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High-intensity exergaming for improved cardiorespiratory fitness: A randomised, controlled trial

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ABSTRACT

Exergaming has been proposed as a promising alternative to traditional endurance training since many experience exergaming as more enjoyable. Therefore, the aim of this trial was to determine the exergaming-induced effect on cardiorespiratory fitness. This parallel-group randomised controlled trial, investigated the effects of regular exergaming among healthy adults (aged ≥ 18 years) who were not endurance-trained. Participants allocated to the exergaming group ($n = 13$) used the Playpulse exergaming platform for a minimum of 45 min twice weekly for eight weeks, whereas the control group ($n = 17$) received no intervention. The primary outcome measure was the between-group difference in peak oxygen uptake ($\dot{V}O_{2peak}$) after the intervention. $\dot{V}O_{2peak}$ increased significantly from baseline (43.9 [SD 7.0]) to after the intervention (45.3 [SD 8.2] mL kg^{-1} min^{-1}) in the exergaming group, compared to the control group (42.4 [SD 7.0] to 42.0 [SD 5.7] mL·kg^{-1}·min^{-1}) with a between-group difference of 2.1 mL kg^{-1} min^{-1} (95% CI: 0.2–4.1; $p = 0.04$). The average score on the Feeling Scale reported during exergaming was 3.4 (95% CI 3.2–3.6), with 3 being "good" and 5 "very good" and was not related to the participants' exergaming skills. There were no adverse events during this trial. Two weekly sessions using the Playpulse exergaming platform can improve $\dot{V}O_{2peak}$. This finding suggests that exergaming can be an efficient form of endurance training. Furthermore, our findings indicate that participants' enjoyed exergaming irrespective of exergaming skills.

Trial registration: ClinicalTrials.gov identifier: NCT04112329..

KEYWORDS
Aerobic fitness; exercise; sedentary living; fitness; technology; active video games

Introduction

The maintenance and improvement of cardiorespiratory fitness over time is vital for longevity, with an 11% lower risk of all-cause mortality for each 1 mL kg^{-1} min^{-1} increase in peak oxygen uptake ($\dot{V}O_{2peak}$) (Imboden et al., 2019). In order to gain health benefits, adults are recommended to accumulate at least 150 min moderate-intensity physical activity or 75 min vigorous-intensity physical activity per week (Piercy et al., 2018). However, less than one-third of Norwegian adults fulfil these guidelines (Hansen et al., 2019), and cardiorespiratory fitness in adults has decreased over the last 20 years (Ekblom-Bak et al., 2019). Enjoyment is the strongest predictor for exercise adherence, and thus should play a central role when developing exercise interventions (Rodrigues, Teixeira, Neiva, Cid, & Monteiro, 2020). Exergaming, which is the combination of video games and physical exertion, is for many individuals perceived as more enjoyable than traditional exercise and has the potential to generate greater adherence (Moholdt, Weiw, Chorianopoulos, Wang, & Hagen, 2017; Oh & Yang, 2010; Warburton et al., 2007). So-called "flow", in which the player is motivated by playing the game and not by any potential outcomes from playing, is an essential factor in successful games (Sweetser & Wyeth, 2005). In addition to being enjoyable, a successful exergame should induce physiological training adaptations (Sinclair, Hingston, & Masek, 2007). The latter point is the main limitation for many previous exergaming interventions, and overall, the exercise intensity elicited during most exergames is light-to-moderate (Dutta & Pereira, 2015). We are aware of only three studies that have used maximal cardiopulmonary exercise testing with measurements of $\dot{V}O_{2peak}$ or maximal oxygen uptake ($\dot{V}O_{2max}$), the gold standard for assessment of cardiorespiratory fitness, before and after an exergaming

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intervention. Two of these studies showed no improvements in $\dot{V}O_{2peak}$, likely due to an unstructured exergaming protocol without any requirements for the frequency of exergaming (Berg, Wang, Lydersen, & Moholdt, 2020; Owens, Garner, Loftin, van Blerk, & Emin, 2011). The third study indicated that $\dot{V}O_{2peak}$ could improve after exergaming; however, this study was limited by small sample size ($n = 14$) (Warburton et al., 2007). Accordingly, a systematic review acknowledged the need for sufficiently powered studies with a recommended exergaming frequency and duration to assess health outcomes after exergaming (Street, Lacey, & Langdon, 2017).

In this randomised, controlled trial, we aimed to determine if two weekly exergaming sessions could improve $\dot{V}O_{2peak}$ after eight weeks in previously untrained individuals. For this purpose, we used the Playpulse cycling exergaming platform, which has previously been shown to elicit vigorous-intensity exercise (Berg & Moholdt, 2020).

We also investigated whether there were any relationships between enjoyment, pleasure and exercise intensity during exergaming, sex, age, body mass index (BMI), gaming skills, and change in $\dot{V}O_{2peak}$. We hypothesised that participants in the exergaming group would increase their $\dot{V}O_{2peak}$ significantly more than those allocated to the control group and that greater gaming skills would affect enjoyment, pleasure, and exercise intensity during exergaming.

Methods

Study design

This single-centre randomised, controlled trial was undertaken at the Norwegian University of Science and Technology (NTNU) and St Olav's University Hospital in Trondheim, Norway. The Regional Committee for Medical and Health Research Ethics in Central Norway (2019/7204) approved the trial. The trial is registered in the ClinicalTrials.gov registry (NCT04112329).

Participants

Healthy individuals aged 18 years or older; inactive (<150 min of moderate-intensity physical activity per week) or not regularly performing endurance training; and able to ride a bike for up to 60 min, were eligible to participate. We excluded individuals with known cardiovascular diseases or who were taking beta-blockers or anti-arrhythmic drugs. To recruit participants, we advertised the trial via the web pages of NTNU and St. Olav's University Hospital, as well as through social media platforms. Before inclusion, all eligible individuals signed a written informed consent form.

Randomisation and masking

All eligible individuals that completed baseline testing were randomly allocated in a 1:1 ratio after stratifying for sex, to either the exergaming or control group. The Unit for Applied Clinical Research at NTNU generated the randomisation scheme, using a computer random number generator with blocks of varying sizes. The researchers (GH and JB) who enrolled the participants received the allocation results on-screen and by email after registration of each new participants and were unaware of the size of the blocks. We did not mask the staff nor participants to group allocation, outcome assessments, or data analyses.

Procedures

Participants in the exergaming group were asked to exercise using the Playpulse exergaming platform at least twice weekly for a minimum of 45 min per session for eight weeks, under supervision. Playpulse is a cycling exergaming platform currently consisting of three different exergames. A more detailed description of the Playpulse exergaming platform is found elsewhere (Berg et al., 2020). In short, forward propulsion on the bicycle generates movement in the game, with a faster cadence generating faster movement and other game benefits. Other actions in the game are performed using buttons on the handlebar. We recorded heart rate (HR) using HR monitors (Polar H10, Polar, Kempele, Finland) during all sessions and stored the data in an online training diary (PolarFlow) for later analysis of exercise intensity. Exercise intensity was classified according to The American College of Sports Medicine's (ACSM) intensity zones (Garber et al., 2011), and we report average and peak HR. Participants filled out two questionnaires; the Physical Activity Enjoyment Scale (PACES) (Kendzierski & DeCarlo, 1991) and the Feeling Scale (Hardy & Rejeski, 1989) after each exergaming session. The PACES and the Feeling Scale were chosen since previous studies show that scores can predict long-term physical activity behaviour and activity choice in adults (Kendzierski & DeCarlo, 1991; Williams et al., 2008). PACES consists of 18 questions scored on a 1–7 Likert scale, and the Feeling Scale is a 11-point scale, ranging from −5 (very bad) to +5 (very good). Also, for the most frequently used game on the Playpulse platform, "Pedal Tanks", we registered exergaming statistics to get a measure of exergaming skills. Pedal Tanks is a multiplayer exergame with the objective to shoot competing players' tanks, capturing their flag, and return it to base. We used the percentage of wins in the game, the ratio between kills and deaths, and experience-points gained per round for each exergaming session to represent exergaming skill. Players gain one experience point for each kill and assist, three experience points for each flag capture and round won, and ten experience points for each round. Participants in the control group were asked to continue with their regular daily routine during the eight week trial period. If not otherwise described, we conducted all assessments before randomisation (baseline) and after the intervention. Assessments of $\dot{V}O_{2peak}$ after the intervention period were undertaken 48–92 h after the last exergaming session. We assessed $\dot{V}O_{2max}$ using an incremental test to exhaustion on a treadmill (Woodway, Waukesha, WI). With individually adjusted start-levels, and an aim to bring participants to volitional exhaustion in 8–12 min, we increased speed or incline every minute by 1 km h^{-1} or 2% until exhaustion. We continuously measured gas exchange using the MetaLyzer IIIB (Cortex, Leipzig, Germany). Previous data from our lab show a test-retest repeatability coefficient of 1.6 mL kg^{-1} min^{-1} using the MetaLyzer (Letnes et al., 2020). Besides volitional exhaustion, we used secondary exhaustion criteria, adjusted for age, as criteria for attainment of $\dot{V}O_{2max}$ (Wagner et al., 2020). Since not all participants fulfilled these criteria, we report the mean of the three highest 10-s values as $\dot{V}O_{2peak}$. We continuously recorded HR (Polar H10, Polar, Kempele, Finland) during the incremental test and used the highest HR from both $\dot{V}O_{2peak}$-assessments to define maximum HR (HR_{max}) for analysis of exercise intensity in the exergaming group.

Body weight and estimated body composition were measured using bioelectrical impedance analysis (inBody 770, Biospace, Soul, South Korea), a reliable alternative to dual-energy X-ray absorptiometry (McLester, Nickerson, Kliszczewicz, & McLester, 2020). Further, BMI was calculated as weight in kilograms divided by the square of height in metres.

Participants wore activity monitors (SenseWear, BodyMedia, Pittsburg, Pennsylvania, United States) on their non-dominant upper arm for seven days before randomisation and seven days after the end of the intervention. With data from three weekdays and the whole weekend, the SenseWear armband can reliably estimate physical activity levels (Scheers, Philippaerts, & Lefevre, 2012). Since few participants fulfilled these criteria, we included data from participants with a minimum of two days in the analysis. Main findings did not differ between those with complete recordings and when using data from only two days of monitoring. The physical activity levels were reported as daily means and categorised into moderate- (3.0–6.0 metabolic equivalents (METs)), vigorous- (6.0–9.0 METs), very vigorous- (>9.0 METs) and moderate-to-very-vigorous intensity physical activity (>3.0 METs).

We measured systolic and diastolic blood pressure, and resting HR in a seated position after 10 min of seated resting at baseline and after the intervention.

At baseline, participants were asked to complete a questionnaire to assess physical activity patterns and media usage during six months before participation.

Outcomes

Our primary outcome was $\dot{V}O_{2peak}$ relative to body mass (mL kg^{-1} min^{-1}), assessed after the intervention. Secondary outcomes were absolute $\dot{V}O_{2peak}$ (L min^{-1}), average daily physical activity levels, body mass, BMI, the relative percentage of body fat, visceral fat area, systolic and diastolic blood pressure, and resting HR. Furthermore, secondary outcomes included exergaming intensity, exergaming skills, and perceived enjoyment and pleasure of exergaming.

Statistical analysis

We calculated the sample size for the study based on a difference of 3.5 mL kg^{-1} min^{-1}, with a standard deviation of 3.0 mL kg^{-1} min^{-1}, in $\dot{V}O_{2peak}$ after the intervention, with 5% level of significance, and with 80% statistical power, using an independent samples-test. According to these calculations, 12 participants were needed in each group. To account for an anticipated drop-out of ∼15%, we aimed to include a minimum of 28 participants (14 per group).

We used the intention-to-treat principle for the statistical analyses, in which all participants with data from at least one time-point were included. We used a linear mixed model, which is unbiased under the missing at random assumption (Ashbeck & Bell, 2016). The outcome variables were used, one at a time, as the dependent variable, participant as random effect, and time-point and the interaction between time-point and group, as covariates. We assumed no systematic effect of group at baseline (Twisk et al., 2018). By visual inspection of Q-Q plots, we checked the normality of residuals and log-transformed variables that did not show normality (absolute $\dot{V}O_{2peak}$, vigorous-intensity physical activity, moderate-to-very vigorous-intensity physical activity, and resting HR). Due to no effect of log-transformation on our main findings, we report the untransformed data.

Simple and multiple regression analyses were performed with exergaming intensity (average and peak relative HR during exergaming), perceived enjoyment

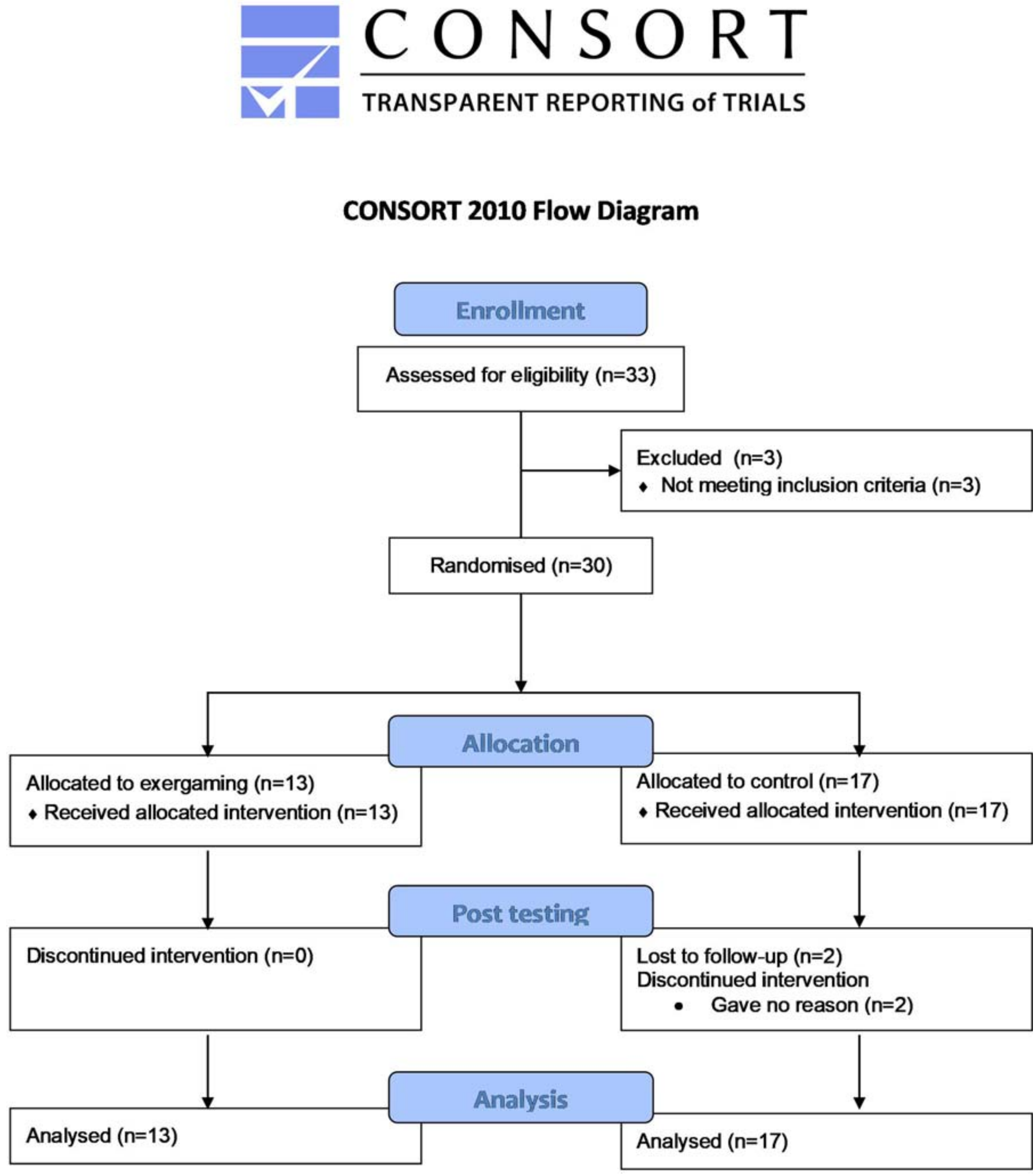

Figure 1. Flowchart for this trial.

(PACES) and pleasure (the Feeling Scale), and change in $\dot{V}O_{2peak}$ from baseline to after the intervention as the dependent variables, and exergaming skills, perceived enjoyment and pleasure, BMI at baseline, $\dot{V}O_{2peak}$ at baseline, age, sex, and participant (not used in regression analyses of change in $\dot{V}O_{2peak}$) as independent variables. For the multiple regression analyses, we first entered sex, participant, and all other independent variables that displayed a significance level $p < 0.25$ in the simple regression model. Then we removed all variables, apart from sex and participant, that did not display statistical significance in the model. Finally, the final multiple regression models were checked for homoscedasticity, and normality of residuals, outliers, and influential points. We used IBM SPSS 26.0 for Windows (Chicago, IL, United States) for all data analyses, and we set the level of significance at 0.05.

Role of the funding source

The funder of the study had no role in study design, data collection, data analysis, data interpretation, or writing

Table 1. Baseline characteristics.

	Exergaming ($n = 13$)	Control ($n = 17$)
Age	30 (8)	32 (9)
Sex	9 (69%)	11 (65%)
VO_{2peak} (mL kg^{-1} min^{-1})	43.9 (7.0)	42.4 (7.0)
VO_{2peak} (L min^{-1})	3.26 (0.94)	3.31 (0.77)
BMI (kg·m^2)	26.1 (5.3)	26.4 (4.4)
Bodyfat (%)	30.1 (9.4)	29.4 (9.4)
MVPA (min d^{-1})	97.3 (37.8)	74.4 (28.0)
Missing data	1 (8%)	3 (18%)
Media use (h d^{-1})	4.7 (2.3)	4.1 (2.0)
Videogaming (h d^{-1})	0.8 (1.9)	1.4 (2.3)

Notes: Data are mean (SD) or *N* (%). Peak oxygen uptake ($\dot{V}O_{2peak}$), body mass index (BMI), moderate-to-very vigorous-intensity physical activity (MVPA).

of the report. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Results

Participants were recruited between 18 September 2019 and 1 November 2019. We screened 33 individuals for eligibility, of whom 30 were randomly assigned to either an exergaming group ($n = 13$) or a no-intervention control group ($n = 17$) (Figure 1). Table 1 shows the baseline characteristics of the participants.

The exergaming group showed significantly higher relative $\dot{V}O_{2peak}$ compared to the control group after the intervention, with a between-group difference of 2.1 mL kg^{-1} min^{-1} (95% CI 0.2–4.1, $p = 0.04$) (Table 2, Figure 2). The between-group difference for absolute $\dot{V}O_{2peak}$ after the intervention (0.11 l·min^{-1} 95% CI −0.05–0.26, $p = 0.18$) was not statistically significant (Table 2, Figure 2).

Table 2. Results from linear mixed model for primary and secondary outcomes. Peak oxygen uptake ($\dot{V}O_{2peak}$), body mass index (BMI), systolic blood pressure (SBP), diastolic blood pressure (DBP), resting heart rate (RHR), moderate-intensity physical activity (MPA), vigorous-intensity physical activity (VPA), very vigorous-intensity physical activity (VVPA), moderate-to-very vigorous-intensity physical activity (MVPA).

		Exergaming		Control		Effect	
		N	Mean (SD)	*N*	Mean (SD)	Estimate (95% CI)	*P*
Peak oxygen uptake							
$\dot{V}O_{2peak}$ (mL kg^{-1} min^{-1})							
	Baseline	13	43.9 (7.0)	17	42.4 (7.0)		
	After intervention	13	45.3 (8.2)	15	42.0 (5.7)	2.1 (0.2–4.1)	0.04
$\dot{V}O_{2peak}$ (L min^{-1})							
	Baseline	13	3.26 (0.94)	17	3.31 (0.77)		
	After intervention	13	3.33 (0.93)	15	3.31 (0.87)	0.11 (−0.05–0.26)	0.18
Body composition							
Body mass (kg)							
	Baseline	13	74.7 (19.7)	17	78.9 (16.3)		
	After intervention	13	74.3 (16.9)	15	78.7 (16.9)	−2.6 (−8.7–3.5)	0.39
BMI (kg·m^2)							
	Baseline	13	26.1 (5.3)	17	26.4 (4.4)		
	After intervention	13	26.0 (5.4)	15	26.1 (4.3)	0.0 (−0.3–0.3)	0.99
Bodyfat (%)							
	Baseline	13	30.1 (9.4)	17	29.4 (9.4)		
	After intervention	13	29.8 (10.0)	15	28.7 (7.8)	−0.1 (−1.1–1.0)	0.92
Visceral fat (cm^3)							
	Baseline	13	105.0 (56.7)	17	111.1 (52.0)		
	After intervention	13	105.9 (60.1)	15	106.2 (43.4)	2.0 (−3.3–7.3)	0.44
Blood pressure and resting heart rate							
SBP (mmHg)							
	Baseline	13	118 (11)	17	127 (10)		
	After intervention	13	118 (8)	15	120 (9)	−1 (−5–3)	0.72
DBP (mmHg)							
	Baseline	13	78 (10)	17	83 (8)		
	After intervention	13	75 (8)	15	78 (6)	−1 (−4–2)	0.56
RHR (beats min^{-1})							
	Baseline	13	68 (11)	17	68 (10)		
	After intervention	13	65 (11)	15	67 (7)	−3 (−8–3)	0.37
Physical activity							
MPA (min d^{-1})							
	Baseline	12	85.8 (31.1)	14	68.1 (27.2)		
	After intervention	13	74.7 (49.3)	14	61.4 (25.1)	5.5 (−7.8–18.8)	0.41
VPA (min d^{-1})							
	Baseline	12	10.6 (12.5)	14	5.7 (6.4)		
	After intervention	13	13.2 (18.2)	14	5.6 (8.4)	3.4 (−1.1–8.0)	0.14
VVPA (min d^{-1})							
	Baseline	12	0.8 (1.6)	14	0.5 (1.1)		
	After intervention	13	1.7 (3.0)	14	0.2 (0.8)	0.7 (−0.0–1.4)	0.05
MVPA (min d^{-1})							
	Baseline	12	97.3 (37.8)	14	74.4 (28.0)		
	After intervention	13	89.8 (64.1)	14	67.4 (27.1)	9.6 (−6.5–25.6)	0.24

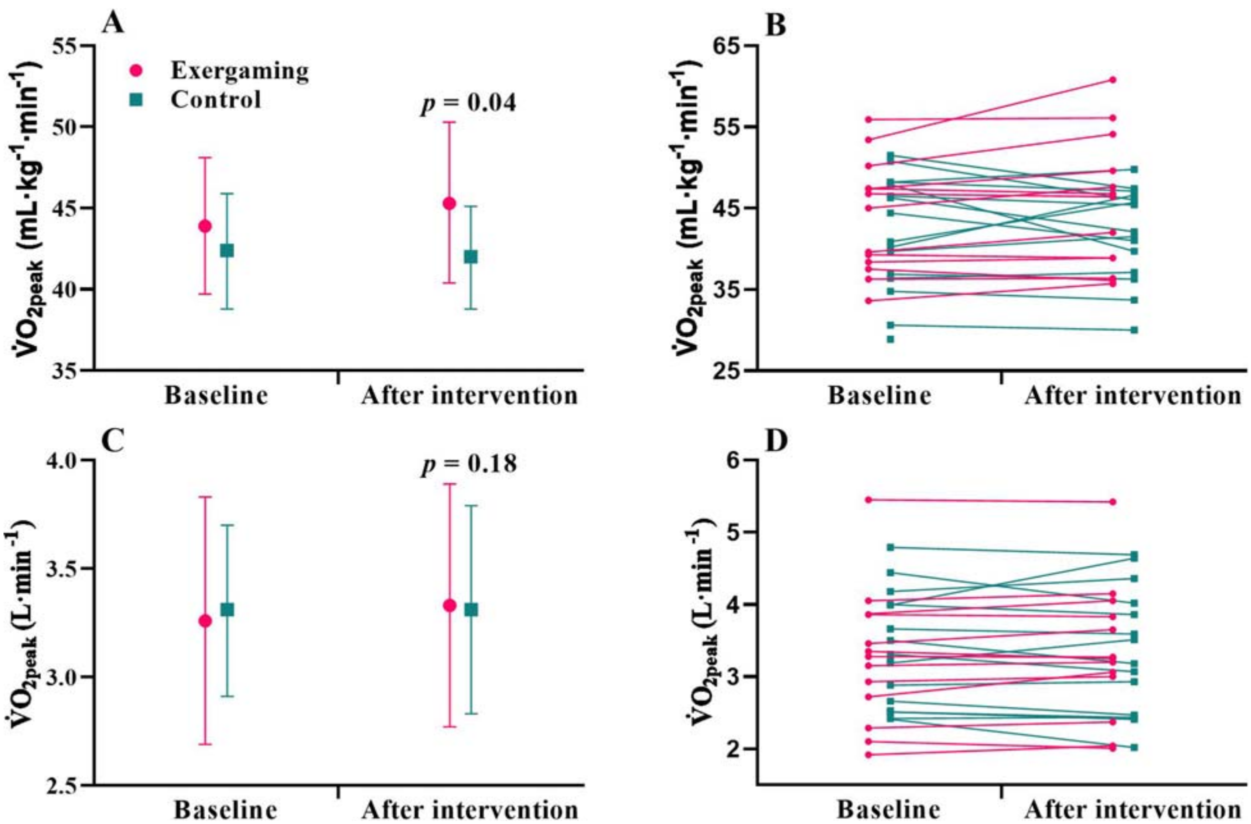

Figure 2. Peak oxygen uptake ($\dot{V}O_{2peak}$) at baseline and after the intervention. (A) Mean relative $\dot{V}O_{2peak}$, (B) relative $\dot{V}O_{2peak}$ for each participant, (C) mean absolute $\dot{V}O_{2peak}$, and (D) absolute $\dot{V}O_{2peak}$ for each participant. Error bars represent 95% CI. *p*-values are for the estimated interaction effect between time-point and group from the linear mixed model.

There were no significant between-group differences in moderate-intensity, vigorous-intensity, or moderate-to-very vigorous-intensity physical activity (Table 2). There was an increase in very-vigorous-intensity physical activity after the intervention in the exergaming group compared to the control group, with a between-group difference of 0.7 min·d^{-1} (95% CI −0.0–1.4, p=0.05) (Table 2).

There were no between-group differences in body composition measures, blood pressure, or resting HR after the intervention (Table 2).

Participants in the exergaming group undertook 14.4 (95% CI 13.5–15.3) exergaming sessions with an average of 49.1 min (95% CI 46.9–51.3) per session. The average HR during exergaming sessions was 73.7% of HR_{max} (95% CI 72.7–74.7). The peak HR attained during exergaming sessions was 87.0% of HR_{max} (95% CI 86.1–87.8). On average, 8.7 min (95% CI 7.0–10.3) of each exergaming session was spent with lower than moderate exercise intensity, whereas 19.4 (95% CI 17.7–21.1) and 21.0 (95% CI 18.9–23.1) was spent with moderate- and vigorous-intensity, respectively. The average score on the Feeling Scale was 3.4 (95% CI 3.2–3.6), where 3 is "good" and 5 is "very good". The participants' reported enjoyment on the PACES questionnaire was 96 (95% CI 94–98), out of the maximum score of 126.

Supplementary Table 1 shows results obtained from the simple regression analyses. For average HR during exergaming sessions, the multiple regression model included BMI at baseline, sex, age, $\dot{V}O_{2peak}$ at baseline, PACES score, experience points gained per round, the kill to death ratio, and participant ($R^2 = 0.41$, $p < 0.001$) (Supplementary Table 2). The multiple regression model for peak HR during exergaming sessions included BMI at baseline, sex, age, $\dot{V}O_{2peak}$ at baseline, PACES score, the Feeling Scale score, the kill to death ratio, and participant ($R^2 = 0.43$, $p < 0.001$) (Supplementary Table 3). For the PACES score, the multiple regression model included BMI at baseline, sex, average HR during exergaming sessions, and participant ($R^2 = 0.14$, $p < 0.001$) (Supplementary Table 4) whereas the model for the Feeling Scale score included BMI at baseline, sex, peak HR during exergaming sessions, and participant ($R^2 = 0.15$, $p < 0.001$) (Supplementary Table 5). When controlling for all other variables in the model, sex explained 24% ($p < 0.001$) and 7% ($p = 0.002$) of the variance in average and peak HR in exergaming sessions, respectively. Exercise intensity was higher for females with average relative HR 7.2 percentage points (95% CI 4.8–9.6) and peak relative HR 3.3 percentage points (95% CI 1.3–5.3) higher, compared to males. Sex was the strongest independent predictor of average HR during exergaming, and BMI the strongest independent predictor of peak HR attained, both explaining 33% ($p < 0.001$) of the variance, after controlling for the other variables in the model. For PACES and the Feeling Scale score, sex explained 6% ($p = 0.007$) and 3% ($p = 0.05$) of the variance. Females rated exergaming sessions on average 7 points (95% CI −14 to −2) and 0.5 points (95% CI −0.9 to −0.0) lower than males on PACES and the Feeling Scale, respectively. The strongest predictor for PACES score was participant, explaining 9% ($p < 0.001$) of the variance, and peak HR attained during exergaming was the strongest predictor for the Feeling Scale score, explaining 10% ($p < 0.001$) of the variance. No independent variables could significantly predict change in $\dot{V}O_{2peak}$ (Supplementary Table 1).

There were no adverse events at any stage during this trial.

Discussion

The main finding of this trial was that two weekly exergaming sessions for eight weeks improved $\dot{V}O_{2peak}$ compared to a no-intervention control group. Besides from a small (less than 1 min d^{-1}) increase in very vigorous physical activity for the exergaming group after the intervention, no effect was observed from exergaming on the secondary outcome measures. We have shown that two weekly exergaming sessions of 45 min improve $\dot{V}O_{2peak}$, and can therefore be a viable exercise training alternative for individuals reporting not to perform endurance training.

Although a previous study suggested greater improvements in $\dot{V}O_{2max}$ after three weekly sessions of exergaming for six weeks compared to conventional endurance training (Warburton et al., 2007), this is the first adequately powered randomised controlled trial that has investigated the effect of regularly performed exergaming on measured cardiorespiratory fitness. Contrary to our findings, twelve weeks of regularly performed exergaming failed to show an increase in estimated cardiorespiratory fitness in the Wii Heart Fitness Trial (Bock et al., 2019). In our study, exergaming participants spent most of the completed sessions at moderate- or vigorous-exercise intensity, which is above the suggested threshold for improving cardiorespiratory fitness (Swain & Franklin, 2002). The observed between-group difference of 2.1 mL kg^{-1} min^{-1} is less than the suggested improvement in $\dot{V}O_{2peak}$ after endurance training interventions (Milanović, Sporiš, & Weston, 2015). However, the effects of endurance training are greater for those with the lowest baseline cardiorespiratory fitness level (Swain & Franklin, 2002), and although our participants reported not to be endurance-trained, they accumulated on average 85.0 min per day of moderate-to-very vigorous-intensity physical activity at baseline. Furthermore, the baseline $\dot{V}O_{2peak}$ for the female participants was higher than both the average inactive population and those classified into low and medium physical activity levels (Aspenes et al., 2011). Also, it should be noted that there was no difference between groups in absolute $\dot{V}O_{2peak}$. A lack of improvement in absolute $\dot{V}O_{2peak}$ combined with a slightly greater, although not statistically significant, weight loss (−2.6 kg) in the exergaming group suggests that the observed improvement in relative $\dot{V}O_2$ could partly be explained by lifestyle changes not related to the exergaming intervention. However, since 1 mL kg^{-1} min^{-1} increase in $\dot{V}O_{2peak}$ is associated with a lower risk of all-cause mortality, the observed between-group difference in the present study is of clinical importance (Imboden et al., 2019).

Although we observed a slight increase in very vigorous-intensity physical activity after the intervention in the exergaming group, we did not demonstrate any significant improvements after exergaming in the other measures of physical activity, anthropometrics, resting HR and resting blood pressure. The Wii Heart Fitness Trial reported a significantly increased self-reported physical activity after the end of 12 weeks of three weekly 50 min exergaming sessions compared to traditional endurance training (running and cycling), and a no-intervention control group (Bock et al., 2019). However, they found no difference in objectively measured physical activity (Bock et al., 2019), which is in line with our findings. The observed increase in very vigorous-intensity physical activity in the exergaming group in our study indicates that exergaming participants performed slightly more high-intensity exercise after the intervention. Since exercise with very vigorous-intensities is associated with significantly higher $\dot{V}O_{2peak}$ despite markedly lower weekly exercise duration (Nes et al., 2012), it might be more important than exercise at moderate- and vigorous-intensity for improving and maintaining $\dot{V}O_{2peak}$. However, although statistically significant, we argue that the 0.7 min d^{-1} increase in very vigorous-intensity physical activity after the intervention in the exergaming group has little clinical relevance. Altogether, our data suggest that when the exergaming group no longer had access to the exergaming platform, they returned to their baseline physical activity levels.

To achieve changes in the other secondary outcomes, including body composition, resting blood pressure and

HR, a more extended intervention period and higher weekly exercise volumes might be necessary (Batacan, Duncan, Dalbo, Tucker, & Fenning, 2017; Sultana, Sabag, Keating, & Johnson, 2019).

A successful exergame should induce both enjoyment during the activity and physiological adaptations to exercise (Sinclair et al., 2007). Therefore, we sought to understand what factors could influence enjoyment and exercise intensity during the intervention. We found that sex was independently associated with both the PACES and the Feeling Scale score; women reported slightly lower enjoyment and pleasure during exergaming compared to men. This finding is in contrast to previous findings showing similar enjoyment between sexes (Soltani, Figueiredo, & Vilas-Boas, 2020). However, although ratings of enjoyment and pleasure were statistically significant predictors, the sex differences in these variables in the present study were marginal, therefore providing little clinical relevance. Interestingly, we found that exergaming skills did not influence ratings of enjoyment or pleasure. To experience immersion and flow during gameplay, the game should require concentration, give the player a sense of control over their actions, have clear goals, provide appropriate feedback, and balance challenge with the player's skills (Sweetser & Wyeth, 2005). The Playpulse exergaming platform was designed according to these principles (Hagen, Chorianopoulos, Wang, Jaccheri, & Weie, 2016). Our findings, therefore, suggest that this exergaming platform can generate enjoyment and pleasure irrespective of the player's skills. One explanation for the similar enjoyment and pleasure irrespective of exergaming skills can be that the platform also provides a social gaming experience through collaboration and competitiveness, which can compensate for the lack of player's skills. Indeed, social interaction can contribute to flow in games (Sweetser & Wyeth, 2005). Overall, with the importance of enjoyment for exercise adherence (Rodrigues et al., 2020), these findings, are important for successful long-term implementation, thus clinically relevant.

Our findings also show that sex was the strongest independent predictor of average HR during exergaming, whereas BMI at baseline was the strongest independent predictor of peak HR in exergaming. During exergaming, women exercised at a higher average intensity than men, whereas a higher BMI at baseline was associated with a lower peak intensity during exergaming. Furthermore, in contrast to previous findings (Soltani et al., 2020), we found that higher exergaming skills lead to both higher average and peak intensities during exergaming. However, since no independent variables, including exergaming intensity, affected subsequent change in $\dot{V}O_{2peak}$, these findings provide minimal clinical relevance.

The main limitation of the present study is the lack of comparison with a more conventional form of exercise, which prevents us from relating perceived enjoyment and pleasure during exergaming to traditional exercise training, and its potential for long-term adherence. The data on exergaming skills are solely based on statistics derived from one of the three games on the exergaming platform, and we cannot exclude that exergaming skills in the other games might have altered our findings. Also, the slightly skewed sex distribution might have influenced our findings. Finally, this trial is limited by using a short follow-up period, and further research should determine the long-term effects of regularly using this exergaming platform.

Conclusion

We show that two weekly sessions of exergaming can improve cardiorespiratory fitness in healthy, but not endurance-trained adults. In this study, neither exergaming skills nor initial fitness affected enjoyment, pleasure or changes in $\dot{V}O_{2peak}$, which suggests that this exergaming platform can be enjoyed by adults independent of their exergaming skills. Future studies should determine the effectiveness in other populations and whether exergaming can increase adherence to physical activity on a population level.

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Disclosure statement

AIW reports financial interest in Playpulse AS, the company that develops the exergaming platform used in the present study. AIW does not work or is directly involved with Playpulse AS, but he owns some shares in the company. Playpulse AS had no role in preparing the manuscript. JB, GH, and TM declare no conflicts of interest.

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