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Development of an Exergame to Deliver a Sustained Dose of High-Intensity Training: Lessons Learned in a Formative Pilot Randomized Trial

Abstract

Background: Sport science can play a critical role in reducing health inequalities. The inverse relationship between life-expectancy, cardiorespiratory fitness and socioeconomic status could be addressed by performing high-intensity training (HIT), delivered in a class salient and accessible approach. Commercially available exergames have shown encouraging compliance rates but are primarily designed for entertainment purposes rather than focussing on health-related outcomes. A serious game tailored towards delivering an exercise stimulus, whilst reducing the aversive protocols associated with HIT, could be beneficial to engage and improve health outcomes in socially deprived males.

Objective: The aims were to develop an exergame capable of delivering HIT and evaluate the effect on selected health outcomes in men recruited in regions of socioeconomic deprivation.

Methods: We conducted an exploratory trial in our target population and participants were allocated to intervention (n = 14) or control groups (n = 10) by third-party minimisation. The intervention was a 6-week training program consisting of 3 sessions of exergaming per week. The sessions involved a structured warm-up then brief intermittent repetitions in the form of boxing rounds (10, 20 and 30-sec) against their peers with a work/rest ratio of 0.25.

Results: Retention to the intervention was 87%. Over the duration of the intervention, session attendance was 68%, repetition mean and peak heart rates (% of maximal) and session ratings of perceived exertion (arbitrary units) were 86.3±5.4%, 89.9±6.1% and 7.5±2.2AU, respectively. The effect of the intervention, when compared to the control, was a likely small beneficial improvement in predicted VO_{2max} (3.0; 90% confidence limits ± 2.6%). Effects on body mass, waist circumference and blood pressure were either trivial or unclear.

Conclusions: Over the 6-week intervention, the exergame delivered a consistent and sustained dose of HIT, with some beneficial effects on aerobic fitness in the target population.

Keywords: active video gaming; intervention fidelity; boxing and metabolic syndrome

Introduction

The latest government audit of university-based research in the UK has highlighted the need for more sport and exercise research to target health inequalities that persist in society [1]. There are strong inverse relationships between life-expectancy, cardiorespiratory fitness and socioeconomic status [2-4]. Since these trends are exacerbated in males, improving fitness in men living in regions of socioeconomic deprivation could be important for addressing health inequalities. High-intensity training (HIT) is a time-efficient way to improve fitness over a short duration [5] and a growing body of evidence advocates this form of exercise for public health interventions [6]. HIT is known to stimulate a combination of central and peripheral adaptations promoting an enhanced availability, extraction and

utilization of oxygen [7,8]. Although these findings are encouraging, these previous studies have tended to prescribe exercise with a focus on cycling and running [9-12]. Some argue that the psychologically aversive nature of high-intensity exercise means that this training will not be adopted or maintained by many people [13]. Thus, while the physiological benefits of HIT are unequivocal, there is ongoing debate about its relevance across populations, particularly for those less-motivated individuals. Finding ways to improve its acceptability could be the key to improve the wider acceptance of HIT.

The concept of exergaming, or active video gaming, has been around since the 1980s and affords unrivalled opportunities to reward exercise through visual, audio, haptic and mental stimuli. Exergaming-based interventions have understandably shown improved rates of compliance, adherence and social inclusion (e.g. [2]). Despite this, however, and after nearly a decade of research, the potential for exergaming to improve levels of fitness on a population level has not been realised [14]. A possible reason is that most of the research is based on commercially available exergames which are designed primarily for entertainment. In other areas of health research, such as physiotherapy, researchers have overcome these shortfalls by creating their own exergames, specifically geared to the physiological needs of the clinical or 'at risk' population. These serious games are purposively designed to train physiological systems at a level that is sufficient to cause positive adaptation. Importantly, these serious exergames have succeeded in improving health-related outcomes (e.g. balance and falls risk) and demonstrate their potential for use in other health professions [15].

A major challenge with improving HIT and exergaming is to translate positive laboratory-based findings into interventions that can directly affect those individuals who need it most and can also be administered on a larger scale [16,17]. Whether, or not, the concept of serious exergaming can contribute in this regard requires firstly that a game is tailored towards reducing the aversive protocols associated with HIT and secondly that the intervention is capable of improving fitness in our target population. Given that the commercially available games are known to deliver, at best, low to moderate levels of exercise [18], our first aim was to describe the development of a serious exergame for this purpose. Our second aim is to quantify its real-world fidelity and potential to improve fitness and health outcomes in males recruited in regions of socioeconomic deprivation over a 6-week intervention.

Methods

Development of the game and intervention

During the pre-intervention period, we held regular focus groups comprising 'in house' participants, computer programmers and exercise scientists with specialisms in delivering HIT. Together we explored opportunities to gamify HIT protocols. Boxing was an obvious theme for gamification as it involves high-intensity exercise [19] and the subculture already exists within our target population of lower working-class males of the North-East of England [20,21]. The complete set of

hardware used in the trials comprised: a single computer with a dedicated graphics card (GeForce GTX 960, [22]); two standard 23-inch monitors; two Kinect™ for Windows sensors; four wrist-mounted wireless inertial measurement units (developed in-house to reduce latency in the Kinect™ datastream) and two wireless chest-worn heart-rate monitors (Polar RS400, Polar Electro Oy, Kempele, Finland). In addition, the participants wore boxing-specific resistance bands (ShadowBoxer Pty, Australia) to increase levels of exertion and reduce eccentric muscle contractions during the deceleration phase of punching. The movement data from the sensors were streamed to our gaming engine [23] via a User Datagram Protocol with a latency of approximately 15ms. The C# programming language was used throughout to create scripts for gameplay (Figure 1a). Input from the skeletal tracking module of the Kinect system and inertial measurement units were converted to a digital avatar using purpose-written functions to convert each body segment long-axis (19 in total) into 3-dimensional quaternions can be seen with the hardware setup in Figure 1. The C# programming language was used throughout to create scripts for gameplay (Figure 2).

Figure 1. The exergaming system comprising hardware and software with real-time avatar mapping.
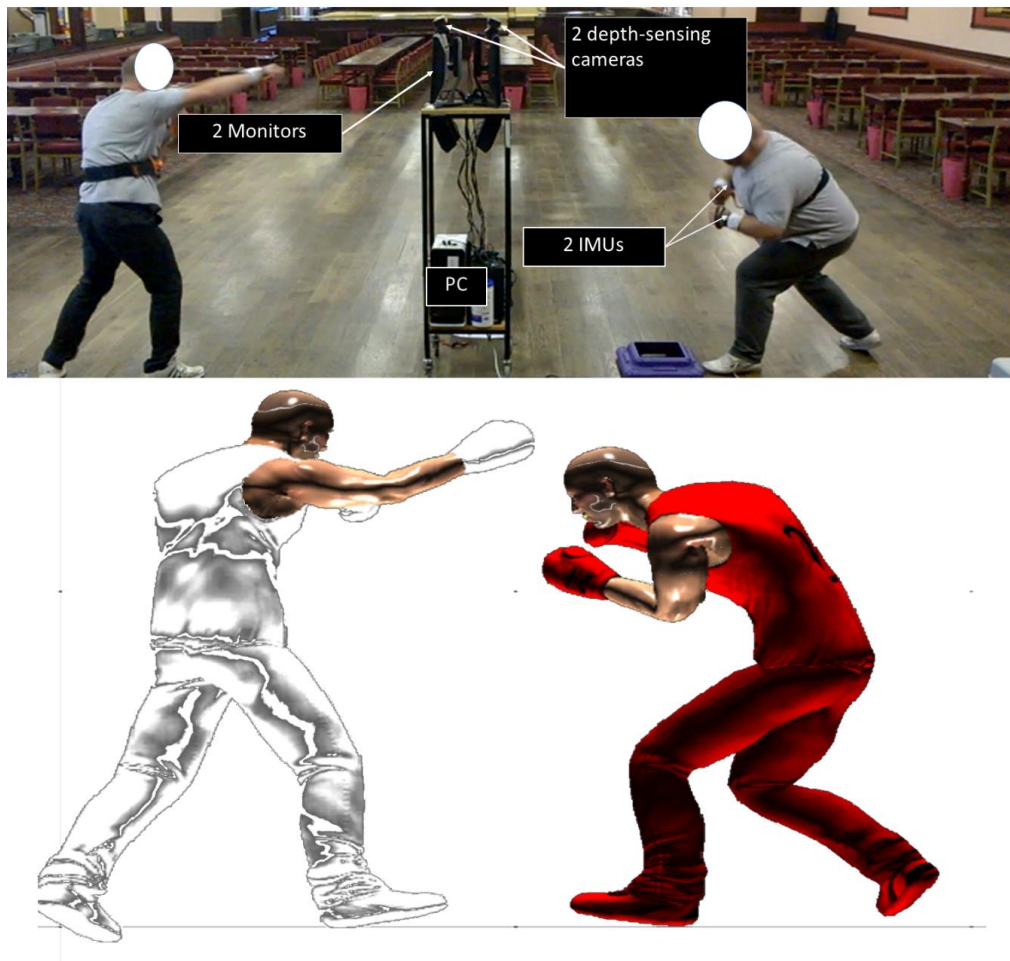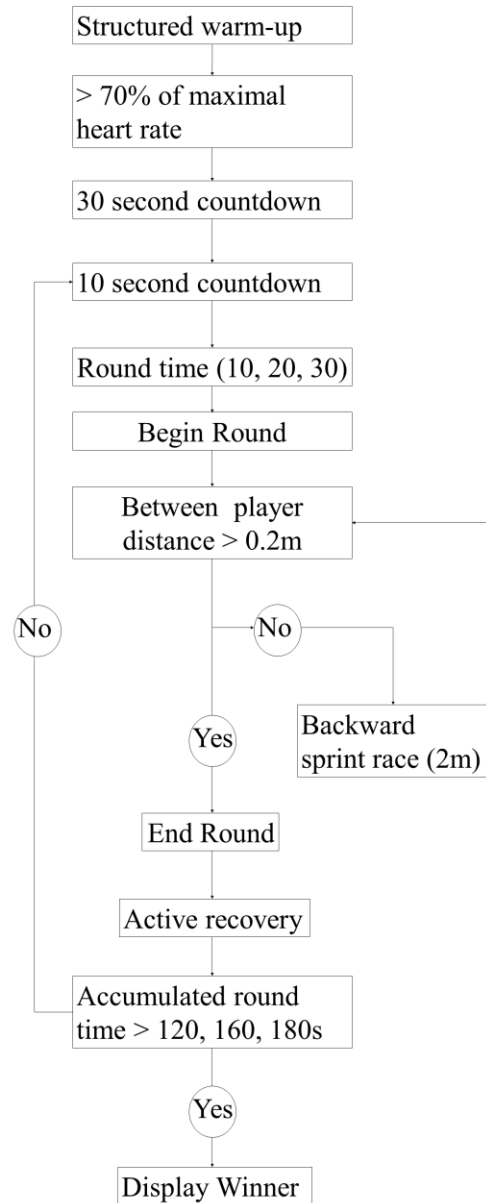
Figure 2. Machine state variables used in controlling the game.

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                    ┌─────────────────────┐
                    │  Structured warm-up │
                    └─────────────────────┘
                              │
                    ┌─────────────────────┐
                    │ > 70% of maximal    │
                    │ heart rate          │
                    └─────────────────────┘
                              │
                    ┌─────────────────────┐
                    │ 30 second countdown │
                    └─────────────────────┘
                              │
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                    │ 10 second countdown │
                    └─────────────────────┘
                              │
                    ┌─────────────────────┐
                    │ Round time (10, 20, 30) │
                    └─────────────────────┘
                              │
                    ┌─────────────────────┐
                    │    Begin Round      │
                    └─────────────────────┘
                              │
                    ┌─────────────────────┐
                    │  Between  player    │
                    │  distance > 0.2m    │
                    └─────────────────────┘

        (No)            (No)                 ┌─────────────────┐
                                             │ Backward        │
                        (Yes)                │ sprint race (2m)│
                                             └─────────────────┘
                    ┌─────────────────────┐
                    │    End Round        │
                    └─────────────────────┘
                              │
                    ┌─────────────────────┐
                    │  Active recovery    │
                    └─────────────────────┘
                              │
                    ┌─────────────────────┐
                    │ Accumulated round   │
                    │ time > 120, 160, 180s │
                    └─────────────────────┘
                              │
                            (Yes)
                              │
                    ┌─────────────────────┐
                    │  Display Winner     │
                    └─────────────────────┘
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Commercial games are primarily designed for entertainment and recreation for younger populations, and tend to have colourful and visually busy game and user-interfaces [24]. Furthermore, commercially available games are mostly designed for enjoyment and not based on basic exercise principles. In order for games to promote beneficial changes in health, they need to engage physiological systems in a meaningful manner that is relevant for the function being trained [25]. Our philosophy was to ensure that the gameplay was simple and, where possible, true to the rules of boxing. Each avatar was assigned collision objects with inertial characteristics on the trunk, head and hands, thus enabling the physics-engine to

superimpose realistic joint movements in response to being hit. As in real boxing, the primary mechanism for scoring was to successfully land a punch on either the trunk or head of the opponent. The number of points awarded per punch was the product of the current heart rate (expressed as a percentage of maximal) and speed of impact (ms^{-1}). Thus, for example, a punch landing to the head with a relative speed of $9ms^{-1}$ and at 95% of maximal heart rate (i.e. 95% HR_{max}) was awarded 8.55 points (i.e. 9 x 0.95). Each participant was provided with biofeedback in the form of a partial arc positioned around the opponent's head; the angle subtended by this arc was linked to the current heart rate (Figure 3). For example, when Player 1 was working at 50% of maximal heart rate, an arc of 180° was displayed around the head of Player 2. The players were made aware that the angle of the arc was proportional to their current training intensity, which in turn contributed strongly to punch power and points scoring. They were also aware that large global displacements of their centre of mass (e.g. bouncing up and down) would increase this intensity but with a lag of approximately 20-30s [26]. This arc was visible in their monitor only and was active throughout the exergaming session (i.e. during both repetitions and rest), essentially allowing the participants to self-regulate training intensity per the oncoming requirements of the game. Although we kept on-screen text to a minimum, we elected to display a countdown timer during some periods. These were during the final 30-sec of active recovery to encourage the elevation of training intensity in preparation for a repetition and during the latter 10-sec of each repetition to encourage 'all out' punching right up until the bell. Following preliminary tests, we removed the ability to block punches as this was observed to be energetically undemanding; thus, the only forms of defence were to attack before being hit or to dodge the oncoming punch using whole body movements. For similar reasons, we limited the periods of allowable close-up punching. Specifically, after 1-sec of close-up punching, the referee interrupted the fight (shown in the striped shirt in Figure 3) and ordered both participants to race back to their respective corners (i.e. 3m backwards of backwards stepping). The winner of each mini-race received an additional 50 points; equivalent to approximately 6-7 well-timed punches. After several iterations of observing kinematics, heart rates and tactics during gameplay, we prepared the exergaming system (i.e. both hardware and software) for use in the target settings.

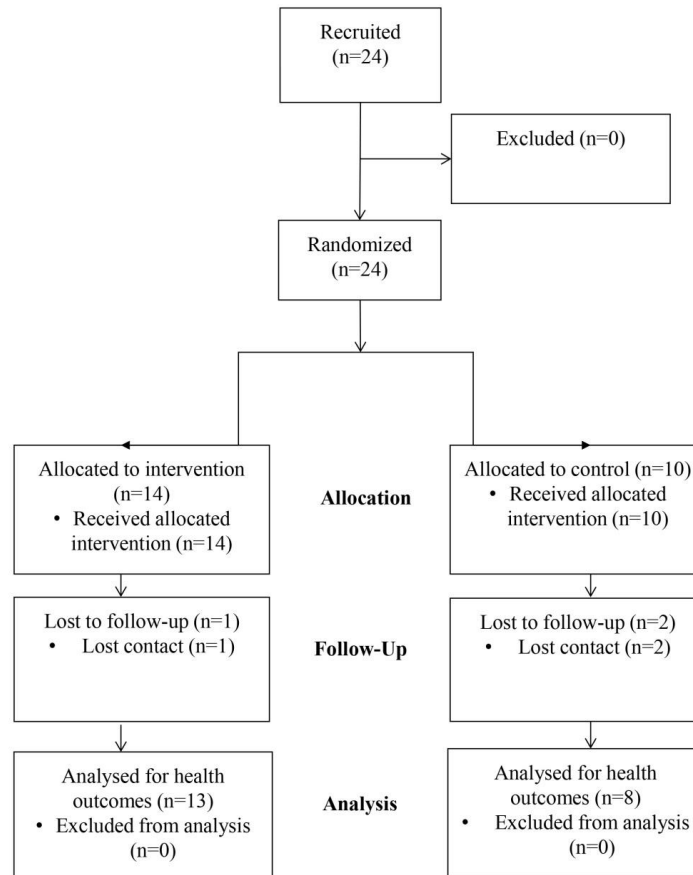Figure 3. The three visual outputs communicating instructions and actual game play to the users.

Participants

We conducted a 6-week exploratory controlled trial designed to assess the fidelity of the game in terms of delivering the intended training stimulus and to examine the effect of the intervention on selected health outcomes. As appropriate for an exploratory trial, we did not conduct formal sample size estimation *a priori*, rather the confidence intervals would be used to inform future trials. Men are commonly referred to as a hard-to-reach population to engage in health promotion activities [27] where a targeted recruitment approach at locations predominantly attended by men may facilitate uptake of participants. Therefore, to maximise recruitment within our intended population, relevant gate keepers were approached at institutions positioned within regions of social deprivation. Thus, two settings used for recruitment and the trials were a social club and mosque, both situated within deprived regions of Middlesbrough, UK (TS1 and TS4). Recruitment in the social club relied heavily on the gate-keeper (club secretary), whereas uptake of South Asian men from a local mosque was more straightforward; all nine mosque participants were recruited from a single demonstration (and we had similar experiences in previous iterations). Presumably, the intervention was culturally salient in this population; the North of England has developed some famous prominent Muslim boxers (e.g. Amir Kahn, Naseem Hamed) in recent years and when delivered in the safe form was acceptable to the respected leaders of the religious groups (i.e. the Imam of the mosque). Twenty-four males were recruited into the trial (Figure 4) using relevant gate keepers at institutions positioned within regions of social deprivation. Two recruitment drives (October 2014 and February 2015) took place and these involved live demonstrations of the technology followed by word-of-mouth and snowballing approaches. The exergaming system was

important in this recruitment process because it provided something tangible and interesting to engage potential participants.

Figure 4. Participant flow though the trial.

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                    ┌─────────────────┐
                    │    Recruited    │
                    │     (n=24)      │
                    └─────────────────┘
                             │          ┌─────────────────────┐
                             ├─────────▶│   Excluded (n=0)    │
                             │          └─────────────────────┘
                             ▼
                    ┌─────────────────┐
                    │   Randomized    │
                    │     (n=24)      │
                    └─────────────────┘
                             │
          ┌──────────────────┴──────────────────┐
          ▼                                       ▼
┌──────────────────────┐              ┌──────────────────────┐
│ Allocated to          │  Allocation  │ Allocated to control │
│ intervention (n=14)   │              │ (n=10)               │
│ • Received allocated  │              │ • Received allocated │
│   intervention (n=14) │              │   intervention (n=10)│
└──────────────────────┘              └──────────────────────┘
          │                                       │
          ▼                                       ▼
┌──────────────────────┐              ┌──────────────────────┐
│ Lost to follow-up     │  Follow-Up   │ Lost to follow-up    │
│ (n=1)                 │              │ (n=2)                │
│ • Lost contact (n=1)  │              │ • Lost contact (n=2) │
└──────────────────────┘              └──────────────────────┘
          │                                       │
          ▼                                       ▼
┌──────────────────────┐              ┌──────────────────────┐
│ Analysed for health   │  Analysis    │ Analysed for health  │
│ outcomes (n=13)       │              │ outcomes (n=8)       │
│ • Excluded from        │              │ • Excluded from      │
│   analysis (n=0)      │              │   analysis (n=0)     │
└──────────────────────┘              └──────────────────────┘
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Inclusion criteria were deliberately broad to maximise recruitment, that is 'apparently healthy', as defined by ACSM guidelines and aged 18-55 years old [28]. Participants were given a £15 shopping voucher upon completion of follow-up measures (week 7) irrespective of their adherence to the intervention protocol or group allocation. The intervention took place in November-December 2014 (social club) and March-April 2015 (mosque). Postcode data were analysed to match against indices of multiple deprivation in lower-layer super output areas to check whether the cohort fell within our target population. Two participants (8%) lived in the least deprived 20% (decile 8), 20 participants (83%) lived in the most deprived 20% areas in England (decile 2) and one participant (6%) lived in the most deprived 1% of areas (decile 1). The participants were broadly split between White (58%, n=

14) and South Asian (42%, n=10). Body mass index [29] and waist circumference [30] cut-points were adjusted for ethnicity. Accordingly, 63% had abdominal obesity, 37.5% were overweight and 41.7% were obese. Within this group the 45-50-year-old category was most common (33%) followed by 18-24 (29%), 25-34 (17%), 35-44 (17%) and 51-55 (4%) categories. A third-party minimisation process using baseline measures of age, waist circumference and predicted VO_{2max} was used to remove bias in group allocation. The control group were instructed to maintain their current physical activity levels and inform the researchers should any changes arise during the intervention period. One of the control group decided to embark on his own fitness program following the pre-intervention tests, but was included in the data analysis. Participant flow through the trials is shown in Figure 2, whereby three participants were lost to follow-up (control = 2; intervention = 1). Overall retention to the intervention which encompassed baseline and follow-up measures was 87%. To explore perceptions of the exergame and the HIT regime, semi-structured interviews were conducted with five intervention participants following the 6-week training period which were analysed semantically. The study was approved by the Ethics Committee of Teesside University, UK and written informed consent was obtained from all participants.

Measures

Participants' baseline characteristics (mean ± SD) are shown in Table 3. All measures were assessed pre- and post-intervention. Blood pressure was collected on the left arm positioned at heart height with the subjects in a seated position by an automatic upper arm blood pressure monitor (Omron MX13). Measures were made at least three times at three-minute intervals where an average of the two lowest measures was used for analysis [31]. Waist circumference was measured using the World Health Organisation guidelines [32]. Predicted VO_{2max} was obtained by performing a submaximal 8-minute ramped step test [33]. Heart rate response (Polar T34; PolarElectro OY, Kempele, Finland) and simultaneous breath-by-breath expired gas were collected using a portable indirect calorimeter (Cosmed K4 b2; Rome, Italy), calibrated per the manufacturer's guidelines. Individual maximal heart rate was estimated (HR_{max}) [34] and plotted against VO_2 data for the determination of predicted VO_{2max}.

Intervention Delivery

Evidence recommends a minimum duration of 12 weeks for a HIT protocol to promote favourable changes in blood pressure and anthropometric measurements of obesity [35]. However, a 6-week intervention was selected as a minimum of 13 sessions (0.16 work/rest ratio) is sufficient to elicit moderate improvements in VO_{2max} in sedentary individuals [5]. Additionally, there is still ambiguity regarding the 'optimal' work-to-rest ratio when designing HIT interventions, particularly in populations with varied age, baseline fitness and training experience [36]. Therefore, longer duration HIT models (1-4 min) were deemed unsuitable for our target population [37]. Furthermore, mini-games (such as the current exergame) have short life-spans where adherence to a longer intervention (e.g. 12 weeks) may diminish over time and influence health outcomes. This was evident from a 12-week

pilot study (unpublished data) using an exergame in the same population that saw attendance drop from 53% during week 2 to 16% during week 12. At the beginning of the exergaming session, participants were required to complete a 6-minute structured warm-up, consisting of a series of exercises on a 210mm step until both participants reached >70% HR_{max}. Session workloads with volumetric progression were set automatically once the user's identifying information was entered. The session workloads were 120-sec, 150-sec and 180-sec of work during weeks 1 and 2, weeks 3 and 4, and weeks 5 and 6, respectively. To avoid staleness, the repetition lengths (10, 20 or 30-sec) were randomly selected at the beginning of each round. We set the work-to-rest ratio at 1:4 and thus the respective repetitions were followed by 40, 80 or 120-sec of active recovery. Each exergaming session took approximately 30-40 minutes to complete, including equipment set-up, warm-up with additional enjoyment and task immersion questionnaires upon completion of the HIT bouts (not reported here). Heart rate responses were taken within repetitions, and therefore did not include any of the recovery period. This therefore avoided an overestimation of physiological load, which can occur when heart rate continues to rise after exercise cessation [26].

Statistical Analysis

Data are presented as mean ± standard deviation (SD). Exergaming session attendance was calculated using descriptive statistics. Training data (heart rate [repetition mean and peak], RPE) were analysed using a mixed linear model with a random intercept (SPSS v.23, Armonk, NY: IBM Corp). This approach enabled us to calculate: 1) the within-participant variability in the training dose [38], expressed as a SD; 2) the effect of HIT repetition duration (entered as a fixed effect) on heart rate and RPE; 3) the change in heart rate and RPE across the 6-week HIT intervention, with session number (1-18) entered as a fixed effect. A priori, we defined a minimal practically important difference (MPID) in training heart rates as two percentage points, given that when training at high-intensity this difference influences the adaptive response [39]. The MPID for RPE was set at one arbitrary unit (AU) on the Borg CR10 scale, representing a full increment change on the scale. Inferences were then based on the disposition of the 90% confidence limits (CL) for the mean difference to these MPID; the probability (percent chances) that differences in heart rate and RPE between HIT repetitions of different durations or across the 6-week intervention were substantial (> 2 percentage points, >1 AU) or trivial was calculated as per the magnitude-based inference approach described by Batterham & Hopkins [40], an approach that has been advocated within user research [41]. These percent chances were qualified via probabilistic terms assigned using the following scale: 25–75%, possibly; 75–95%, likely; 95–99.5%, very likely; >99.5%, most likely [42]. To determine the magnitude of the within-participant variability in our training heart rate and RPE, the values were doubled and then interpreted against afore-mentioned MPID. All training data effects were evaluated mechanistically, whereby if the 90% CL overlapped the thresholds for the smallest worthwhile positive and negative effects, the effect was deemed unclear [42]. The effect of HIT on our outcome measures was determined using a custom-made spreadsheet [43] with the baseline value of the dependent variable used as a

covariate to control for baseline between-group imbalances. Following this, standardised thresholds for small, moderate and large changes (0.2, 0.6 and 1.2, respectively) [42] derived from between-subject standard deviations of the baseline values were used to assess the magnitude of all effects, with magnitude-based inferences subsequently applied. Here, all inferences were categorised as clinical, with the default probabilities for declaring an effect clinically beneficial being <0.5% (most unlikely) for harm and >25% (possibly) for benefit [42].

Results

Mean session attendance was 68% (range 0% to 100%). Nine of the 14 intervention participants attended at least 75% of the prescribed exergaming sessions. The total number of repetitions performed was 1268 (range 6 to 136 per participant) and the descriptive training data for the exergaming intervention are presented in Table 1. The magnitude of the within-participant variability in all intensity measures was moderate.

Table 1. Exercise intensity data for the HIT intervention.

Intensity measure	Mean ± SD	Within-subject variability; ±90% CL
Mean heart rate (%)	86.3 ± 5.4	4.7; ±0.2
Peak heart rate (%)	89.9 ± 6.1	5.7; ±0.2
Session RPE (AU)	7.5 ± 2.2	1.6; ±0.1

HIT, high-intensity interval training; SD, standard deviation; CL, confidence limits; AU, arbitrary units

Mean exercise intensity data for the 10-sec, 20-sec, and 30-sec repetitions are presented in Table 2. The effect of repetition duration on mean heart rate was substantially higher heart rates during the 30-sec repetitions when compared to the 20-sec (2.2 percentage points; ±90% confidence limits 0.5 percentage points) and 10-sec repetitions (3.5 percentage points; ±0.5 percentage points). Peak heart rates were also substantially higher for the 30-sec repetitions when compared to the 20-sec (3.6 percentage points; ±0.6 percentage points) and 10-sec repetitions (6.4 percentage points; ±0.6 percentage points). The effect of repetition duration on RPE was most likely trivial.

Table 2. Exercise intensity data for the HIT repetition duration.

Intensity measure	10-sec repetitions	20-sec repetitions	30-sec repetitions
Mean heart rate (%)	84.7 ± 5.3	85.9 ± 6.6	88.2 ± 3.5
Peak heart rate (%)	86.8 ± 4.9	89.5 ± 7.7	93.2 ± 3.4
Session RPE (AU)	7.4 ± 2.2	7.5 ± 2.4	7.6 ± 2.0

HIT, high-intensity interval training; SD, standard deviation; CL, confidence limits; AU, arbitrary units

The mean exercise intensity scores per exercise session along with the individual data points to illustrate the variability around the mean score are presented in Figure 5. Across the intervention, the regression slope revealed most likely trivial changes in mean heart rate (0.1 percentage points; ±90% Confidence Limits 0.2 percentage points), peak heart rate (0.1 percentage points; ±0.2 percentage points), and RPE (0.1 AU; ±0.1 AU) across the duration of the 6-week HIT intervention.

Figure 5. Group mean (large open squares) and individual (small closed triangles) heart rates (session mean and session peak) and ratings of perceived exertion (RPE) across the 6-week exergaming intervention period (Session numbers 1–18).

When compared to the control group, the effect of the exergaming intervention was a likely small beneficial improvement in predicted VO_{2max}. The standard deviation of the individual responses in predicted VO_{2max} to the exergaming intervention was 3.4 (90% confidence limits ±3.1). All other effects were either most likely trivial (body mass, waist circumference) or unclear (systolic blood pressure, diastolic blood pressure) (Table 3).

Table 3. Outcome measures at baseline along with the ANCOVA adjusted change scores and the between-group comparisons of the change scores.

| Outcome measures | Intervention group (n = 13) | | Control group (n = 8) | | Group comparison (HIT-control) |
	Baseline values mean ± SD	Change score mean ± SD	Baseline values mean ± SD	Change score mean ± SD	Difference between groups (% mean; ±90% CL)
Body mass (kg)	87 ± 22	-1.1 ± 2.0	88 ± 20	-0.5 ± 1.6	-0.5; ±1.4
Waist circumference	97 ± 15	-0.6 ± 1.6	100 ± 14	-0.3 ± 1.6	-0.3; ±1.3
Predicted VO$_{2max}$ (mL•kg^{-1}•min^{-1})	43.7 ± 8.8	3.2 ± 4.1	39.5 ± 8.5	0.2 ± 2.4	3.0; ±2.6
Systolic blood pressure	130 ± 9	-5.9 ± 5.5	134 ± 12	-2.7 ± 6.7	-3.2; ±5.2
Diastolic blood pressure	80 ± 10	-5.1 ± 5.7	86 ± 9	-5.1 ± 7.1	-0.1; ±5.8

HIT, high-intensity interval training; SD, standard deviation; CL, confidence limits; VO$_{2max}$, maximal oxygen consumption

Participants who engaged in interviews ranged between 25 and 50 years of age and attended between 60 and 100% of the exercise sessions. Data revealed that participants found the exergame to be challenging but rewarding;

"At the start you think this is too hard but as you go on and it does get easier, I say it gets easier but you extend the time don't you so you're doing more. Half way through the second week I started to appreciate that, what you're doing is making it harder to keep testing me, do you know what I mean? And you can feel it, you can feel it that you are getting better at the game. I think it still knacks you out [exhausts you] because you start trying harder as it goes on" (Participant 1 – 50 year old social club worker).

"At the beginning it was killing me [exhausting me], but as I carried it on it was still killing me and then it started to get like, better, my heart wasn't working as hard

and I was getting more fit to the point where I coped well, to the point where I was

actually still working my hardest at the level I wanted to". (Participant 4 – 25 year old

hospital worker).

Participants found that the competitive aspects resulted in a changing game scenario between players and rounds for each training session which facilitated motivation to attend and engage;

"There was always something else that kept you interested, kept you wanting to

do more. If you go for a run, its more like "I'm just running", that's it. The fact that you

were fighting someone, a different opponent – you had to change, you either didn't

have to work as hard [or you should be] or you had to work harder than you could".

(Participant 4 – 45 year old hotel worker).

"I just thought it was a fun way to exercise. If it wasn't competition, it would be

hard to be doing that 2-3 times a week to train at that intensity. Like you would go the

odd time training that intense but if it's against someone you're more likely to put

100% in. You know, if my heart rate had have got that high just doing it by myself,

maybe once or twice but not on a consistent thing like that, in a competition against

someone else it does push you to train harder, it did me, it did push me to train

harder." (Participant 2 – 25 year old, unemployed).

The variance in the allocated workload was a motivating factor but highlighted that repeated 30 second bursts may have discouraged him from attending exercise sessions;

"It was probably just right, just right really and I liked how it varied 10, 20, 30 – I didn't want to do 30 seconds all the time". (Participant 3 – 34 year old community worker).

"I always felt as though the 10 seconds were mad [hard] to be honest, because no sooner than you were like finished, then you had to wait about 30 seconds before a 20 second one started or something like that. I loved the 30 second ones. I thought that was great, that was just enough, like 30 seconds in that one round and that was just more than enough sort of thing, you know?" (Participant 4 – 45 year old hotel worker).

Finally, some gameplay elements such as heart rate integration and visual feedback of a successful punch were encouraging for participants;

"All I knew that if I see the ring go round the head, the further round it is, if I hit him the more points I'd get, so I knew that and I knew every time it flashed I'd caught him. I knew my heart rate was there and I knew the timer was ticking down at the bottom. But the movements and everything else were excellent. " (Participant 1 – 50 year old social club worker).

Discussion

Principal Results

The present study developed a novel HIT intervention using exergaming. Obtaining information about whether the game was used as intended by the target population is a fundamental stage in the development cycle. We evaluated its use in men recruited from regions of socioeconomic deprivation, a population predisposed to low life-expectancy. The training data is indicative of a consistent and progressive dose of HIT (>85% of maximal heart rate) over the duration of the 6-week intervention. Given that our protocol for measuring training intensity is conservative (i.e. [38]), we are confident that the game was used by the participants as intended. Furthermore, we also found clear beneficial effects on predicted VO_{2max}

and these findings together demonstrate the potential usefulness of exergaming for the future delivery of HIT.

Despite the respective popularities of both HIT and video gaming, there have been no previous attempts to combine these concepts in the form of an exercise intervention. As such, there are no studies against which to directly compare our training data, although the intensity levels are clearly greater than those measured for commercially available exergames [18]. In fact, our training data are more comparable to those from a recent high-intensity exercise programmes delivered via traditional means and described as a high-quality dose of HIT [38]. For example, our repetition peak heart rates of 89% of maximal when averaged over the duration of the 6-week intervention were only two percentage points below their levels. While we cannot pinpoint the specific mechanisms underpinning this success, we suggest the feedback and point-scoring made a strong contribution. Specifically, by matching point-scoring to current training intensity and enabling users to self-regulate and maximise their intensity it was possible to deliver a consistent dose of HIT. Furthermore, given that these levels were based on their own individual maximal levels (i.e. relative to maximal heart rate), the participants were also aware that these were attainable (e.g. [44]). Accordingly, after the first session during which users became familiar with the game concepts, intensity levels remained consistent throughout the 6-week intervention, indicative of a high-quality dose of HIT.

When our outcome data are compared with those from other HIT programmes, however, our improvements in fitness were relatively modest. For example, the effect on predicted VO_{2max} was only half the pooled effect for untrained males of 6.2% [5]. This relatively smaller improvement could be due to a range of factors (e.g. age), although given that we analysed the outcome data on an intention-to-treat basis, non-attendance was the most probable cause. Specifically, our attendance of 68% is much lower than is typical for lab-based studies and more similar to other community-based trials involving HIT. For example, our attendance data was similar to other boxing themed interventions (79%, [45]), mixed-gender HIT programmes (75% for maximal volitional intensity training; [46]), obese males (57%, [47]) and community-based HIT interventions using adult populations (58% to 77%, [48]). Thus, although there were some positive findings related to this HIT intervention (e.g. ease of recruitment in the target population and training at the intended dose), some of the usual problems associated with conducting exercise interventions in the community remained. Despite favourable changes in VO_{2max}, there were no clear beneficial effects for body mass, waist circumference and blood pressure when compared to our control group. We suspect that our intention-to-treat analysis and shorter intervention period (<12 weeks) influenced these outcome measures when compared to other HIT studies [35,49].

In summary, we have established that HIT can be delivered via exergaming but that the usual problems of attendance remain. Clearly, finding strategies to improve attendance will be important in future development cycles. One of the appealing features of HIT amongst our participants was the time-efficient nature of HIT. However, the delivery of our exergaming sessions in many cases required travel to and from the venue on a thrice-weekly basis. This could add hours onto a relatively

brief period of HIT and for some, this was a major disincentive to attend. On a more positive note, however, online gaming is now a major part of the gaming industry and through internet protocols and greater bandwidth, these exergaming sessions could be delivered over the Internet. Further work into the acceptability of delivering exercise in this manner may need to be undertaken but the benefits of doing exercise at work or at home would most probably appeal to some of our participants. Furthermore, by using these technologies effectively it may be possible to exploit other opportunities to further motivate, such as social media to improve competitiveness and camaraderie [50].

Limitations

There were several limitations to this study which need to be overcome in a larger trial. First, our sample only included White Europeans and South Asian males recruited from regions of socioeconomic deprivation. The acceptability of this intervention across different ethnicities and other socioeconomic groups is therefore not known. Second, we administered a sub-maximal fitness test despite it being known that such tests are prone to errors [51]. Third, mini-games such as this usually have a short lifespan [52,53] and it is not known how much longer the exergame could maintain interest beyond this 6-week intervention. Future studies are needed to explore the acceptability of a maximal VO_{2max} test within this population. Fourth, participant blinding was not possible in this study and we therefore cannot rule out cluster contamination and participant allocation resentment. Fifth, we did not perform an economic evaluation of this intervention. Whether these benefits, given the costs of treating symptoms associated with lack of exercise, set against the costs of developing and delivering the intervention, requires formal evaluation in future research.

Conclusions

Exergaming can be configured to deliver a sustained and consistent dose of high-intensity exercise, resulting in improved fitness in a group of males living in regions of socio-economic status over a 6-week program. Furthermore, class-salient interventions delivered to specific populations have the potential to facilitate adherence and attendance. Exergaming is inherently scalable and has good reach into our population although future strategies using internet protocols could improve the real-world-effectiveness.

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Conflicts of Interest
None declared.

Abbreviations
AU: arbitrary units
CL: confidence limits
HIT: high-intensity training
HR_{max}: heart rate maximum
MPID: minimal practically important difference
RPE: ratings of perceived exertion
VO_{2max}: maximal oxygen consumption

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