DIABETES RESEARCH AND CLINICAL PRACTICE 154 (2019) 35–42

Contents available at ScienceDirect

Diabetes Research and Clinical Practice

journal homepage: www.elsevier.com/locate/diabres

Reduction in HbA1c with Exercise videogames among participants with elevated HbA1c: Secondary analysis of the *Wii Heart Fitness* trial

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ARTICLE INFO

Article history:
Received 4 January 2019
Received in revised form
3 June 2019
Accepted 18 June 2019
Available online 22 June 2019

Keywords:
Video games
Exercise
Physical activity
Diabetes
Prediabetes

ABSTRACT

Aims: Physical activity plays an important role in blood glucose management, yet most adults with elevated blood glucose do not engage in regular physical activity. Exercise videogames (EVGs) may be an attractive alternative for persons who have not found standard exercise modalities appealing.

Methods: This sub-study within a larger trial examined the effects of 12 weeks of EVGs versus standard exercise (e.g., treadmill, cycling) and a control condition among individuals with elevated HbA1c (100% prediabetic). This study was conducted at a university research lab. Outcomes included HbA1c and weekly minutes of moderate to vigorous physical activity (MVPA) assessed using self-report and accelerometer. Other health risk indices (e.g., lipids) and psychosocial constructs shown to influence exercise participation (e.g., intrinsic motivation) were assessed.

Results: Participants ($n = 84$), averaged age 51.4 years (range 20–79), 80% were female, and 77.4% were non-Hispanic. Baseline HbA1c ranged from 5.7% to 6.4% (39–49 mmol/mol). At week 12, EVG participants demonstrated an average 2% reduction in HbA1c compared to a 0.6% reduction in Standard and Control groups (p's = 0.04 and 0.03). EVG participants engaged in significantly more MVPA than Standard (+17 min/week) and Controls (+54 min/week) (p's < 0.05), had reduced LDL cholesterol ($p = 0.05$) and trends suggesting reduced body fat ($p = 0.10$). EVG participants reported higher exercise enjoyment and motivation compared to other participants.

Conclusions: EVGs may be an attractive and effective tool to improve management of blood glucose that might contribute toward preventing the onset of type 2 diabetes among those with prediabetes.

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https://doi.org/10.1016/j.diabres.2019.06.011
0168-8227/

1. Introduction

The prevalence of type-2 diabetes continues to grow and currently affects 9.4% of U.S. adults affecting over 30 million people [1], and accounts for 90–95% of all diabetes cases. Prediabetes, a condition indicated by hemoglobin A1c (HbA1c) of 5.7–6.4% (39–46 mmol/mol) is associated with increased risk of developing type-2 diabetes. The incidence of prediabetes is also on the rise [1,2]. An estimated 33.9% of U.S. adults aged 18 years or older (84.1 million people), and nearly half (48.3%) of adults aged 65 years and older have prediabetes [1]. Approximately 5–10% of people with prediabetes will develop type-2 diabetes each year [3].

The risk of type-2 diabetes increases with age, obesity and physical inactivity [2]. Risk factors for both diabetes and prediabetes include an elevated body mass index (BMI $\geq$ 25 kg/m^2), physical inactivity, low levels of high-density lipoprotein (HDL) cholesterol and elevated triglycerides [4]. Lifestyle interventions that emphasize changes in diet and increasing regular physical activity are a first-line approach to the treatment of prediabetes and type-2 diabetes [4]. Research data demonstrate that participating in regular physical activity may delay or avoid the progression of prediabetes to type-2 diabetes [5]. Patients who do not respond to lifestyle interventions may need to be considered for pharmacologic and other more invasive medical interventions.

Despite the benefits of physical activity, less than half of American adults, including those with type-2 diabetes and prediabetes engage in regular physical activity [6]. Exercise videogames (EVG) may be a practical, attractive and easily disseminated form of exercise, which may appeal to individuals who have not found traditional forms of physical activity engaging [7,8]. However, there is insufficient research to determine whether EVG play alone is sufficient to engender prolonged engagement in physical activity or make clinically meaningful improvements in HbA1c, lipids or other health indices relevant to reducing the risk of type-2 diabetes.

We recently conducted a randomized clinical trial examining the efficacy of EVGs for promoting and maintaining physical activity and for reducing cardiovascular risk among 285 generally healthy adults [9,10]. Participants were randomized to a program of either EVGs or Standard exercise (e.g., treadmill walking, stationary cycling), or a Control condition. Results showed that median time spent in moderate to vigorous physical activity (MVPA) among EVG participants at end of treatment (EOT) was 85 min/week greater than that of Controls (b = 85.67, 95% CI: 36.97–134.38). Standard exercise participants also engaged in significantly more MVPA at EOT compared to Controls (b = 55.67, 95% CI: 7.66–103.70). Most interesting, EVG participants engaged in significantly more MVPA (+17 min/week) at EOT compared to the Standard exercise condition (b = 30.00, 95% CI: 4.46–64.46). Among EVG (but not Standard) participants, minutes of weekly MVPA remained significantly higher than controls though the six-month follow up (b = 16.00, 95% CI: 0.91–75.91).

While all participants were screened by self-report for no history of type-2 diabetes, 86 individuals who enrolled in that study had elevated HbA1c values at baseline (>5.7%; >39 mmol/mol). The goal of the present study is to examine the effect of EVGs on time spent in MVPA, HbA1c, and other health risk indices among this sample of adults with elevated HbA1c.

2. Methods

2.1. Study design

For this sub-study we analyzed data from 84 participants in the parent trial who had an HbA1c in the prediabetic range (HbA1c 5.7–6.4%; (39–46 mmol/mol).

Detailed methods used in the parent study have been published elsewhere [9]. In brief, individuals who phoned in response to advertisements were screened for eligibility (e.g., generally healthy, age > 18 years, no health conditions that would limit or contraindicate exercise, did not own a video game console). Eligible individuals provided written informed consent and completed assessments at program entry that included objective and self-report measures of physical activity, laboratory testing for physiological (health risk) outcomes (e.g., body composition, fitness testing) and completed survey instruments assessing psychosocial constructs derived from Social Cognitive Theory (SCT) and Self-Determination Theory (SDT). Both SCT and SDT have been widely studied for the promotion of physical activity [11,12]. Research has shown that psychosocial constructs derived from these theories including self-efficacy [13], self-regulation [14], and perceived enjoyment of physical activity [15,16] predict physical activity participation.

Participants were randomly assigned to either: (a) EVGs or (b) Standard exercise; or (c) a Control group that received weekly mailings on general health topics not related to physical activity or diet (e.g., health screenings, sleep hygiene, sun protection, handling 'cold and flu season'). Participants in both EVG and Standard conditions attended exercise sessions in our laboratory (50 min, 3 times weekly for 12 weeks). All exercise sessions were supervised by trained research staff that monitored each participant's heart rate (Polar RS400 monitor) throughout each session to ensure that he/she was engaging in physical activity within their targeted range for moderate-to-vigorous physical activity (MVPA). The target heart rate range for MVPA was calculated using the Karvonen Formula [17].

2.2. Measures

The primary outcome for this sub-study was HbA1c at EOT. Other measures included minutes of MVPA at EOT (Week 12), and through 6-months follow up using the interviewer-administered 7-day Physical Activity Recall (PAR) interview [18,19], and objective (accelerometer) data. The PAR is a reliable well-validated instrument that captures and categorizes time spent in various activities including moderate and vigorous physical activity, sedentary activities and time spent sleeping. Physiological assessments conducted at study enrollment (baseline) and EOT included blood draws for HbA1c and lipid testing (total cholesterol, triglycerides, HDL and LDL). Dual energy X-ray absorptiometry (DXA) was used to assess body composition including muscle, fat, and bone mass measurements collected from whole body and regional areas (e.g., trunk) [20]. Anthropomorphic measures included waist and hip circumference, height and weight (assessed using a calibrated balance beam scale).

Participants completed surveys at baseline, EOT and all follow-ups to assess psychosocial constructs derived from SCT and SDT posited to influence physical activity uptake and continuance. These included the following: The Exercise Motivations Inventory (EMI) [21] which assesses eight types of motivation for exercise from the perspective of SDT (i.e., stress management, revitalization, affiliation, health pressures, ill health avoidance, positive health, strength and endurance and nimbleness), the Behavioral Regulation in Exercise Questionnaire (BREQ-2) [22] was used to assess self-determined motivation in physical exercise. The BREQ-2 contains five subscales (i.e., external, introjected, identified, intrinsic and amotivational). The 12-item Exercise-Induced Feeling Inventory (EFI) was used to assess four distinct feeling states (i.e., Revitalization, Positive engagement, Tranquility and Physical exhaustion) occurring in response to physical activity [23]. Enjoyment of physical activity assessed using the 8-item Physical Activity Enjoyment Scale (PACES) [24], and a 5-item instrument assessing Self-efficacy for physical activity. Dietary patterns were assessed using the Rate Your Plate (RYP) instrument [25], which is a simplified food-frequency questionnaire that focuses on foods contributing to the most fat, saturated fat, and cholesterol to the American diet.

2.3. *Statistical analyses*

Descriptive statistics for the overall study (n = 285) have been presented elsewhere [10]. Using Analysis of Variance (ANOVA) for continuous variables, chi-squared tests for categorical variables and non-parametric tests as appropriate, baseline demographics, physiologic data and measurements were compared between conditions among the sub-sample of participants with elevated HbA1c (n = 84). Any variables not balanced across conditions were included as covariates provided they were correlated with the outcome under consideration (at a modest $p < 0.10$ level).

Unadjusted outcomes are presented by study arm. Using a series of generalized linear models, we tested the association between condition and outcomes at EOT controlling for baseline. Models allow for a flexible distribution of the outcome, as well as adjustment for confounders (including diet). Contrasts were specified so that all pairwise comparisons could be made: EVG vs Standard Exercise, EVG vs Control and Standard Exercise vs. Control. Models use a likelihood-based approach to estimation, and thus included all randomized participants with prediabetes/diabetes, without directly imputing missing outcomes.

As in the parent study, we used Quantile Regression to model physical activity outcomes, as the median is a better measure of central tendency when outcomes are skewed (as is the case with min/week of MVPA). Models included condition (specified with contrasts to allow for pairwise comparisons) and adjusted for baseline value. All analyses were carried out in SAS 9.3 with alpha set at 0.05 (except where otherwise specified).

3. Results

An equivalent allocation of participants was randomized to each treatment condition (n = 27, 28 and 29 in EVG, Standard and Control, respectively). Participants averaged 51.4 years of age (SD = 11.5, range 20–79), 79% were female, and 77.4% were non-Hispanic white. A full description of the baseline characteristics of this sample is presented in Table 1. There were no significant differences in baseline variables between

Table 1 – Sample Characteristics.

Variable	Control (n = 29)	Standard (n = 28)	EVG (n = 27)	All (n = 84)
Age in years, mean (SD)	52.0 (9.1)	52.3 (13.5)	49.3 (11.2)	51.4 (11.5)
Gender, % female	26 (89%)	19 (70%)	21 (78%)	66 (80%)
Employed, % yes	20 (74%)	20 (71%)	19 (73%)	59 (73%)
Marital Status, % married/partnered	17 (65%)	18 (69%)	15 (56%)	50 (63%)
Education, % at least some college	22 (85%)	23 (88%)	22 (81%)	67 (85%)
Ethnicity, % Hispanic	2 (10%)	1 (4%)	2 (9%)	5 (7%)
Race, % White	24 (83%)	25 (89%)	21 (78%)	70 (83%)
Waist Circumference	96.9 (13.3)	99.1 (14.9)	98.4 (12.9)	98.1 (13.6)
Hip Circumference	111.1 (12.2)	109.6 (11.6)	111.9 (10.8)	110.9 (11.5)
LDL Cholesterol	134.3 (38.4)	147.1 (34.1)	138.3 (54.3)	139.8 (42.7)
HDL Cholesterol	58.2 (15.6)	54.3 (11.7)	57.7 (17.7)	56.7 (15.1)
Triglycerides	109.6 (54.8)	128.6 (70.3)	127.3 (93.6)	121.6 (73.8)
MVPA min/week	Median = 0	Median = 40	Median = 30	Median = 32.5
	Range 0–420	Range 0–310	Range 0–220	Range 0–420
HbA1c % (mmol/mol)	Mean = 5.9 (0.14)	Mean = 5.9 (0.20)	Mean = 5.8 (0.23)	Mean = 5.9 (39)
Range	Range 5.7–6.1	Range 5.7–6.4	Range 5.7–6.6	Range 5.7–6.4

Abbreviations: EVG, exercise video games; MVPA, moderate to vigorous physical activity; Data are presented as mean (SD), n (%) or median with interquartile range.
There were no significant between-group differences at baseline (p's > 0.05).

Table 2 – Adjusted Effects of Condition on Physical Activity, Physiological and Psychosocial Outcomes.

	EVG vs Control	Standard vs Control	EVG vs Standard
HbA1c at EOT[1]	−0.16 (0.06)*	0.04 (0.08)	−0.15 (0.06)*
MVPA at EOT	54 (44.75)*	40 (45.01)*	17 (3.21) *
Total cholesterol	−11.19 (8.63)T	−12.63 (8.53)T	1.45 (7.39)
LDL	−20.09 (10.04) *	−10.97 (10.84)	−9.12 (9.37)
HDL	−1.86 (2.51)	−1.45 (2.48)	−0.41 (2.18)
Triglycerides	−12.19 (14.52)	−0.25 (14.43)	−11.94 (12.52)
Body fat (total)	−1.19 (0.81)T	0.20 (0.86)	−0.62 (0.78)
Body fat (trunk)	−1.42 (1.00)T	−0.33 (1.08)	−0.76 (0.99)
Enjoyment of exercise	6.04 (3.26)*	1.61 (3.33)	4.43 (2.79)T
Regulation	−0.07 (0.20)*	0.11 (0.20) *	−0.18 (0.17)
Engagement	1.39 (0.80)*	1.59 (0.80) *	−0.22 (0.69)
Self-efficacy	0.25 (0.24)	0.28 (0.24)	−0.03 (0.21)
Motivation (Stress Management)	1.22 (1.03)	−0.01 (1.02)	1.21 (0.87)T
Waist circumference	− 5.35 (3.10)	− 3.03 (3.04)	−2.32 (2.73)
Weight	−6.34 (3.77)T	0.38 (3.84)	−6.71 (3.48)T

Abbreviations: EOT, end of treatment; MVPA, moderate to vigorous physical activity; LDL, low density lipoprotein; HDL, high density lipoprotein.
Effects are unstandardized regression coefficients (SE's).
[1] Mean difference in HbA1c between groups at end of treatment.
* $p < 0.05$.
T $p = 0.10$.

conditions (p's > 0.05). EVG participants attended an average of 26.31 (73.1%) Sessions over 12 weeks (SD = 7.88) and Standard participants attended an average of 27.54 (76.5%) sessions (SD = 8.30), with no significant between-group differences.

EVG participants had significant reductions in HbA1c by EOT compared to Controls (b = −0.16, SD = 0.06, p = 0.04) and compared to Standard participants (b = −0.15, SD = 0.06, p = 0.03). Specifically, EVG participants had a 2% reduction in HbA1c on average by EOT compared to 0.6% reduction in both Standard and Control groups (p's = 0.04 and 0.03). There was no significant difference in HbA1c between Standard and Controls (p = 0.62). No interaction was observed between initial HbA1c at baseline and the effect of intervention on HbA1c level at EOT. At baseline 100% of participants in this study had A1c ≥ 5.7. At EOT, 70.3% of participants had A1c ≥ 5.7 (29.7% had A1c levels below 5.7). Analyses of randomization groups showed that 50.0% of EVG, 20.8% of SE and 12.5% of Controls had A1c below 5.7 at EOT (Table 3).

3.1. *Physical activity*

The pattern of findings with respect to MVPA outcomes was similar in this sub-sample of participants with elevated HbA1c as with the larger sample in the parent study [10]. Within this sub-sample, here was no significant difference in exercise intensity during the 12-week intervention. During supervised exercise sessions, median heart rate was 111 bpm in the EVG group (inter quartile range = 31) and 106 bpm (inter quartile range = 30) for Standard exercise. EVG participants engaged in significantly more min/week of MVPA at EOT compared to both Standard (+17 min) and controls (+54 min), with Standard also outperforming controls at EOT (+40 min/week). At six months, EVG participants had significantly greater median min/week of MVPA compared to Control (b = 16.00, 95% CI: 0.92–75.91). There was no difference in MVPA at six months between Standard and Control and a trend for EVG vs. Standard (b = 8.31, 95% CI: −7.80–64.43). Objective data obtained from accelerometry was significantly correlated with MVPA data obtained using the PAR at baseline and EOT, though not significant at 6-month follow-up (rho = 0.29, p = 0.03 at baseline, rho = 0.41, p = 0.02 at EOT, rho = 0.22, p = 0.32 at 6-month follow-up).

3.2. *Other health risk indices*

EVG participants had significantly lower levels of LDL cholesterol at EOT compared to Control (p = 0.05, b = -20.09, SE = 10.04). There was no difference for comparisons of Standard vs Control (p = 0.32), or EVG vs Standard (p = 0.33). Results also indicated a trend for differences in total cholesterol

Table 3 – Percent of participants in each randomization group with HbA1c Levels in the normal or prediabetic range, at baseline and end of treatment (EOT).

HbA1c	EVG (n = 27)		Standard (n = 28)		Control (n = 29)	
	Baseline	EOT	Baseline	EOT	Baseline	EOT
<5.7	0	50%	0	20.8	0	12.5
5.7–6.4	100	50%	96.4	79.2	100	87.5

between EVG vs Control and for Standard vs. Control (p's = 0.10), with lower total cholesterol at EOT for both EVG and Standard compared to Controls (b's = −11.19, SE = 8.63 and −12.63, SE = 8.53, respectively). Total cholesterol did not differ significantly between EVG and Standard (p = 0.85). There were no significant differences in HDL, triglycerides, or waist and hip circumference between groups (p's > 0.15). Finally, data suggested a trend favoring EVG over Control for lower percent trunk fat at EOT (b = −1.42, SE = 1.00, p = 0.10) and total body fat at EOT (b = −1.19, SE = 0.81, p = 0.10). No significant differences were noted for Standard vs. Control or for EVG vs Standard (p's > 0.15) in total or trunk fat. Finally, there were no significant differences between conditions on dietary patterns (RYP), weight or BMI (p's > 0.15), although a trend favoring EVG on weight loss compared to Standard (p = 0.06) and Control (p = 0.10). These data are presented in Table 2.

3.3. *Psychosocial factors*

EVG participants had significantly greater exercise enjoyment (PACES) scores at EOT vs Control (b = 6.04, SE = 3.26, p = 0.05), and a trend for higher enjoyment scores compared to Standard (b = 4.43, SE = 2.79, p = 0.10). There were no differences in exercise enjoyment between Standard vs Control (p = 0.63). Measures of motivation showed significantly higher intrinsic regulation (BREQ) scores at EOT in the EVG group vs Control (b = 0.65, SE = 0.23, p = 0.01) and Standard vs Control (b = 0.61, SE = 0.09, p < 0.001), as well as higher positive engagement (EMI) in EVG vs Control (b = 1.39, SE = 0.80, p = 0.05) and Standard vs Control (b = 1.59, SE = 0.80, p = 0.05). There were no significant differences between EVG and Standard (p = 0.76) conditions in positive engagement. Data suggested a trend toward higher scores on exercise for stress management (EMI) at EOT among EVG vs Standard participants (b = 1.21, SE = 0.87, p = 0.10). No significant differences in exercise self-efficacy were observed between groups. A full description of group effects on each the physical activity, physiological and psychosocial outcomes at EOT are presented in Table 2.

4. Discussion

To our knowledge this is the first randomized clinical trial to demonstrate greater improvements in HbA1c among adults using EVGs compared to Standard exercise modalities and Controls. In this study we observed a significant reduction in HbA1c among those using EVGs compared to both a no-intervention control and a standard exercise condition. Only one previous study has examined changes in HbA1c among those using EVGs [26]. In that study, adults diagnosed with type-2 diabetes showed significant within-subject (pre-post) improvements in physical activity participation, body mass index and HbA1c (−0.3%) after 12 weeks of home use of the Wii Fit Plus. In the present study a comparatively larger (−2%) reduction in HbA1c was observed among EVG participants versus Standard exercise and Control groups (both −0.6%), and a significantly larger proportion of those randomized to EVG had normal levels of HbA1c (i.e., <5.7) compared to either standard exercise or controls.

Lifestyle interventions that focus on weight loss, dietary changes and physical activity are recommended by the American Diabetes Association as the first line of treatment to prevent or delay the onset of type-2 diabetes [4]. Engaging in regular physical activity has demonstrable beneficial outcomes for adults with type-2 diabetes [28–30] and those in prediabetes [31] including improved weight loss, increased fitness, reduced medication usage and improvements in HbA1c/fasting glucose. Although no diet or weight loss intervention was included in the current study, results of this study suggest that improvements in the cholesterol profile can be achieved despite minimal to no weight loss.

Studies of interventions to prevent the onset of type-2 diabetes have been less clear regarding the effects of exercise alone. A recent systematic review of studies among adults who were at high risk for diabetes onset due to impaired glucose tolerance indicated that interventions that combine physical activity and diet can significantly delay or reduce the onset of type-2 diabetes [32]. In preventing diabetes onset, such lifestyle interventions compare well with pharmacotherapies. Indeed, interventions that combine physical activity and weight loss have been shown to reduce the risk of developing diabetes by 58% versus metformin which reduced the risk by 31% [33]. More importantly, in this study increased physical activity by way of EVGs was able to achieve results similar to pharmacotherapy without the side effects associated with the anti-diabetes medications [34]. EVGs also appear to be more enjoyable and thus, perhaps more sustainable than standard forms of physical activity. Given that the current evidence is still lacking to support physical activity alone as a method to prevent diabetes onset [32], this study builds on previous trials to support physical activity through EVGs as a safe method to significantly lower glycaemia in individuals with abnormal HbA1c levels.

The present study used rigorous methods including supervised laboratory exercise sessions, continuous heart rate monitoring during sessions and physical activity assessments that included an interviewer-administered self-report measure and objective accelerometry. Both EVG and Standard groups attended the same number of lab exercise sessions for the same duration. Thus, differences between these groups in weekly MVPA minutes measured at EOT are reflective of physical activity performed outside the lab, suggesting that EVG participation may generalize to encourage uptake of other forms of physical activity in addition to playing EVGs (since participants did not have an exercise video game console at home during the 12-week intervention). This may in part be explained by the increased levels of enjoyment of physical activity (PACES) and stress management (EMI) that were seen among those randomized to EVGs compared to Standard exercise and controls. Individuals randomized to EVG also showed significantly higher Intrinsic regulation (BREQ-2) and Positive engagement (EFI) compared to controls. These constructs are derived from Self-Determination Theory (SDT) and have been widely studied in the promotion of physical activity [11,12] and may provide a foundation for understanding the role of EVGs in physical activity SDT proposes that people are likely to persist in a behavior that satisfies psychological needs such as autonomy and competence

[35–37] resulting in increased intrinsic motivation, which in turn is posited to produce more dedication to goal attainment and to maintaining behavior over time. Studies have shown that enjoyment of physical activity [15,16] is predictive of greater physical activity participation [38]. Research on non-active video games indicates that perceived in-game competence and autonomy predict game enjoyment, preferences, duration of play, and post-play feelings of well-being [39]. The effects seen in this study of EVGs on these constructs may help to explain the greater participation in MVPA seen among participants randomized to EVGs which, in turn, may have affected outcomes such as reductions in HbA1c, body fat and other risk factors.

4.1. *Limitations*

An important limitation of this study was that it was not designed to effect change on HbA1c specifically, and therefore the sample size was smaller, the analyses were not powered appropriately, and confounding variables were not necessarily included (as noted above). Regardless, stunning significant change was demonstrated.

Second, the exercise conditions in this study were conducted in supervised laboratory conditions. We therefore cannot determine whether compliance with recommended levels of exercise would be seen if EVGs were used solely in the home environment. The study by Kempf and Martin [26] reported less MVPA among their participants in a home-use protocol than was seen in the present study. Supervised, controlled exercise intervention studies are effective in preventing the onset of type 2 diabetes [40], however, long term adherence to exercise remains problematic [31]. There is a need to identify effective approaches to enhancing adherence to long-term lifestyle changes including exercise, particularly among sedentary individuals and those at elevated risk for metabolic disorders including diabetes and prediabetes.

Third, this study did not include an extended follow up. Studies of diabetes prevention often follow participants for two years or longer [41]. In the present study participants were assessed for MVPA for 6 months following the end of treatment. While EVG participants continued to engage in more MVPA than those in the Standard and control arms during the 6-month follow up, overall MVPA levels dropped and it is unclear whether the lower amounts of MVPA seen at follow up would have continued to impact HbA1c significantly.

Fourth, there was a limited range of HbA1c values in this study. HbA1c values represented primarily levels below the diagnostic threshold for type-2 diabetes (6.5 mg/dl). Nearly all participants (97.6%) had HbA1c values in the pre-diabetic range (5.7–6.4 mg/dl). A *meta*-analysis examining the efficacy of pharmacologic therapies found the degree of reduction in HbA1c is higher with higher levels of HbA1c at baseline [27]. However, similar work has not been done with physical activity interventions in those with prediabetes. Thus, it is not known whether EVGs may prove more or less effective in reducing HbA1c among those with higher HbA1c levels than were seen in this trial.

Finally, this study did not include comprehensive measures of glucose metabolism. We did not assess fasting blood glucose, glucose tolerance or assays of insulin resistance. However, HbA1c is the best indicator of overall glycemic control [42] as it is the best measure of chronic glycaemia, more closely associated with risk of complications, and less biologic variability than glucose-based tests.

4.2. *Conclusions*

When used under supervised laboratory conditions, a 12-week program of EVGs outperformed standard exercise and controls for reductions in HbA1c in individuals with HbA1c levels in the prediabetes to diabetes range. Results of this study indicate that when used in this laboratory setting, EVGs compare well with the effects of pharmacotherapies and lifestyle interventions for their effects on HbA1c. Additional long-term studies are needed to verify the efficacy of supervised exercise training sessions versus broader lifestyle interventions regarding their ability to prevent the onset of diabetes in people with prediabetes and to examine the relative cost effectiveness.

Contributions

BCB led the research and wrote the manuscript. SID performed data analysis and wrote the manuscript. ERS contributed to the discussion. ERS, WW, JTC, RL and BHM reviewed and edited the manuscript.

Funding

This study was funded through a grant from the National Institutes of Health, National Heart, Lung and Blood Institute to Dr. Bock (R01 HL 109116).

Declaration of Competing Interest

All authors have no competing conflicts of interest to declare.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.diabres.2019.06.011.

REFERENCES

[1] Center for Disease Control and Prevention. National Diabetes Statistics Report, 2017. Atlanta, GA: Centers for Disease Control and Prevention, U.S. Dept of Health and Human Services, 2017.
[2] American Diabetes Association. Classification and diagnosis of diabetes. Sec. In Standards of Medical Care in Diabetes – 2018. Diabetes Care. 2018; 41(Suppl. 1):S13-S27. https://doi.org/10.2337/dc18-S002.
[3] Forouhi NG, Luan J, Hennings S, Wareham NJ. Incidence of Type 2 diabetes in England and its association with baseline impaired fasting glucose: the Ely study 1990–2000. Diabet Med 2007;24(2):200–7. https://doi.org/10.1111/j.1464-5491.2007.02068.x.

[4] Aschner PM, Munoz OM, Giron D, Garcia OM, Fernandez-Avila DG, Casas LA, et al. Clinical practice guideline for the prevention, early detection, diagnosis, management and follow up of type 2 diabetes mellitus in adults. Colomb Med (Cali) 2016;47(2):109–31.
[5] Jadhav RA, Hazari A, Monterio A, Kumar S, Maiya AG. Effect of physical activity intervention in prediabetes: a systematic review with meta-analysis. J Phys Act Health 2017;14 (9):745–55. https://doi.org/10.1123/jpah.2016-0632.
[6] Morrato EH, Hill JO, Wyatt HR, Ghushchyan V, Sullivan PW. Physical activity in U.S. adults with diabetes and at risk for developing diabetes, 2003. Diabetes Care 2007;30(2):203–9. https://doi.org/10.2337/dc06-1128.
[7] Serber ER, Ciccolo J, Palmer K, Cobb V, Tilkemeier PL, Bock BC. The feasibility of exercise videogames for cardiovascular risk reduction among adults: a pilot for" Wii heart fitness". J Sports Med Phys Fitness 2016;56(3):319–27.
[8] Street TD, Lacey SJ, Langdon RR. Gaming your way to health: a systematic review of exergaming programs to increase health and exercise behaviors in adults. Games Health J 2017;6(3):136–46. https://doi.org/10.1089/g4h.2016.0102.
[9] Bock BC, Thind H, Dunsiger SI, Serber ER, Ciccolo JT, Cobb V, et al. Exercise videogames for physical activity and fitness: design and rationale of the Wii Heart Fitness trial. Contemp Clin Trials 2015;42:204–12. https://doi.org/10.1016/j.cct.2015.04.007.
[10] Bock BC, Dunsiger S, Ciccolo JT, Serber ER, Wu WC, Tilkemeier P, et al. Exercise videogames improve physical activity participation and indices of health risk in the Wii Heart Fitness trial: A randomized clinical trial. Am J Prev Med. in press.
[11] Dewar DL, Morgan PJ, Plotnikoff RC, Okely AD, Batterham M, Lubans DR. Exploring changes in physical activity, sedentary behaviors and hypothesized mediators in the NEAT girls group randomized controlled trial. J Sci Med Sport 2014;17 (1):39–46. https://doi.org/10.1016/j.jsams.2013.02.003.
[12] Short CE, James EL, Plotnikoff RC. Theory-and evidence-based development and process evaluation of the Move More for Life program: a tailored-print intervention designed to promote physical activity among post-treatment breast cancer survivors. Int J Behav Nutri Phys Activity 2013:10124. https://doi.org/10.1186/1479-5868-10-124.
[13] McAuley E, Blissmer B. Self-efficacy determinants and consequences of physical activity. Exerc Sport Sci Rev 2000;28 (2):85–8.
[14] Conn VS, Valentine JC, Cooper HM. Interventions to increase physical activity among aging adults: a meta-analysis. Ann Behav Med 2002;24(3):190–200. https://doi.org/10.1207/S15324796ABM2403_04.
[15] Salmon J, Owen N, Crawford D, Bauman A, Sallis JF. Physical activity and sedentary behavior: a population-based study of barriers, enjoyment, and preference. Health Psychol 2003;22 (2):178–88. https://doi.org/10.1037/0278-6133.22.2.178.
[16] Williams DM, Papandonatos GD, Napolitano MA, Lewis BA, Whiteley JA, Marcus BH. Perceived enjoyment moderates the efficacy of an individually tailored physical activity intervention. J Sport Exerc Psychol 2006;28(3):300–9. https://doi.org/10.1123/jsep.28.3.300.
[17] Karvonen MJ. The effects of training on heart rate: a longitudinal study. Ann Med Exp Biol Fenn 1957;35:307–15.
[18] Blair SN, Haskell WL, Ho P, Paffenbarger Jr RS, Vranizan KM, Farquhar JW, et al. Assessment of habitual physical activity by a seven-day recall in a community survey and controlled experiments. Am J Epidemiol 1985;122(5):794–804. https://doi.org/10.1093/oxfordjournals.aje.a114163.
[19] Sallis JF, Haskell WL, Wood PD, Fortmann SP, Rogers T, Blair SN, et al. Physical activity assessment methodology in the five-city project. Am J Epidemiol 1985;121(1):91–106. https://doi.org/10.1093/oxfordjournals.aje.a113987.
[20] Andreoli A, Scalzo G, Masala S, Tarantino U, Guglielmi G. Body composition assessment by dual-energy X-ray absorptiometry (DXA). Radiol Med 2009;114(2):286–300. https://doi.org/10.1007/s11547-009-0369-7.
[21] Markland D, Ingledew DK. The measurement of exercise motives: factorial validity and invariance across gender of a revised exercise motivations inventory. Br J Health Psychol 1997;2(4):361–76. https://doi.org/10.1111/j.2044-8287.1997.tb00549.x.
[22] Markland D, Tobin V. A modification to the behavioural regulation in exercise questionnaire to include an assessment of amotivation. J Sport Exerc Psychol 2004;26 (2):191–6. https://doi.org/10.1123/jsep.26.2.191.
[23] Gauvin L, Rejeski WJ. The exercise-induced feeling inventory: development and initial validation. J Sport Exerc Psychol 1993;15(4):403–23. https://doi.org/10.1123/jsep.15.4.403.
[24] Kendzierski D, DeCarlo KJ. Physical activity enjoyment scale: two validation studies. J Sport Exerc Psychol 1991;13(1):50–64. https://doi.org/10.1123/jsep.13.1.50.
[25] Gans KM, Hixson ML, Eaton CB, Lasater TM. Rate your plate: a dietary assessment and educational tool for blood cholesterol control. Nutr Clin Care 2000;3(3):163–9.
[26] Kempf K, Martin S. Autonomous exercise game use improves metabolic control and quality of life in type 2 diabetes patients - a randomized controlled trial. BMC Endocr Disord 2013;13:57. https://doi.org/10.1186/1472-6823-13-57.
[27] Sherifali D, Nerenberg K, Pullenayegum E, Cheng JE, Gerstein HC. The effect of oral antidiabetic agents on A1C levels: a systematic review and meta-analysis. Diabetes Care 2010;33 (8):1859–64. https://doi.org/10.2337/dc09-1727.
[28] Sigal RJ, Kenny GP, Boule NG, Wells GA, Prud'homme D, Fortier M, et al. Effects of aerobic training, resistance training, or both on glycemic control in type 2 diabetes: a randomized trial. Ann Intern Med 2007;147(6):357–69.
[29] Plotnikoff RC, Costigan SA, Karunamuni ND, Lubans DR. Community-based physical activity interventions for treatment of type 2 diabetes: a systematic review with meta-analysis. Front Endocrinol (Lausanne) 2013;4:3. https://doi.org/10.3389/fendo.2013.00003.
[30] Church TS, Blair SN, Cocreham S, Johannsen N, Johnson W, Kramer K, et al. Effects of aerobic and resistance training on hemoglobin A1c levels in patients with type 2 diabetes: a randomized controlled trial. JAMA 2010;304(20):2253–62. https://doi.org/10.1001/jama.2010.1710.
[31] Kerrison G, Gillis RB, Jiwani SI, Alzahrani Q, Kok S, Harding SE, et al. The effectiveness of lifestyle adaptation for the prevention of prediabetes in adults: a systematic review. J Diabetes Res 2017;2017:8493145. https://doi.org/10.1155/2017/8493145.
[32] Hemmingsen B, Gimenez-Perez G, Mauricio D, Roque IFM, Metzendorf MI, Richter B. Diet, physical activity or both for prevention or delay of type 2 diabetes mellitus and its associated complications in people at increased risk of developing type 2 diabetes mellitus. Cochrane Database Syst Rev 2017;12:CD003054. https://doi.org/10.1002/14651858.CD003054.pub4.
[33] Knowler WC, Barrett-Connor E, Fowler SE, Hamman RF, Lachin JM, Walker EA, et al. Reduction in the incidence of type 2 diabetes with lifestyle intervention or metformin. N Engl J Med 2002;346(6):393–403. https://doi.org/10.1056/NEJMoa012512.
[34] Ali S, Fonseca V. Overview of metformin: special focus on metformin extended release. Expert Opin Pharmacother 2012;13(12):1797–805. https://doi.org/10.1517/14656566.2012.705829.

[35] Deci EL, Ryan RM. The "what" and "why" of goal pursuits: human needs and the self-determination of behavior. Psychol Inq 2000;11(4):227–68. https://doi.org/10.1207/S15327965PLI1104_01.
[36] Deci EL, Ryan RM. Handbook of self-determination research. Rochester, NY: University Rochester Press; 2002.
[37] Ryan R, Frederick C, Lepes D, Rubio N, Sheldon K. Intrinsic motivation and exercise adherence. Int J Sport Psychol 1997;28(4):335–54.
[38] Lewis BA, Williams DM, Frayeh AL, Marcus BH. Self-efficacy versus perceived enjoyment as predictors of physical activity behavior. Psychol Health 2016;31(4):456–69. https://doi.org/10.1080/08870446.2015.1111372.
[39] Ryan RM, Rigby CS, Przybylski A. The motivational pull of video games: a self-determination theory approach. Motiv Emot 2006;30(4):344–60. https://doi.org/10.1007/s11031-006-9051-8.
[40] Boniol M, Dragomir M, Autier P, Boyle P. Physical activity and change in fasting glucose and HbA1c: a quantitative meta-analysis of randomized trials. Acta Diabetol 2017;54(11):983–91. https://doi.org/10.1007/s00592-017-1037-3.
[41] Barnett AH. Long-term glycemic control in patients with diabetes? US Endocrinol 2006;2(2):1–7. Available from: https://doi.org/10.17925/USE.2006.00.02.1h.
[42] Nathan DM. Diabetes: advances in diagnosis and treatment. JAMA 2015;314(10):1052–62. https://doi.org/10.1001/jama.2015.9536.