Virtual-reality exergaming improves performance during high-intensity interval training

Matthew Farrow[1,3] Christof Lutteroth[2,3], Peter C. Rouse[1], James L. J. Bilzon[1,3]

[1] Department for Health, University of Bath, Bath UK

[2] Department of Computer Science, University of Bath, Bath UK

[3] Centre for the Analysis of Motion, Entertainment Research and Applications (CAMERA), University of Bath, Bath UK

Corresponding author:

Professor James Bilzon, Department for Health, University of Bath, BA2 7AY, UK

Email: J.Bilzon@bath.ac.uk

Tel: +44 (0)1225 383174

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Abstract

Purpose: To determine if: i) mean power output and enjoyment of high-intensity interval training (HIIT) are enhanced by virtual-reality (VR)-exergaming (*track* mode) compared to standard ergometry (*blank* mode), ii) if mean power output of HIIT can be increased by allowing participants to race against their own performance (*ghost* mode) or by increasing the resistance (*hard* mode), without compromising exercise enjoyment.

Methods: Sixteen participants (8 males, 8 females, VO_2max: 41.2 ± 10.8 $ml^{-1} \cdot kg^{-1} \cdot min^{-1}$) completed four VR-HIIT conditions in a partially-randomised cross-over study; 1a) *blank*, 1b) *track*, 2a) *ghost*, and 2b) *hard*. VR-HIIT sessions consisted of eight 60 s high-intensity intervals at a resistance equivalent to 70% (77% for hard) maximum power output (P_{MAX}), interspersed by 60 s recovery intervals at 12.5% P_{MAX}, at a self-selected cadence. Expired gases were collected and VO_2 measured continuously. Post-exercise questionnaires were administered to identify differences in indices related to intrinsic motivation, subjective vitality, and future exercise intentions.

Results: Enjoyment was higher for *track* vs. *blank* (difference: 0.9; 95% CI: 0.6, 1.3) with no other differences between conditions. There was no difference in mean power output for *track* vs. *blank,* however it was higher for *track* vs. *ghost* (difference: 5 Watts; CI: 3, 7), and *hard* vs. *ghost* (difference: 19 Watts; 95% CI: 15, 23).

Conclusions: These findings demonstrate that VR-exergaming is an effective intervention to increase enjoyment during a single bout of HIIT in untrained individuals. The presence of a ghost may be an effective method to increase exercise intensity of VR-HIIT.

Key Words: gamification; exercise intensity; intrinsic motivation, enjoyment

Introduction

Insufficient physical activity accounts for 6-10% of deaths from major non-communicable diseases worldwide (Lee et al., 2012). A lack of time is frequently cited as the most common barrier to physical activity participation (Trost, Owen, Bauman, Sallis, & Brown, 2002). Consequently, interval training has received substantial attention as a time-efficient solution, particularly due to reported physiological benefits and psychological responses (MacInnis & Gibala, 2017; Stork, Banfield, Gibala, & Martin Ginis, 2017). High-intensity interval training (HIIT) typically involves short bursts of near maximal exercise (>80% maximum heart rate) interspersed with low-intensity recovery phases (Gibala, Little, MacDonald, & Hawley, 2012). It is now well-established that HIIT produces beneficial effects over moderate-intensity continuous training for a range of relevant health outcomes, including, cardiorespiratory fitness, insulin sensitivity, and vascular function (Jelleyman et al., 2015; Milanovic, Sporis, Weston, 2015; Ramos, Dalleck, Tjonna, Beetham, & Coombes, 2015). Despite the greater physical demands, an acute bout of HIIT can also be perceived as more enjoyable and a preferred exercise modality compared to moderate intensity continuous training, making HIIT a promising solution to the physical inactivity endemic (Thum, Parsons, Whittle, & Astorino, 2017).

Short-term training adherence to HIIT in laboratory settings is high, and preliminary evidence suggests participants are able to independently adhere to prescribed HIIT programmes for at least 4-5 weeks (Jung, Bourne, Beauchamp, Robinson, & Little. 2015; Vella, Taylor, & Drummer, 2017). However, given that 40-65% of individuals withdraw after 3-6 months of initiating a physical activity programme, concerns remain about the long-term adherence, particularly in habitually inactive individuals (Annesi, 2001; Biddle & Batterham, 2015; Dishman & Buckworth, 1996). These concerns are supported a recent study, reporting that following a HIIT intervention in overweight/obese adults, only 40% were adhering to the programme 12-months later (Roy et al., 2018). In line with self-determination theory, intrinsic motivation is a key regulator of long-term physical activity behaviour, underpinned by feelings of enjoyment, personal accomplishment, and excitement (Teixeira, Carraca Markland, Silva, & Ryan, 2012). In particular, the enjoyment of physical activity can predict long-term physical activity behaviour (i.e. adherence after 6 and 12 months), to a greater extent than self-efficacy, among inactive individuals (Lewis, 2016). Furthermore, autonomous regulators of exercise behaviour such as enjoyment are associated with subjective vitality, a positive indicator of psychological well-being (Rouse, Ntoumanis, Duda, Jolly, Williams, 2011). Therefore, while exercise enjoyment an important outcome per se, increasing exercise enjoyment may also promote adherence to a HIIT programme.

Virtual-reality (VR) - exergaming provides a potential vehicle for delivering HIIT to increase exercise effort and enjoyment. VR-exergaming is defined as the integration of a cycle ergometer into an immersive video game environment, with this technology becoming increasingly prevalent in fitness centres and gymnasia. Previous studies have demonstrated that adherence to moderate-intensity cycling in young men was higher among those using integrated video game ergometers compared to standard ergometry (Rhodes, Warburton, & Bredin, 2009; Warburton et al., 2007). This may be explained by the higher levels of enjoyment reported in response to an acute bout of moderate-intensity cycling with the addition of a video game component compared to standard ergometry (Glen, Eston, Loetscher, & Partitt, 2017; Monedero, Lyons, & O'Gorman, 2015; Warburton et al., 2007). Similarly, while the gamification of HIIT is perceived to be more enjoyable than low-intensity walking, it is unclear if VR-HIIT can increase acute effort and/or enjoyment compared to standard ergometry HIIT (Moholdt, Weie, Chorianopoulos, Wang, & Hagen, 2017).

If VR-HIIT can enhance exercise enjoyment and elicit greater physiological adaptations, it may offset some of the progressive fatigue and negative affective responses experienced during traditional HIIT (Frazao et al., 2016; Wood, Olive, LaValle, Thompson, Greer, & Astorino, 2016). Evidence suggests that more immersive and integrated exergame solutions generate greater enjoyment and higher exercise intensity during self-regulated intensity cycling (Glen et al., 2017). For example, allowing individuals to visualise and compete against a virtual competitor can increase exercise intensity compared to no visual display, by distracting the individual away from feelings of fatigue (Glen et al., 2017; Shaw, Buckley, Corballis, Lutteroth, & Wuensche, 2016; Williams, Jones, Sparks, Marchant, Midgley, & McNaughton, 2015). Given the positive psychological responses to exergaming, it is plausible that exercise intensity of HIIT may be substantially increased and that participants will engage to meet the increased demand. Such methods may therefore be effective in increasing and/or maintaining exercise intensity during HIIT.

The objectives of this study were to determine if: i) mean power output and enjoyment of an acute bout of HIIT are enhanced by VR-exergaming (*track* mode) compared to standard ergometry (*blank* mode), and ii) mean power output of HIIT can be increased by allowing participants to race against their own performance (*ghost* mode) or by increasing the resistance (*hard* mode), without compromising exercise enjoyment.

Methods

Participants

A total of 21 young, healthy men and women volunteered and provided written informed consent to participate in this study. The inclusion criteria were: aged between 18 and 40 years, classified as sedentary or recreationally active as determined by the International

Physical Activity Questionnaire (IPAQ), and no contraindications to vigorous exercise as determined by a Physical Activity Readiness Questionnaire (PAR-Q) (Thomas, Reading & Shephard, 1992) and a general health questionnaire. The study was approved by the University of Bath's Research Ethics Approval Committee for Health (REACH) and conformed to the requirements of the Declaration of Helsinki. Five participants withdrew from the study before completion of all visits, due to injury (n=1), personal time constraints (n=3), and an unwillingness to complete all aspects of the study (n=1). A total of 16 participants (8 male and 8 female) completed all study visits (Table 1).

Experimental design

Participants visited the laboratory on five separate occasions, at least 3 days apart, for baseline testing (one visit) and four VR-HIIT sessions. Baseline testing consisted of an assessment of peak aerobic capacity and a HIIT familiarisation session. The four VR-HIIT conditions were i) *blank* mode ii) *track* mode, iii) *ghost* mode, and iv) *hard* mode. Due to game design it was not possible to fully randomise the order of trials; however, the order within each set of trials was randomised. The first set of trials for each participant were always the *blank* and *track* modes, and the second set were always the *ghost* and *hard* modes. Prior to each VR-HIIT session, participants were asked to avoid vigorous physical activity (48-h prior), caffeine and alcohol (24-h prior), and food and fluids (except water) (3-h prior). Compliance with these procedures was checked verbally prior to the start of each trial.

Baseline testing

Peak oxygen uptake capacity ($\dot{V}O_2$peak) was determined during a continuous incremental cycling test on an electronically braked cycle ergometer (Lode, Excalibur Sport, the Netherlands). The test began with a 3-minute warm-up at 50 W before a 20 W $\cdot$ min^{-1} continuous ramp protocol, whereby participants cycled at a self-selected cadence until they could no longer cycle above 50 rpm. $\dot{V}O_2$peak was defined as the highest 15-breath rolling average achieved during the test. In all tests, two or more of the following criteria were met: heart rate (HR) within 10 beats of age-predicted maximum (220-age), respiratory exchange ratio $\geq$ 1.15, rating of perceived exertion (RPE) $\geq$ 19, and/or volitional exhaustion (Thompson, Gordon, & Pescatello, 2010).

Following 20-minute rest, participants completed a HIIT familiarisation session consisting of 8 x 60 s intervals at 70% maximum power output (P_{MAX}) with 60 s recovery intervals at 12.5% P_{MAX}, including a one-minute warm-up and cool-down. The purpose of this session was to familiarise participants with the desired exertion the HIIT protocol required and the Category-Ratio 10 Scale (CR-10) scale, as this scale was not visible during the VR-HIIT sessions (Borg, 1982).

VR-HIIT sessions

All VR-HIIT sessions were performed on the same electronically braked cycle ergometer as used in baseline testing whilst wearing a commercially available head-mounted display (Vive, HTC, Taiwan) connected to a PC (Intel Xeon E5 2680, USA), running the Unity game engine. The game involved cycling along a straight road whilst avoiding slow-moving trucks, whereby players could lean their head left or right to move laterally. A sunny scene was displayed during the low-intensity phases (warm-up, recovery intervals, and cool-down) to evoke a relaxed mood. A night scene was displayed during the high-intensity phases with police cars with emergency flashing lights following the player, to evoke a sense of pressure and urgency (Figure 1). In the case of a collision with a truck, the truck simply disappeared without further consequence.

[INSERT FIGUE 1 HERE]

During all game modes (*blank*, *track*, *ghost*, and *hard*) a countdown timer for the current phase and the current RPM were shown. At the start of the *ghost* and *hard* modes, a message was displayed reading "the exergame may change the intensity of the workout to make it easier or harder". The distance behind or ahead of the ghost avatar during the exercise was displayed throughout the game. On-screen prompts were displayed to alert participants that each high-intensity phase was beginning and ending.

The *blank* mode acted as the control condition and involved a blank blue screen being displayed throughout. The *track* mode was the basic game mode, with the purpose to record the participant's performance for the *ghost* and *hard* modes. During the *ghost* and *hard* modes, the participant's *track* mode performance was displayed as a separate avatar, which reset to the same starting point as the participant at the start of each high-intensity phase. Participants were instructed at the start of the *ghost* and *hard* sessions that the aim of the game was to beat their ghost avatar during the high-intensity phases.

Each participant's average RPM for high-intensity and low-intensity phases was recorded during the familiarisation session and used to calculate the corresponding torque to achieve 70% P_{MAX} and 12.5% P_{MAX} for the *blank*, *track*, and *ghost* modes (Brown et al., 2016). Each VR-HIIT consisted of a one-minute warm up, followed by eight 60 s high-intensity intervals interspersed by 60 s low-intensity phases, and a one-minute cool-down. The torque of the high-intensity phases in the *hard* mode was set 10% higher than in the other three conditions, whilst the low-intensity torque remained unchanged. Before each *blank* and *track* condition, to allow participants to self-select their desired intensity, the following message was displayed:

"If you cycle at __ rpm during the low-intensity phase and __ rpm during the high-intensity phase, you will match the intensity of exercise that you performed in the familiarisation session. If you cycle at a higher rpm, then the intensity will be harder. If you cycle at a lower rpm, then the intensity will be lower. We would like you to at least equal the intensity you exercised in the familiarisation session."

Physiological measures

Throughout each VR-HIIT exercise bout, expired gases were collected continuously using an online metabolic cart (ParvoMedics TrueOne 2400, Utah, USA), and used to calculate total oxygen consumption ($\dot{V}O_2$) (Frayn, 1983). Total session energy expenditure (kcal) was calculated using: $0.550*\dot{V}CO_2 + 4.471*\dot{V}O_2$ (Jeukendrup & Wallis, 2005) for high-intensity exercise. When RER exceeded 1.0, energy expenditure was calculated assuming a relationship of 5 kcal utilized for each 1 L of O_2 consumed (Williams et al., 2013). Peak HR (Polar H10, Kempele, Finland) for each high-intensity bout was recorded and is presented as a % of maximum HR achieved during the maximal exercise test (%HR_{MAX}).

Psychological measures

Participants were asked for their RPE (CR-10) (Borg, 1982) immediately following each high-intensity interval and completion of the exercise session. Immediately following completion of exercise in a VR-HIIT session, participants completed a set of questionnaires (see below).

Intrinsic motivation - Three subscales (Interest/Enjoyment, Effort/Importance, and Competence) of the Intrinsic Motivation Inventory (IMI) (Ryan, 1982) were administered. Responses were scored on a 7-point Likert scale ranging from "not at all true" (1) to "very true" (7).

Subjective vitality - A five-item version of the Subjective Vitality Scale (Ryan & Frederick, 1997) included five statements: i) At this moment, I feel alive and vital, ii) Currently I feel so alive I just want to burst, iii) At this time I have energy and spirit, iv) At this moment I feel alert and awake, and v) I feel energized right now. Responses were scored on a 7-point Likert scale ranging from “not at all true” (1) to “very true” (7).

Exercise intentions - Participant’s intentions to engage in the exercise just completed over the next month was assessed using a 2-item measure (Jung, Bourne, & Little, 2014). The two items were statements: i) I intend to engage in the type of exercise I performed today at least 3 times per week during the next month; and ii) I intend to engage in the type of exercise I performed today at least 5 times per week during the next month. Responses were scored on a 7-point scale ranging from “very unlikely” (1) to “very likely” (7). Participants were told that they should assume they had access to the VR-exergaming equipment when answering these questions.

Statistical analyses

Based on the data produced by Barathi et al. (2018), it was calculated that 20 participants were needed to identify a statistically significant difference in mean power output between *track* and *ghost* conditions (effect size = 0.67), with a power of 0.8 and alpha set at 0.05. Due to technical error for 2 participants, all $\dot{V}O_2$, energy expenditure, and $\%HR_{MAX}$ analyses were performed for 14 participants. All other analyses were performed using data from all 16 participants. As we failed to reach our calculated a-prior sample size, a post-hoc analysis of the difference in mean power output between the track and ghost conditions (effect size = 1.10) was performed, revealing a power of 0.99 with alpha set at 0.05. To identify sex differences in post-exercise psychological measures, two-way repeated measures ANOVAs (trial x sex) were performed. There were no significant interaction effects and therefore all consequent analyses were performed with males and females grouped together. Due to complex trial design (i.e. two randomised groups) and instructions given to participants between trials, it was deemed appropriate to conduct two-way paired t-tests with Ryan-Holm

Bonferroni step-wise adjustments (*track* vs. *blank*, *ghost* vs. *track*, *hard* vs. *ghost*) for average power output, energy expenditure, and all post-exercise psychological measures. Significance was accepted at $P < 0.05$. Data are presented as Δ change scores with 95% CI's unless otherwise stated. In addition, effect sizes (Cohen's *d*) are included, and interpreted as: small effect = 0.20-0.49, medium effect = 0.50-0.79, and large effect ≥0.80 (Cohen, 1988).

Results

Five of the 16 participants reported that they noticed the increased resistance in the *hard* condition in comparison to the *ghost* condition**.**

[INSERT TABLE 1 HERE]

On average, participant's exercised at 74 ± 3, 74 ± 3, 76 ± 4, and 84 ± 5 % of P_{MAX} during the *blank*, *track*, *ghost*, and *hard* conditions respectively. There was no significant difference in mean power output for *track* vs. *blank* (Table 2). Mean power output was 3% higher for *ghost* vs. *track* (*P* <0.01; *d*=0.10), and 9% higher for *hard* vs. *ghost* (*P* <0.01; *d*=0.36) (Table 2). There was no significant difference in total energy expenditure for *track* vs. *blank* (Table 2). There was a 7% higher total energy expenditure for *ghost* vs. *track* (*P* =0.04, d=0.27) (Table 2). Total energy expenditure was 12% higher for *hard* vs. *ghost* (*P* <0.01, *d*=0.45) (Table 2).

[INSERT TABLE 2 HERE]

Interest/enjoyment was significantly higher (*P* <0.01, *d*=1.67) for *track* vs. *blank*, with no other significant differences between conditions (Figure 2). Subjective vitality was significantly higher for *track* vs. *blank* (difference: 0.8, 95% CI: 0.1, 1.5, p= 0.03, *d*=0.76), with no other significant differences between conditions. Session RPE was significantly higher (difference: 0.9, 95% CI: 0.4, 1.3, *P* <0.01; *d*=0.65) for *hard* vs. *ghost*, with no other significant differences between conditions. There were no significant differences in effort/importance or exercise intentions between conditions.

[INSERT FIGURE 2 HERE]

Discussion

The primary findings of this study are that: i) an acute bout of HIIT is more enjoyable when delivered through a VR-exergaming platform compared to standard ergometry; ii) when participants are able to visualise and race against their previous performance, they perform HIIT at a higher intensity and; iii) by increasing the mechanical ergometer resistance, exercise intensity can be further increased, without compromising exercise session enjoyment.

As reported across various cycling exergaming studies, enjoyment in the present study was higher in the basic exergaming condition (*track*) compared to the control condition (*blank*), demonstrating that an acute bout of HIIT can be made more enjoyable by integrating it into a VR-exergaming platform (Mondero et al., 2015; Rhodes et al., 2009; Warburton et al., 2007). The concomitant increase in subjective vitality observed between *blank* and *track* modes demonstrates that VR-exergaming elicited feelings of excitement and energy, indicating that intrinsic motivation was fostered (Ryan & Frederick, 1997). These differences did not translate into any change in exercise intentions between *blank* and *track* modes, which we speculate may be attributed to the novelty of the VR-equipment, with participants failing to immediately accept their future access to the equipment. In contrast with a similar previous study design, there were no differences in measures of exercise intensity (%HR_{MAX}, power output, energy expenditure) between *blank* and *track* modes (Glen et al., 2017). This may either reflect the level of immersiveness of our basic VR-exergaming mode which failed to distract users from the exercise (Glen et al., 2017) or the instructions given to participants prior to both *blank* and *track* modes. However, given that acute exercise enjoyment is a predictor of future adherence, this finding highlights the potential of VR-exergaming as a method of promoting HIIT to the general population (Lewis, 2016). Further research should determine whether VR-exergaming interventions sustain enjoyment and exercise intentions over time.

Participants worked harder during HIIT when they were able to visualise and race against their previous performance, as evidenced by a ~3% increase in mean power output between the *ghost* and *track* modes. This is in contrast with findings from competitive male cyclists, who performed no faster during a 16.1 km time-trial when shown a visual display of themselves compared to no visual display (Williams et al., 2015). This likely reflects the difference in the training status of participants, with trained cyclists able to pace themselves, whereas non-cyclists aren't aware of pacing strategies and therefore VR provides a distraction from perceptions or sensations of fatigue (Glen et al., 2017). This increase in intensity between the *ghost* and *track* modes may have substantial applications to the delivery of HIIT programmes in the real-world, providing a self-adjustment tool for increases in maximum power output, and motivating individuals to exercise at a sufficient intensity (Weston, Taylor, Batterham, & Hopkins, 2014). Importantly, this increase was achieved without any adverse psychological responses (i.e. no difference in perceived exertion, enjoyment, or subjective vitality for *track* vs. *ghost*). Instead, an increase in competence was observed, likely due to the participant's being able to meet the challenge of out-performing their previous performance, indicating this may also be a feasible method to foster intrinsic motivation during HIIT (Teixeira et al., 2012).

A novel finding of this study is that participants exercised at a substantially higher intensity (~9% increase in mean power output between *ghost* and *hard* modes) during VR-HIIT when the mechanical resistance of the ergometer was increased by 10%. This mimics findings from moderately trained males, who performed a 2000-m time-trial faster when able to visualise their best familiarisation performance, although they were told this was another individual (Corbett, Barwood, Ouzounoglou, Thelwell, & Dicks, 2012). We believe the response achieved in the present study may be attributed to the 'feedforward' concept, whereby the participant identifies with the ghost avatar as a 'self-model' performing at a level they have yet to achieve, motivating them to meet the increased challenge (Basso & Belardinelli, 2006). The nature of HIIT (i.e. short bursts of intense exercise) is likely to aid this effect, as participants can realistically meet the demands of the challenge during the initial high-intensity phases, ensuring competence is maintained, and enhancing motivation for the more challenging phases ahead, as fatigue develops. Despite an increase in perceived exertion, there were no changes in psychological variables (e.g. intrinsic motivation, subjective vitality), suggesting that although participant's recognised that they were working harder, it may be a viable method to increase the intensity of HIIT whilst maintaining exercise enjoyment.

Limitations

Firstly, due to the game design it was not possible to fully randomise the order of the trials, and therefore a familiarisation effect may be present, particularly when comparing *track* vs. *ghost*. Secondly, it could be argued that psychological outcomes (e.g. enjoyment) of the control condition (i.e. *blank* mode) may be lower compared to traditional HIIT (i.e. without a VR-headset). We used a blank VR condition to counteract any negative side-effects associated with first-time VR-headset use. Thirdly, the sample group consisted largely of recreationally active individuals with moderate fitness levels, and therefore the effectiveness of such methods in habitually inactive individuals is unclear. Finally, this was an acute study, which assessed acute response to a single exercise session. Whether these responses have any meaningful impact on exercise adherence remains to be determined.

Conclusion

VR-exergaming increases the enjoyment of a single bout of HIIT and may be an effective tool to engage the general population with HIIT as an exercise training mode. By allowing individuals to visualise their previous performance, it is possible to increase the exercise stress of HIIT. This also appears to motivate participants to overcome an increase in mechanical resistance and work significantly harder, without negatively influencing enjoyment.

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Figure Legend

Figure 1: (Left to right) i) Low-intensity phases whilst avoiding trucks. ii) High-intensity phases against a ghost avatar.

Figure 2. Perceived enjoyment following the four VR-HIIT sessions.

Table 1. Participant characteristics

	Men (n=8)	**Women (n=8)**	**All (n=16)**
Age (y)	22 ± 2	21 ± 2	22 ± 4
Height (m)	1.78 ± 0.05	1.67 ± 0.05	1.73 ± 0.09
Body mass (kg)	67.7 ± 7.0	61.8 ± 6.5	66.6 ± 11.5
BMI (kg · m^{-2})	21.5 ± 2.0	22.3 ± 2.7	22.1 ± 2.5
Gaming hours (hours · $week^{-1}$)	3.6 ± 3.8	2.0 ± 2.6	2.8 ± 3.2
$\dot{V}O_2$peak (ml · kg^{-1} · min^{-1})	48.2 ± 10.8	34.2 ± 7.4	41.2 ± 10.8
P_{MAX} (Watt)	274 ± 57	198 ± 46	237 ± 57

Data presented as mean ± SD.

BMI; body mass index, $\dot{V}O_2$peak; peak oxygen uptake, P_{MAX}; maximum power output

Table 2. VR-HIIT session intensity metrics

	Blank	***Track***	***Ghost***	***Hard***
Mean PO (Watt)	173 (149, 198)	176 (149, 202)	181 (154, 208) [#]	199 (169, 229)*
Total $\dot{V}O_2$ (L)	48.2 (40.7, 55.7)	49.6 (41.8, 57.3)	53.0 (44.6, 61.4)	60.6 (50.6, 70.5)*
Total EE (kcal)	239 (203, 276)	246 (208, 284)	265 (223, 306) #	300 (251, 349)*
Mean %HR_{MAX}	88 (84, 91)	88 (85, 92)	88 (85, 92)	90 (87, 93)*

Data are means and 95% CIs.

[#] significantly different (*track* vs. *ghost*, $P < 0.05$). * significantly different (*ghost* vs. *hard*, $P < 0.05$). Mean PO; mean power output. Total $\dot{V}O_2$; total oxygen consumption. Total EE; total energy expenditure. Mean %HRmax; mean percentage of maximum heart rate.