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Effects of home-based exergaming on cardio-metabolic and cognitive health in physically inactive individuals

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Abstract

Aims: To examine the effects of a home-based exergame training over 6 weeks on cardio-metabolic and cognitive health, as well as training adherence, in physically inactive individuals.

Materials and Methods: Twenty participants were equipped with an exergame system specifically designed for use at home. Each participant performed at least three weekly exercise sessions at ≥80% of their individual maximum heart rate, over 6 weeks. Exercise duration increased biweekly until 75 min of vigorous exercise were performed in Weeks 5 and 6. Maximum oxygen uptake (VO_{2max}), cardio-metabolic profiling, and neuro-cognitive tests were performed at baseline and study end. Additionally, training adherence was assessed via training diaries.

Results: After 6 weeks of home-based exergaming, VO_{2max} increased significantly, while there was a significant decrease in heart rate (resting and maximum), blood pressure (systolic, diastolic and mean), and low-density lipoprotein cholesterol. Dynamic balance and reaction time improved after 6 weeks of exergaming. Training adherence was 88.4%.

Conclusions: Home-based exergaming induced a clinically relevant increase in VO_{2max}, a determinant of cardiovascular health, accompanied by further improvements in cardiovascular, metabolic and neuro-cognitive parameters. Exergaming may, therefore, offer an innovative approach to increasing regular physical activity, improving metabolic risk profile, and preventing chronic diseases.

KEYWORDS
cardiovascular disease, exercise intervention, weight control

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1 | INTRODUCTION

With an estimated 1.4 billion adults being physically inactive, sedentary behaviour represents a major public health risk, translating into a significant increase in chronic diseases and premature death.[1,2] To counterbalance this, the World Health Organization advocates 150 min of moderate or 75 min of vigorous physical activity per week for adults.[3] Regular physical activity induces measurable benefits in cardiovascular risk factors, such as changes in body composition and improved glycaemic control.[4,5] However, only a fraction of the general population currently implements such recommendations in daily life.[6] Multiple factors may pose a barrier to regular physical activity, such as urbanization, time constraints, increasing work hours, family commitments, inadequate financial resources, or lack of motivation.[7,8] Novel and alternative strategies are therefore required to increase regular engagement in physical exercise, especially in previously sedentary individuals. We recently reported on the development of a home-based exercise gaming system, a so-called 'exergame', as a potential resource to increase motivation for physical activity.[9] Exergames, if well designed, combine physical and cognitive training through immersive integration of physical exercises within a motivating video game.[10] A home-based exergame system may constitute an attractive option for sedentary individuals, for whom regular attendance at a gym or other training institutions is fraught with organizational or emotional burdens.[11–13] As shown previously, a compact home-based exergame system transfers the functions of the larger, stationary versions available in gyms (e.g., the ExerCube) to the individual home setting.[14] Technically, home-based systems consist of motion trackers worn on the wrists and ankles of the player, translating body movements into movement-based actions of a game character, shown in real time on a screen in front of the player. Besides the virtual game scenario, the trackers provide additional feedback via integrated light, sound and vibration to allow a physical immersive game experience. In a recent proof-of-concept study, the home-based system was considered usable and enjoyable by healthy adults.[9] The present study aimed to translate and validate the concept of a home-based exergame in a real-world scenario by measuring the effects of a 6-week training programme on cardio-metabolic and cognitive health in previously sedentary adults.

2 | MATERIALS AND METHODS

2.1 | Study participants

Twenty sedentary but otherwise healthy adults were enrolled in the study. Recruitment flyers were distributed via social media platforms and the internal distribution lists of the University of Bern, Switzerland. Screening visits were conducted at the Department of Diabetes, Endocrinology, Clinical Nutrition and Metabolism, at Bern University Hospital. Key inclusion criteria were age between 18 and 55 years; physical inactivity, defined as (1) weekly performance of less than 150 min of moderate physical activity, (2) less than 75 min of vigorous physical activity, or (3) a combination of both; and a body mass index (BMI) between 18.5 kg/m^2 and 35.0 kg/m^2. Key exclusion criteria were diagnosis of overt metabolic disease (including diabetes mellitus of any type), known cardiovascular disease (CVD), and current pregnancy. The present study was reviewed and approved by the Ethics Committee of the Canton of Bern (ID 2021–02182) and registered at Clinicaltrials.gov under the unique identifier NCT04633590 prior to recruitment.

2.2 | Study design

The study was designed as a prospective, open-label investigation. The primary endpoint was change in maximum oxygen uptake (VO_{2max}) during cardiopulmonary exercise testing (CPET) between baseline and study end. Secondary endpoints comprised training adherence, changes in maximal power output, blood pressure (systolic, diastolic and mean), heart rate (maximum and resting), anthropometry (body weight, BMI, waist circumference, whole body adipose tissue, visceral adipose tissue, and lean mass), dynamic balance, reaction time, metabolic parameters (fasting glucose, glycated haemoglobin [HbA1c], total cholesterol, low-density lipoprotein cholesterol [LDL-C], high-density lipoprotein cholesterol [HDL-C], triglycerides [TG]), as well as glucose profiles measured by a continuous glucose monitoring (CGM) system (mean 24 h of CGM glucose, mean CGM glucose during daytime and during nighttime, and related coefficients of variation) before and after 6 weeks of exergaming.

2.3 | Study procedures

At baseline, after a 10-h overnight fast, participants arrived at the study centre for a medical examination. Anthropometric measures (height, weight, waist circumference) were taken using an electronic ultrasound scale, body composition was measured using electronic body composition analysis (InBody Europe, Amsterdam, Netherlands). Blood pressure was measured in triplicate after resting in a supine position for 15 min. A fasting blood sample was taken for the analysis of metabolic parameters. Beta human chorionic gonadotropine (hCG) was measured in female participants of childbearing potential, additionally. Participants were asked to complete the International Physical Activity Questionnaire short form to assess habitual physical activity levels. Participants' smoking status was also documented. Afterwards, a CGM device (Dexcom G6; Dexcom, San Diego, CA, USA) was equipped according to the manufacturers' instructions. CGM glucose was measured over 72 h preceding the pre-exercise CPET, together with a food diary and an activity monitor (Garmin Venu 2 smartwatch; Garmin, Lenexa, KS, USA). After 72 h, participants were re-invited to the study centre after a 10-h overnight fast. Data from the CGM system and the activity monitor were obtained. Participants' dynamic balance was tested using the Y-Balance Test^{tm} testkit (YBT1, Danville, VA, USA), as described elsewhere.[15] Executive cognitive function was assessed using the 'Test for Attentional

Performance' (TAP) test kit (PSYTEST, Psychologische Testsysteme, Herzogenrath, Germany) as described elsewhere.[16] Finally, CPET was conducted under the supervision of a trained cardiologist at the study centre using an electronically braked cycle ergometer with breath-by-breath spirometry (COSMED Omnia, Rome, Italy). VO_{2max}, resting and maximum heart rate, systolic, diastolic and mean blood pressure were recorded during CPET. After completion, participants were given an exercise diary, which was then used by participants to manually record their exercise sessions. In order to track heart rate during exercise sessions, participants were given a heart rate monitor (Wahoo, TICKRx, Atlanta, GA, USA) to wear around their chest. After completion of the baseline study visit, the home-based exergame system was delivered and installed at the participants' home. Figure 1 provides an overview of the home-based exergame system and its active application. Base Station A and B allowed the coordinates of the motion trackers (HTC VIVE Trackers) to be located and calculated. Motion trackers were mounted on a charging station between workouts and were applied to the wrists and ankles of the player during exercise sessions. Players also wore a heart rate monitor, which allowed the exergame software to adapt individually to the participant's performance capabilities. Each movement of the player was translated into a movement of a virtual avatar, which was displayed on the television screen and was manoeuvred through obstacles in the game world. A touch-display located on a gaming PC was used for start/stop and setup of the exercise game. Movements captured by the motion trackers of the physically

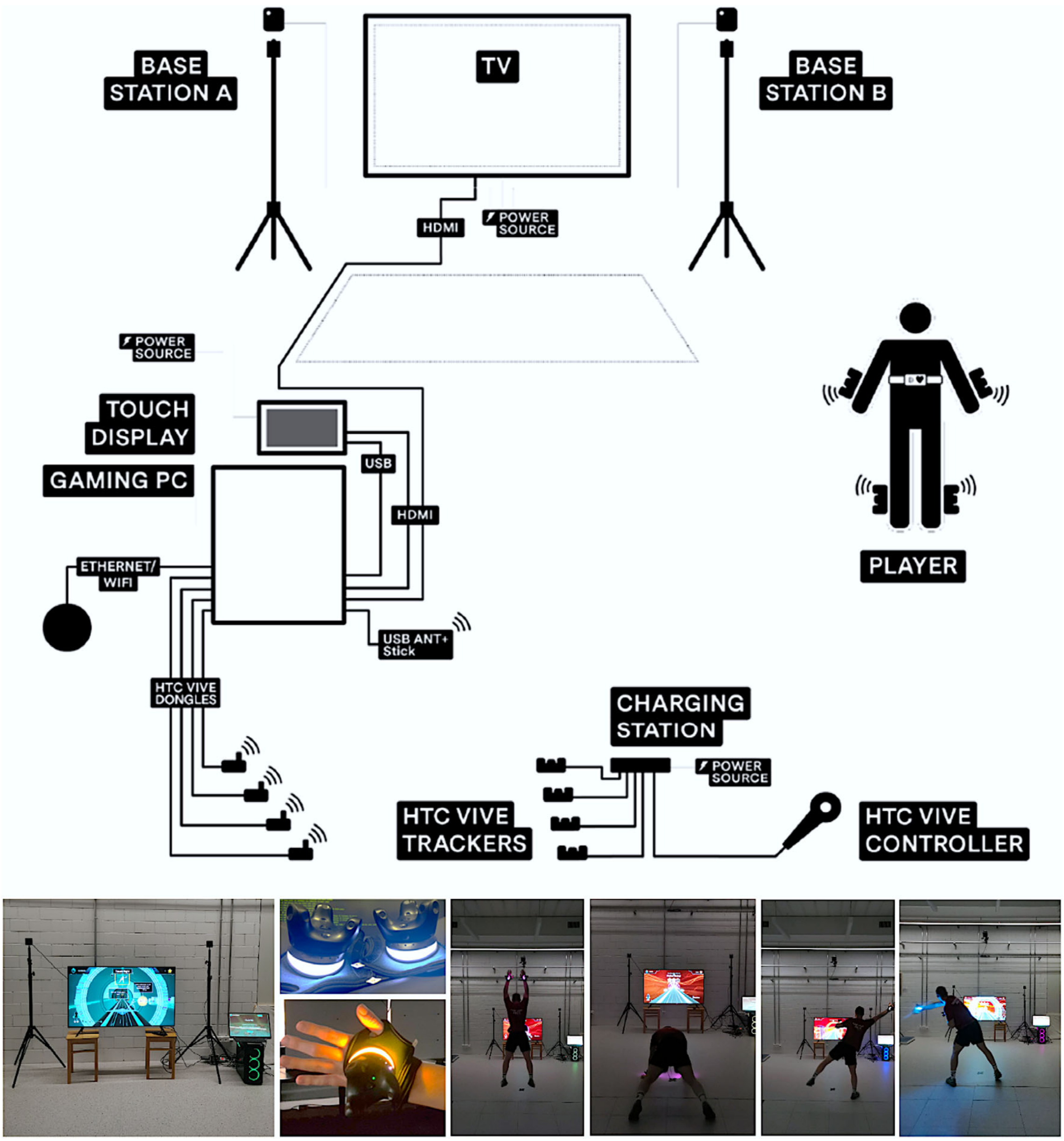

FIGURE 1 Setup and usage of the home-based exergame system, showing the hardware components, the setup and the active application of the HomeExergame System.

active player are translated into corresponding movements of the avatar in the virtual environment in real time. Several types of obstacles need to be overcome by different aerobic and anaerobic movements, including lunges, jumps, burpees, squats, and more. After completion of the 6-week training programme (see below), the anthropometric measurements, analysis of metabolic parameters, CPET, and the collection of data from the CGM device, activity monitor and food diary were repeated.

2.4 | Home-based exergame system training

Participants were provided with a stepwise training plan comprising three exercise sessions per week. In Weeks 1 and 2, each session lasted for 19 min (4 × 3 min +45 s of exercise interspersed with 1 min of rest; tutorials included). In Weeks 3 and 4, each session lasted for 24 min (4 × 5 min of exercise interspersed with 1 min of rest), increasing to 30 min in Weeks 5 and 6 (5 × 5 min of exercise interspersed with 1 min of rest). Session intensity was set at ≥80% of maximum heart rate achieved during baseline CPET. During each exercise session, a game character (i.e., an avatar) was guided through a virtual parkour through body movements performed by the player. These movements included dynamic exercises (jumps, triples, punches, burpees and side steps) and stationary exercises (squats and lunges) in order to overcome virtual obstacles or activate checkpoints.

2.5 | Statistical analysis

To assess changes in physiological parameters before and after the exergame training sessions statistical testing was performed using a paired *t*-test and a paired Wilcoxon test. First, a Bartlett test was performed to determine the homogeneity of variances. If the *p* value was less than the significance level of 0.05, the null hypothesis that the variance was the same for all groups was rejected. In this case the paired Wilcoxon test was seen as more appropriate than the paired *t*-test.

2.5.1 | A priori power calculation for the primary endpoint: changes in VO_2max

A cohort of 20 physically inactive individuals allowed for detection of a 3.5-mL·kg^{-1}·min^{-1} difference in VO_{2max} (based on a standard deviation of 3.5 mL·kg^{-1}·min^{-1}; $p < 0.05$ two-tailed), with 80% power. Such a difference in VO_{2max} was a priori deemed to be of clinical significance, as there was a 8%–17% reduction in all-cause mortality for each 1-MET (∼3.8 mL·kg $_{axe}{}^{-1}$·min^{-1}) increase in VO_{2max}.[39] The standard deviation was based on previous investigating changes in VO_{2max} with exercise in lean individuals.[40] Statistical analysis was performed using R version 4.2.2 with the package 'ucrt' version 2022-10-31.

2.5.2 | Post hoc correction for secondary endpoints

Post hoc correction for secondary endpoints was applied using Benjamini Hochberg correction, with a false discovery rate of 0.05 and 34 tests.

3 | RESULTS

A total of 20 participants (six women, 14 men) completed the study per protocol, with a mean age of 31.4 ± 10.5 years (Table 1). Adherence was high, with a total of 88.4% of all exercise sessions (18 sessions per participant in total) completed over the course of the study (Supplementary Figure S1). Six weeks of home-based exergaming induced a significant increase in VO_{2max} ($p = 0.02$), accompanied by a decrease in resting ($p = 0.008$) and maximum heart rate ($p = 0.005$), and systolic ($p = 0.03$), diastolic ($p = 0.003$) and mean blood pressure ($p = 0.002$), as measured during CPET, with no visible difference according to sex (Figure 2 and Table 2). While no anthropometric changes were observed over 6 weeks, LDL-C decreased significantly ($p = 0.01$), and TG increased ($p = 0.05$). Fasting glucose and HbA1c did not change, but there was an increase in mean CGM glucose readings, especially during daytime ($p = 0.03$), while mean glucose readings overnight were unchanged, albeit accompanied by higher variation (Table 2). The Y-Balance test revealed an increase in dynamic balance during backward-directed movements ($p = 0.03$ for right back right; $p = 0.02$ for left back left), and the TAP test showed a reduction in decision errors ($p = 0.05$; Table 2). Importantly, the number of daily steps was comparable over the study period, excluding an interference effect on outcomes from additional exercise (Table 2).

4 | DISCUSSION

Six weeks of home-based exergaming induced a significant increase in VO_{2max} and led to meaningful reductions in heart rate, blood pressure and LDL-C in previously sedentary adults, accompanied by improved balance and cognition.

VO_{2max} and resting heart rate are considered relevant determinants of cardiovascular function. Of note, VO_{2max} is a key predictor of cardiorespiratory fitness (CRF) and strongly correlates with risk of

TABLE 1 Baseline characteristics of study participants.

Ethnicity: White, *n* (%)	20 (100)
Sex: female, *n* (%)	6 (30.0)
Age, years	31.4 ± 10.5
BMI, kg/m^2	24.4 ± 4.2
Smoking status: active smoker, *n* (%)	6 (30.0)
MET min per week	366.2 ± 119.1

Note: Data are presented as proportion of the total study population in percent or as mean ± standard deviation.
Abbreviations: BMI, body mass index; MET, metabolic equivalent.

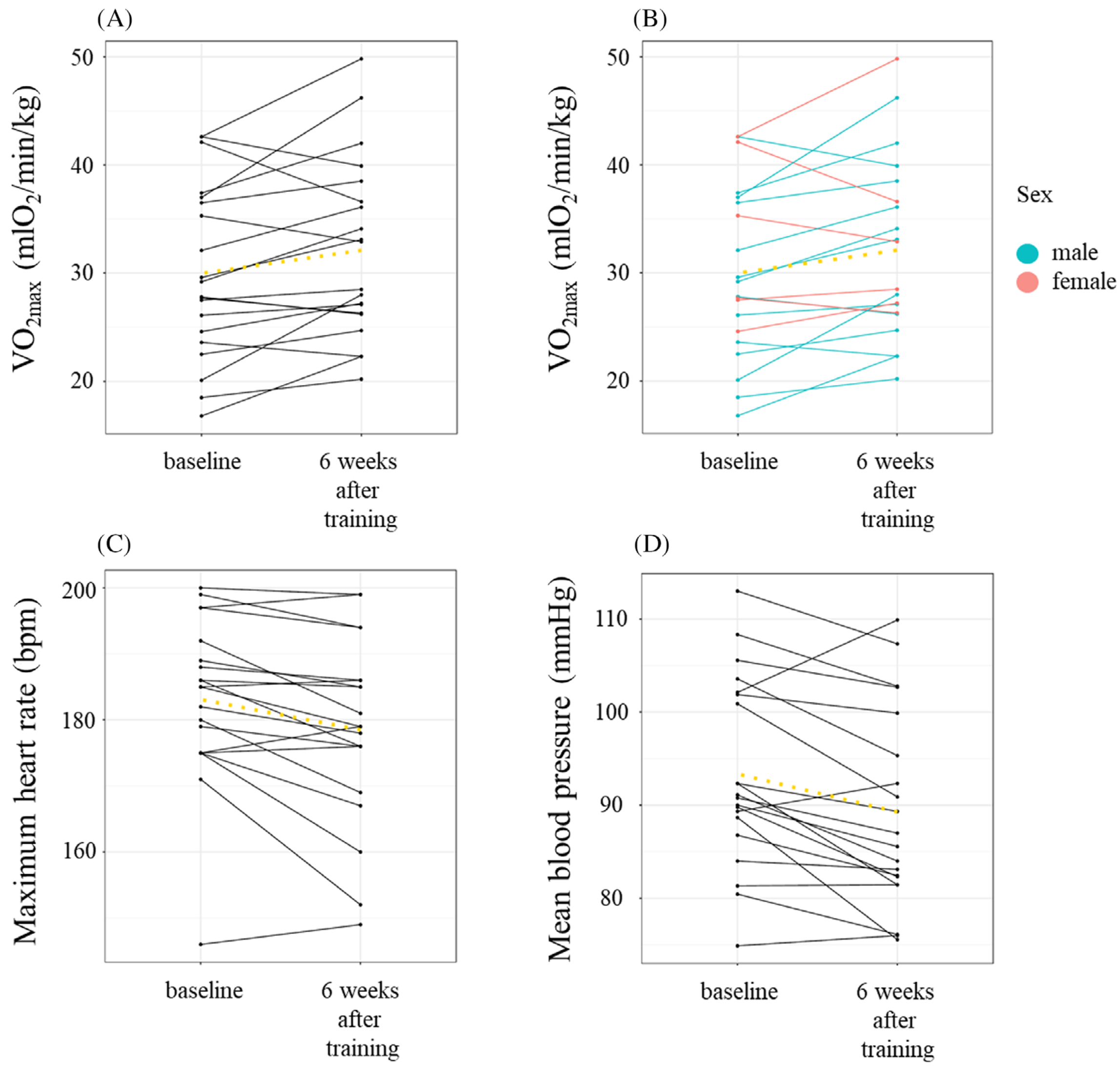

FIGURE 2 Individual changes in cardiorespiratory fitness. Scatter plots of changes in markers of cardiorespiratory fitness before and after 6 weeks of training with the HomeExergame system are shown. Dashed yellow lines indicate the mean differences. VO_{2max}, maximum oxygen uptake.

CVD.[17] While many studies have shown that low CRF is associated with a high risk of CVD and all-cause mortality, improvements in CRF were found to reduce excess mortality by approximately 11% per 1-mL/min/kg increase in VO_{2max}.[18–20] In parallel, an elevated heart rate is associated with a higher CVD incidence and mortality in the general population and predicts poorer prognosis for patients with hypertension or acute coronary syndrome.[21–25] A study performed in the general population revealed that an increase of heart rate by 5 bpm was accompanied by a 12% higher risk of all-cause mortality, and a recent study confirmed this association also for very low and very high resting heart rates.[26]

Exercise has been shown to reduce these cardiovascular risks in numerous studies.[27] Exergame interventions may be novel and innovative means to motivate people towards regular physical activity and exercise.[28] However, previous studies investigating the potential of exergame interventions have so far led to ambiguous conclusions. Two recent studies showed no effects of exergaming on VO_{2max} when allocating participants to an exergame. However, neither of these studies encompassed a predetermined training frequency.[29,30] Another study, which performed a training intervention similar to the present study, albeit in a smaller sample (seven participants), revealed comparable improvements in CRF after 6 weeks of exergaming.[11] In line with our findings, a recently published randomized controlled trial in healthy adults, who performed at least two sessions of high-intensity exergame training per week for 8 weeks, found similar changes in VO_{2max}.[31] A major difference of the present study compared to previous investigations is the fact that we exclusively included physically inactive healthy individuals (i.e., those without pre-existing medical conditions), to emphasize the potential of exergames in overcoming the barriers towards regular physical activity in primary prevention. This is further corroborated by a training adherence approximating 90%.

TABLE 2 Changes in primary and secondary endpoints.

Parameter	Baseline	After 6 weeks of home-based exergaming	*p* value[a]
CPET measurements			
VO_{2max}, mLO_2/min/kg body weight	30.0 ± 7.8	32.1 ± 8.0	**0.02**
Resting heart rate, bpm	98.4 ± 9.4	91.5 ± 9.1	**0.008**
Max. heart rate, bpm	182.1 ± 12.9	177.9 ± 13.9	**0.005**
Systolic blood pressure, mmHg	117.8 ± 13.7	114.3 ± 12.7	**0.03**
Diastolic blood pressure, mmHg	81.4 ± 8.6	75.6 ± 10.9	**0.003**
Mean blood pressure, mmHg	93.6 ± 9.9	88.5 ± 10.9	**0.002**
Anthropometry			
Body weight, kg	71.4 ± 16.2	72 ± 16.7	0.19
BMI, kg/m^2	24.4 ± 4.2	24.5 ± 4.5	0.22
Waist circumference, cm	85.5 ± 14.6	84.0 ± 14.5	0.16
Body fat, kg	19.5 ± 9.8	19.8 ± 10.4	0.2
Muscle mass, kg	28.9 ± 6.1	29.0 ± 6.0	0.5
Y-balance test			
Right forward, cm	61.7 (56.5–66.8)	65.5 (59.3–69.3)	0.07
Right back left, cm	95.8 (91.5–104)	94.8 (93.0–105.2)	0.29
Right back right, cm	91.2 (86.7–95.2)	94.3 (91.6–104.7)	**0.03**
Left forward, cm	61.8 (58.8–66.7)	65.5 (60.0–71.0)	0.16
Left back right, cm	96.0 (91.7–101.1)	98.3 (91.2–103.5)	0.86
Left back left, cm	90.7 (82.5–96.2)	96.6 (86.0–105.6)	**0.01**
TAP test battery			
'Go/no go' reaction time, ms	478.3 ± 56.1	471 ± 39.1	0.37
'Go/no go' error rate	0.9 ± 2.4	0.3 ± 0.5	0.26
Flex reaction time, ms	414.0 ± 41.7	416.9 ± 38.2	0.75
Flex error rate	1.0 ± 1.2	0.5 ± 0.8	**0.05**
Laboratory measurements			
Fasting glucose, mg/dL	5.0 ± 0.4	5.1 ± 0.5	0.4
HbA1c, mmol/mol	32.9 ± 3.0	32.3 ± 3.5	0.42
Total cholesterol, mmol/l	4.7 ± 1.0.	4.6 ± 1.0	0.09
LDL cholesterol, mmol/l	3.0 ± 1.0	2.7 ± 1.0	**0.01**
HDL cholesterol, mmol/l	1.5 ± 0.4	1.5 ± 0.4	0.36
Triglycerides, mmol/l	1.2 ± 0.6	1.5 ± 1.0	**0.05**
CGM measurements			
CGM mean glucose	5.7 ± 0.5	6.0 ± 0.8	**0.07**
CGM mean glucose daytime	5.8 ± 0.6	6.1 ± 0.8	**0.03**
CGM mean glucose nighttime	5.7 ± 0.5	5.8 ± 0.8	0.44
CGM mean coefficient of variation	15.8 ± 2.7	16.2 ± 3.1	0.56
CGM coefficient of variation daytime	16.9 ± 3.0	16.1 ± 2.8	0.28
CGM coefficient of variation nighttime	11.3 ± 3.0	14.6 ± 4.7	**0.01**
Other			
Daily steps, steps	8277.9 ± 2034.6	8129.0 ± 2149.5	0.71

Abbreviations: BMI, body mass index; CGM, continuous glucose monitoring; CPET, cardiopulmonary exercise testing; HbA1c, glycated haemoglobin; HDL, high-density lipoprotein; LDL, low-density lipoprotein; TAP, Test for Attentional Performance; VO_{2max}, maximum oxygen uptake.
[a]Paired Student's *t*-test for normally distributed data; paired Wilcoxon rank sum test for non-normally distributed data. Data are presented as mean ± standard deviation for normally distributed data and as median (interquartile range) for non-normally distributed data. An alpha-level of ≤0.05 was considered statistically significant. Bold values indicate statistically significant changes. Post hoc correction for secondary endpoints was applied using Benjamini Hochberg correction, with a false discovery rate of 0.05 and 34 tests.

The home-based exergame training approach induced a significant decrease in blood pressure after 6 weeks. A recently published randomized controlled trial compared the acute haemodynamic responses of a single exergame training session in a comparable but stationary exergame setting with regular treadmill training in 28 adult participants.[32] After 45 min of vigorous training, a significant decrease in peripheral and central systolic and diastolic blood pressure was measurable compared to baseline in both interventions. However, the absolute reduction was higher after the exergame session as compared to conventional treadmill training. Comparable to the present study in adults, similar effects of exergaming on endurance capacity and blood pressure were found in children.[33] After 37 weeks of training twice weekly for 45 min, endurance performance increased, while significant reductions in blood pressure and arterial stiffness were observed.

Another relevant finding in the present study was the reduction in LDL-C, corroborating the potential of exergaming to improve the cardiovascular risk profile of sedentary adults.[34] The increase in TG observed in the present study was somewhat unexpected. However, TG levels are a less significant cardiovascular risk factor when compared to LDL-C, and may be subject to acute interfering factors such as diet.[35] Of note, we carefully analysed food protocols in the present study, and did not find evidence of a systematic difference in food intake or composition explaining the observed differences, which may therefore also be a chance finding. (Supplementary Table S1 provides a detailed report of food intake and composition 3 days prior to baseline and follow-up CPET). The same applies to the observed changes in CGM readings. The most likely explanation for the increased variation in glucose detected overnight may lie in the timing of the evening meals (later due to increased time spent exercising).

In parallel with the cardio-metabolic benefits, we also observed improvements in cognitive and neuro-motoric actions, emphasizing the potential of exergaming to positively influence numerous determinants of prolonged health. Previous studies have shown that increased dynamic balance may translate into a decreased risk for ankle injuries.[36] Moreover, improved dynamic balance has been shown to prevent falls in elderly individuals, again emphasizing the preventive potential of exergaming in a broader population.[37,38]

We acknowledge the following strengths and limitations of the present study. This was the first prospective, interventional study investigating a home-based exergame system in healthy, sedentary adults, corroborating the preventive potential of such an approach. While the intervention was non-blinded, the setting was well defined, and allowed for a quantification of clinically relevant outcome parameters. We acknowledge the limited sample size, which was due to the logistical challenges and the amount of technical gear required to supply all participants. Nevertheless, the study allowed for a meaningful analysis of relevant metabolic and cardiovascular changes. Of note, our findings only apply to the population under investigation (i.e., White individuals, and male predominance), limiting generalizability to other groups of interest.

In conclusion, 6 weeks of regular home-based exergaming significantly increased VO_{2max}, reduced heart rate, blood pressure and LDL-C, and improved dynamic balance and cognition in previously sedentary adults. Home-based exergaming may constitute an attractive option to facilitate access to regular exercise, thereby reducing morbidity and mortality related to sedentary behaviour.

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CONFLICT OF INTEREST STATEMENT

Besides their academic careers, ALM-N and AS are also working for Sphery. ALM-N is a cofounder of the start-up company Sphery Ltd, which developed the ExerCube based on the results of her previous research projects. AS has been working as Senior Research and Development Manager at Sphery since November 2019. SN is also a cofounder of Sphery, while YR started working as a Project Manager at Sphery in 2021. The remaining authors have no conflicts of interest to declare. No revenue was paid (or promised to be paid) directly to ALM-N, to AS, to SN, to YR, to Sphery, or to the research institutions.

PEER REVIEW

The peer review history for this article is available at https://www.webofscience.com/api/gateway/wos/peer-review/10.1111/dom.15540.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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