gameplay	z=-2.575, p=.10	z=-3.327, p=.001	z=-3.099, p=.002
S5) Playing this game was a vigorous workout	z=-2.333, p=.002	z=-1.265, p=.206	z=-1.786, p=.074

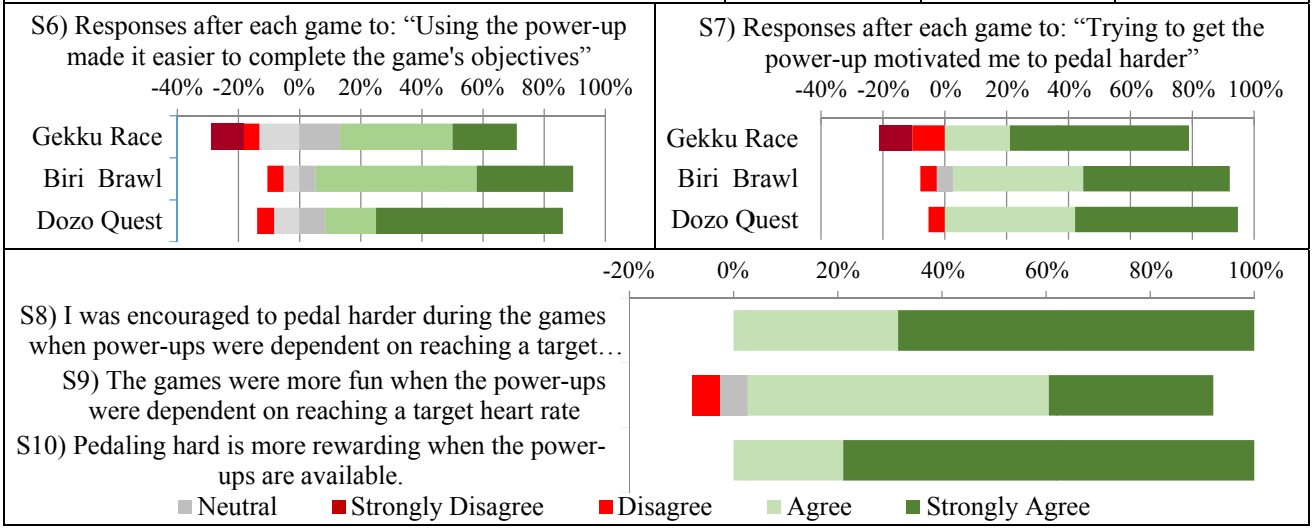

Table 1. Questionnaire responses. S1–S5 were asked after each game in both conditions; S6-S7 were asked after each game in the HR power-up condition only, and S8-S10 were asked after participants had finished both conditions

Game	Average HR	Effect of HR power-up
Dozo Quest	123 bpm	1.01
Biri Brawl	129 bpm	0.66
Gekku Race	137 bpm	0.37

Table 2. We measured the average HR of each game through players' average heart rate while playing the game in the control condition

by the presence of the HR power-ups. In an interview, one participant stated "it's more motivating to get your target heart rate when you get a power-up. [In] the [control condition] you just ignore your heart rate and play the game". Players' increased motivation translated into higher exertion levels. The average amount of time players spent in their target heart rate zone increased for two styles of game (Figure 4), as did the players' mean average heart rate (with the exception of *Gekku Race*).

Q2: Does the effectiveness of power-ups depend on the average exertion level of the game?

We measured each game's average exertion via the players' average heart rate during play of the control condition. These exertion values are summarized in Table 2. A one-way within-subjects ANOVA indicated a significant effect of game on player heart rate ($F(2, 36) = 15.853$, $p<.001$). One-way paired-samples *t* tests with Bonferroni correction indicate that the mean exertion of *Dozo Quest* ($M=122.63$, $SD=16.91$) is significantly lower than the mean exertion of *Biri Brawl* ($M=129.23$, $SD=14.33$, $t(18)=3.10$, $p=.006$, $d=.64$); the mean exertion of *Biri Brawl* is significantly lower than the mean exertion of *Gekku Race* ($M=137.22$, $SD=15.48$, $t(18)=3.19$, $p=.005$, $d=.65$), and the mean exertion of *Dozo Quest* is significantly lower than the mean exertion of *Gekku Race* ($t(18)=5.98$, $p<.001$, $d=1.3$).

In sum, *Gekku Race* is the game with highest average exertion, *Dozo Quest* is the game with lowest average exertion, and *Biri Brawl* lies between them. The effect sizes indicate a large effect on exertion between each game. Therefore, we conclude that there is a large difference in average exertion between the three games.

This difference in average exertion impacted the effect of HR power-ups – the slower the pace of the game, the larger the impact that was seen on both time above target heart rate and average heart rate. Specifically, the effect of HR power-ups on minutes over target heart rate is greatest for *Dozo Quest* (d=.74), then lower for *Biri Brawl* (d=.65) and smallest for *Gekku Race* (d=.5). The effect of HR power-ups on average heart rate follows the same ranking, of *Dozo Quest* (d=1), *Biri Brawl* (d= .66) and *Gekku Race* (d=.37). With the exception of the moderate effect on average heart rate in *Gekku Race*, these are all considered to be large effects.

Q2: Interpretation of results

The power-ups were more effective at increasing player

Figure 4. Mean heart rate and standard error for each game. Hat symbols indicate significant differences.

heart rate in the games with lower average exertion. One explanation for this trend is that in the games with high average exertion, players were closer to target heart rate in the control condition, and therefore required less additional effort to attain the power-up. Not surprisingly, players' responses to the statement "Trying to get the power-up motivated me to pedal harder" (S7, Table 1) show that players were more motivated by the power-ups during the games with lower average exertion.

A major finding from these results is that it is possible to improve heart rate in games with low average exertion. In *Dozo Quest,* players have lots of opportunities to pause, rest and reflect. The HR power-up was successful in motivating players to skip these opportunities.

Q3: Does the effectiveness of the power-up depend on player skill?

We measure players' skill in the game via their score in the control condition of the game. In *Dozo Quest* this was measured as the number of cactuses collected, in *Biri Brawl* as the number of opponents knocked out, and in *Gekku Race* as the number of races won.

A linear regression on players' skill versus players' average heart rate in the HR power-up condition showed no significant correlation in *Dozo Quest* ($r(17)=.308$, $p=.10$), *Biri Brawl* ($r(17)=0.112$, $p=.323$) or *Gekku Race* ($r(17)=.262$, $p=.139$).

Q3: Interpretation of results

We had anticipated that weaker players might be more motivated to obtain the power-up, since it would have a bigger impact on their ability to play the game. The results did not support this hypothesis.

Q4: How does the presence of HR power-ups affect players' enjoyment of the game?

After finishing both conditions for all games, participants responded to the statement "The games were more fun when power-ups were dependent on reaching target heart rate" (S7 in Table 1). 18 participants responded with "Neutral, "Agree" or "Strongly Agree", while one responded with "Disagree". In response to "Pedaling hard is more rewarding when the power-ups were based on HR" (S8 in Table 1), all participants agreed or strongly agreed.

In response to the statement "I found the game to be physically tiring", players reported the games to be significantly more tiring when power-ups were dependent on HR in *Dozo Quest* and marginally significantly more tiring in *Gekku Race*. For the statement "Playing this game was a physical workout" (S5 in Table 1), players gave significantly higher values for the HR power-up condition of *Gekku Race* and marginally significantly higher values for *Dozo Quest*.

Q4: Interpretation of results

Despite concerns that increasing the exertion level of the games could reduce players' enjoyment [34], we found the opposite to be true. Players overwhelmingly reported the HR power-up version of the game to be more fun, and reported the physical exercise to be more rewarding. Being able to pedal hard to obtain the power-ups adds a new form of challenge to the games, likely an important factor of the increased enjoyment. One player described how Dozo Quest changed with the power-up: "the power-up made it go faster and faster is more fun".

While players pedaled harder in the HR power-up version of all games, they did not always perceive the game to be more tiring or to represent a more strenuous physical workout, with significant differences in response to S1 in Table 1 for one game, and marginally significant differences for the others. Not surprisingly, the game (*Dozo Quest*) with the lowest average exertion had the greatest increase in being physically tiring (S1 in Table 1), corresponding to its greatest increase in physical exertion.

DISCUSSION AND IMPLICATIONS FOR DESIGN

The success of HR power-ups demonstrates the potential of designing for exertion in exergames. We now explore the implications of our experience with HR power-ups on the design of exergames.

Exergames as a form of exercise

While the presence of HR power-ups successfully (and dramatically) increased levels of exertion observed in our study, our central question remains whether they are sufficient to turn exergames into viable alternatives to traditional physical activity. In our study, we adopted the highest levels of the ACSM recommendation, 60-80% of heart rate reserve, intended for people who regularly exercise at moderate-to-high intensity. To place this choice in context, the ACSM recommendation for people of low levels of conditioning is 40-59% of heart rate reserve. This might have been more appropriate for the self-reported level of activity of 11 of our 20 participants. As we have seen, in Gekku Race, players spent 52% of their time at or above target heart rate. When the data is reinterpreted using the lower ACSM recommendation of 40-59% as target heart rate, players spent 88% of their time at or above target heart rate in Gekku race. In Biri Brawl, players spent 88%, and in Dozo Quest 79% of their time at or above 40% HRR. These levels indicate that exergames employing HR power-ups are more than adequate for reaching the lower end of the ACSM guidelines for exercise prescription, and on the boundary of being suitable for the higher level of recommendations.

A limitation of our study is that in order to avoid fatigue between conditions, we limited the exergaming segments to five minutes in length. Future studies will test longer play sessions. While further study is required, these results indicate that games using HR power-ups have the potential to provide exercise consistent with ACSM recommendations, particularly for people with low levels of conditioning.

HR power-ups can increase player enjoyment

When asked to respond to the statement "The games were more fun when the power-ups were dependent on reaching a target heart rate" only one of 19 participants disagreed. When interviewed, many participants described that they felt stronger or more powerful in the game when power-ups were present and that they won more with them. Participants also reported enjoying that the power-ups added an extra goal to the game, and that obtaining the power-up gave them a sense of accomplishment. No participants cited the higher exertion required to play the game with HR power-ups as negatively impacting their enjoyment.

Applicability of HR Power-ups

Our study provided evidence that, at least among the games tested, HR power-ups have a larger effect in games where there is a large difference between average and potential exertion. Games with a high average exertion (such as Gekku Race) or low potential exertion (such as Wii Sports Bowling) provide players with limited opportunity to increase their exertion level through gameplay. Developers should consider whether their games have a high potential exertion and a gap between that and average exertion before implementing HR power-ups.

Visible HR power-ups motivate players

Our experience highlights the importance of the effects of HR power-ups being visually clear. One participant stated in reference to her *Gekku Race* avatar "I just wanted to get the power-up so if it wasn't glowing I would try to get it to glow". Another commented on his reaction to a visualization, saying "Once I saw the gekku burst the giant flame, I was like 'Okay! I want to do that again!'". Players' found the visual presentation important in knowing when the HR power-up was in effect, and found the visuals motivational in of themselves.

HR Power-ups create a risk of overexertion.

In all games we presented a warning message on screen if any participants reached 80% HRR. It is important for designers using this method to be aware that HR has a delayed response to load increase that risks overloading participants. It is unclear to players how close their HR is to dropping back down to below target levels. People may continue to push themselves to go harder to avoid dropping below and they may go to unsafe levels.

CONCLUSION

In this paper, we have argued for the need to design for exertion in exergames, addressing the fact that few exergames lead to recommended levels of physical activity and very little of the current research in design of exergames focuses on players' exertion levels. To address this issue, we have presented HR power-ups, a technique for encouraging more vigorous play of exergames. We have shown that HR power-ups can be applied to a wide range of game styles, including a platformer game, a racing game and a fighting game. We found that HR power-ups increased levels of exertion, leading to between 50% and 100% increases in time over target heart rate. HR power-ups were most effective in games with low average exertion. Promisingly, players preferred the versions of the games where HR power-ups were present. We conclude that HR power-ups have great potential in helping to design exergames to be an enjoyable viable alternative to traditional physical exercise.

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