Multiple short bouts of exercise are better than a single continuous bout for cardiometabolic health: a randomised crossover trial

Philip Shambrook1 · Michael I. Kingsley1,2 · Nicholas F. Taylor3 · Daniel W. Wundersitz1 · Claire E. Wundersitz4 · Brett A. Gordon1

Received: 27 April 2020/Accepted: 4 August 2020/Published online: 9 August 2020
© Springer-Verlag GmbH Germany, part of Springer Nature 2020

Abstract

Purpose To compare cardiometabolic responses to five consecutive days of daily postprandial exercise accumulated in three 10-min bouts or a single 30-min bout to a no-exercise control.

Methods Ten insufficiently active adults completed three trials in a randomised order. Each trial comprised five consecutive days of 30 min of exercise either accumulated in three separate 10-min bouts (ACC) after main meals; a single 30-min bout after dinner (CONT); or a no-exercise control (NOEX). Glucose regulation was assessed from an oral glucose tolerance test. Applanation tonometry was used to assess pulse wave velocity approximately 12 h following completion of the final trial.

Results Area under the 2-h glucose curve was similar for CONT (mean; 95% CI 917 mmol L−1 2 h−1; 815 to 1019) and ACC (931 mmol L−1 2 h−1; 794 to 1068, p = 0.671). Area under the 2-h insulin curve was greater following NOEX (70,328 pmol L−1 2 h−1; 30,962 to 109,693) than ACC (51,313 pmol L−1 2 h−1; 21,822 to 80,806, p = 0.007). Pulse wave velocity was lower for ACC (5.96 m s−1; 5.38 to 6.53) compared to CONT (6.93 m s−1; 5.92 to 7.94, p = 0.031) but not significantly lower for ACC compared to NOEX (6.52 m s−1; 5.70 to 7.34, p = 0.151).

Conclusion Accumulating 30 min of moderate-intensity walking in three bouts throughout the day is more effective at reducing markers of cardiometabolic health risk in insufficiently active, apparently healthy adults than a single daily bout. Both accumulated and single-bout walking were equally as effective at reducing postprandial glucose concentrations compared to a no-exercise control. Therefore, accumulating exercise in short bouts after each main meal might be more advantageous for overall cardiometabolic health.

Keywords Glycaemic regulation · Physical activity · Accumulated exercise · Vascular compliance · Postprandial · Insulin

Abbreviations

ACC Accumulated exercise
ANOVA Analysis of variance
AUC Area under the curve
CAVI Cardio-ankle vascular index
CONT Continuous exercise
ECG Electrocardiograph
HbA1c Glycated haemoglobin
Hg Mercury
HRR Heart rate reserve
HRV Heart rate variability
MD Mean Difference
mmol L−1 Millimol per litre
NCD Noncommunicable disease
NOEX No exercise
pmol L−1 Picamol per litre
PWV Pulse wave velocity
T2DM Type 2 diabetes mellitus
VO2peak Peak volume of oxygen consumed

Communicated by Philip D. Chilibeck.
Introduction

Insufficient physical activity is a well-established risk factor for the development of noncommunicable diseases (NCD) including cardiovascular disease and type 2 diabetes (World Health Organization 2018). Furthermore, known factors that increase the risk of NCDs such as obesity and hypertension are more likely to occur in people with low levels of physical activity participation (World Health Organization 2018). International physical activity guidelines have long advocated that individuals undertake regular exercise for health and fitness, yet worldwide up to 40% of adults fail to achieve recommended amounts of physical activity (World Health Organization 2018). Guidelines around the world, including the US and Australia, suggest that adults can accumulate the recommended amount of physical activity for health in multiple short bouts throughout the day (Piercy et al. 2018; Australian Government Department of Health 2014). Accumulating exercise might be an effective strategy for overcoming the most frequently stated reason for being insufficiently active, lack of time (Netz et al. 2008). Therefore, the notion that exercise can be accumulated in multiple short bouts for health and fitness is intuitively appealing.

Previous research comparing the effects of accumulating aerobic exercise in multiple short bouts throughout the day to a single bout once daily differ in their approach with respect to the number, intensity and duration of the bouts. In a 24-week study involving 134 healthy, sedentary postmenopausal women the mean blood glucose declined more in the group undertaking two 15-min bouts of walking than a group undertaking a single 30-min bout without any statistically significant changes in fasting plasma insulin or the 2-h insulin following a glucose tolerance test (Asikainen et al. 2003). Similarly, in a study involving women with type 2 diabetes mellitus (T2DM) Baynard et al. (2005) reported that a single day of 30 min of aerobic exercise undertaken as either a single bout or three 10-min bouts did not differentially alter glucose control following an oral glucose tolerance test (OGTT). However, when studying nine people (seven male, two female) with insulin resistance, six 1-min work bouts of treadmill walking at 90% $HR_{\text{max}}$ with 1 min recovery were reported to be as effective as a single 30-min moderate-intensity bout at lowering glucose (Francois et al. 2014). Both Pahra et al. (2017) and Reynolds et al. (2016) concluded that accumulating exercise was more beneficial for measures of glucose regulation in participants with T2DM when the total amount (45 min and 30 min, respectively) was completed in three separate bouts as opposed to one continuous bout, however it was unclear whether the intensity of each condition was matched. While exercise is widely accepted as a means to improve cardiometabolic health including glucose control and regulation, it has not yet been determined if accumulating exercise in multiple short bouts throughout the day is more or less beneficial than a single bout undertaken once daily.

There is also yet to be consensus for when exercise should be completed in relation to a meal. Exercise in a fasted state has been suggested to reduce the lipaemic response to a meal while postprandial exercise reduces the glycaemic response to a meal (Haxhi et al. 2012). In the limited investigations of accumulated and single-bout exercise, both postprandial (Dipietro et al. 2013) and preprandial (Francois et al. 2014) exercise has been conducted with similar outcomes reported. However, the glycaemic response is likely to be transient with pre-breakfast exercise having no influence on postprandial glucose concentrations following lunch and minimal influence on postprandial glucose response to dinner (Francois et al. 2014). This supports earlier research suggesting that 45 min of moderate-intensity exercise initiated 45 min after consuming breakfast was effective at reducing glucose and insulin concentrations following breakfast but the effect did not persist following the lunch meal in adults with T2DM (Larsen et al. 1997). There is evidence to suggest that walking after an evening meal lowers blood glucose concentrations more than walking before the evening meal in adults with T2DM (Colberg et al. 2009). Therefore, to maximise glycaemic responses and to minimise differences associated with transient responses to exercise completed at different times of day, investigations of accumulated and single-bout aerobic exercise might be better conducted with the single-bout completed after the evening meal on the same day.

Poor glycaemic control and regulation adversely affect heart rate variability (HRV) and pulse wave velocity (PWV: Benichou et al. 2018; Jarczok et al. 2013; Pober et al. 2004; Salomaa et al. 1995; Ashor et al. 2014). Pulse wave velocity, a surrogate measure of arterial stiffness (Van Bortel et al. 2012) was reported to be improved following aerobic exercise, with further improvements obtained at higher intensity (Ashor et al. 2014). Furthermore, Salomaa et al. (1995) reported that elevated insulin and glucose concentrations were negatively associated with arterial stiffness in a cross-sectional study involving over 4700 men and women aged 45 to 64 years. Similarly, Zheng et al. (2015) reported 30 min of aerobic moderate-intensity exercise completed as a single bout and accumulated through two 15-min bouts, with either 20 min or 60 min between bouts, reduced arterial stiffness amongst healthy young men. Exercise might be an effective intervention to reduce the negative effects of glycaemic dysfunction on HRV and PWV. Pober et al. (2004) reported that 60 min of continuous aerobic cycling improved cardiac autonomic function in healthy male volunteers.

Although the benefits of exercise on cardiometabolic health have been confirmed, there has been no agreement...
on how exercise should be prescribed (Shambrook et al. 2018; Oja et al. 2018) or whether exercise should be accumulated in multiple bouts throughout the day or completed as a single-continuous bout of equal duration. Therefore the primary aim of this study was to compare the glycaemic and cardiovascular responses to 5 days of 30 min of daily aerobic exercise accumulated in three 10-min bouts after breakfast, lunch, and dinner, with a single 30-min bout after dinner, and a no-exercise control in apparently healthy adults who did not meet current activity guidelines (Australian Government Department of Health 2014; Piercy et al. 2018). A secondary aim was to investigate whether participants preferred exercise completed in multiple short bouts or as a single bout.

Method

Individuals were recruited to participate in this three-arm randomised controlled, cross-over trial. Adults aged 18 to 65 years were recruited through social media, posters on community noticeboards, and word-of-mouth. Participants were eligible to take part in the study if they were not meeting current physical activity recommendations (Piercy et al. 2018), were free from any diagnosed cardiometabolic disorder, not taking any medication for cardiac or glycaemic disorders, and had no contraindications to walking. Prospective participants were sent information about the study along with a seven-day food diary to be completed before pre-screening and baseline assessment. Participants provided written informed consent before any measures were collected. The study was approved by the La Trobe University Human Ethics Committee (HEC 15-034) and conducted in accordance with the Declaration of Helsinki.

A random number generator (www.randomization.com) was used to generate a block-randomised trial order; the outcomes of which were placed in sealed opaque envelopes. The trial order was revealed to the participant and researchers on successful completion of pre-screening and baseline assessment. It was not possible to blind the participants or experimenters to the trial.

Sample size estimates were based on published data for glucose AUC from a study using similar exercise trials (Baynard et al. 2005). A priori power analysis using GPower 3.1 (Heinrich-Heine University, Dusseldorf, Germany) calculated that a sample size of 10 was sufficient to determine a medium effect (partial eta² 0.06–0.13) for a three-group repeated measures trial with a power of 0.80 and alpha level of 0.05.

Pre-screening and baseline assessment were conducted during two separate laboratory visits. On the first visit, participants attended following an overnight fast and having abstained from any exercise for 48 h. An Adult Pre-exercise Screening Tool (Exercise and Sport Science Australia et al. 2011) was used for health screening and risk stratification. Leisure-time physical activity was assessed using the long-form International Physical Activity Questionnaire (IPAQ Group 2010). Blood samples were collected from an antecubital vein to determine blood lipids, glycated haemoglobin (HbA1c), fasting plasma glucose, and fasting serum insulin. Baseline measurements of stature (Portable Stadiometer; Holtain, Wales), body mass (Model 770 1321004; Seca GmbH & Co., Germany), and waist and hip girths were recorded. Participants unfamiliar with using a motorised treadmill were familiarised with this equipment.

On the second visit, participants were fitted with a 12-lead electrocardiograph (ECG; Cardiovit CS-200 Touch; Schiller AG, Baar, Switzerland) to monitor heart rate and rhythm during a graded exercise test. Participants undertook the Balke-Ware graded exercise test (Pescatello et al. 2013) to volitional exhaustion to determine VO_{2peak}. Respiratory gases were collected and analysed throughout the graded exercise test with an automated metabolic cart (ParvoMedics TrueOne 2400; Sandy, UT). Participants’ rating of perceived exertion (Borg’s 6–20 scale; Borg 1982), heart rate, and manually obtained blood pressure were recorded at 3-min intervals throughout the test. The highest 30-s continuous recorded values obtained during the graded exercise test were used to determine VO_{2peak}. Following completion of the pre-screening and baseline assessment, an accredited practising dietitian provided individual meal plans from the participants’ seven-day food diaries. Meal plans were individually designed to simulate participants’ usual diet and matched to their average energy intake and macronutrient composition. All food was produced and sourced from a local kitchen. The same individualised meal plan was provided to each participant for each trial week. Participants were fitted with an accelerometer (Actigraph GTX3; Actigraph LLC, Florida, USA), worn on a wrist band on the participants’ non-dominant arm to record physical activity during each trial week. Participants were instructed to remove the accelerometer only to avoid immersion in water.

Participants completed each of the three trials for five consecutive days, 30 min after meals. The exercise trials required participants to undertake 30 min of moderate-intensity walking at 55–70% of heart rate reserve (HRR: Karvonen et al. (1957)) equivalent to a brisk walk at 4.0–6.5 km h^{-1} (Piercy et al. 2018), as a single bout, 30 min after consuming the evening meal (CONT), or three separate 10-min bouts, 30 min after breakfast, lunch, and dinner (ACC). Heart rate (FT60; Polar OY, Finland) was recorded every minute throughout each trial and adjustments made as necessary to the treadmill speed or incline to ensure the required intensity was maintained. For the no-exercise control (NOEX), participants were required to remain seated for a total of 60 min following the dinner meal. A wash-out
period of at least 14 days was imposed between trials to minimise potential carry-over effects between trials as previously implemented (Bally et al. 2016; Fig. 1).

For all trials, participants attended the laboratory each Monday to Friday morning in a fasted state to consume their prescribed breakfast and then remain seated for 30 min. Participants completing NOEX or CONT trials were given lunch and allowed to leave with instructions to eat lunch at approximately midday, then remain seated for 30 min. Participants completing the ACC trial completed the first 10-min bout of moderate-intensity walking on the treadmill before leaving the laboratory. Participants completing ACC returned for their lunch, consumed their meal, then sat for 30 min before undertaking 10 min of moderate-intensity walking. All participants returned to the laboratory to consume their evening meal and sit for 30 min before completing the relevant condition. On the final morning of each trial week before eating breakfast, participants were fitted with a five-lead ambulatory ECG (FD12 plus; Schiller AG, Switzerland) to record cardiac electrical activity at a sampling rate of 1000 Hz for 24 h. After the final exercise bout for the week, participants also completed the Physical Activity Enjoyment Scale (Kendzierski and DeCarlo 1991) to evaluate the relevant condition. On the final morning of each trial week before eating breakfast, participants were fitted with a five-lead ambulatory ECG (FD12 plus; Schiller AG, Switzerland) to record cardiac electrical activity at a sampling rate of 1000 Hz for 24 h. After the final exercise bout for the week, participants also completed the Physical Activity Enjoyment Scale (Kendzierski and DeCarlo 1991) to evaluate any preference towards either exercise mode. Participants were requested not to change their physical activity or dietary habits throughout the duration of their involvement in this study, which was confirmed verbally at the start of each trial week.

Approximately 12 h after the final exercise bout of each trial week, participants attended the laboratory following an overnight fast for measurement of arterial stiffness as indicated by PWV, and to complete an OGTT. On arrival, participants assumed a supine position and rested for a minimum of 5 min in a darkened environment. Pulse wave velocity was determined using applanation tonometry according to the manufacturer’s instructions (Sphygmocor® XCEL PWA & PWV; AtCor Medical Holdings Ltd, Australia). A Teflon cannula was inserted into an antecubital vein to allow regular blood sampling. An initial blood draw was taken for the analysis of fasting glucose and insulin. Participants had 5 min to consume an OGTT solution containing 75 g of glucose in 300 ml of water (Gluco Scan; Daniels Health, Australia). Additional blood samples were taken at 30, 60, 90, and 120 min following consumption of the solution for the analysis of plasma glucose and serum insulin. Participants remained seated throughout the OGTT. All blood was collected in BD vacutainers™ (BD, UK) which were taken to a local pathology laboratory as soon as possible after collection. The accelerometer, canula, and five-lead ambulatory ECG were removed after completion of the OGTT.

Two-hour glucose and insulin area under the curve (AUC) were calculated using the trapezoidal rule. Insulin sensitivity from the OGTT was determined using the Stumvoll insulin sensitivity index (SISI) (Stumvoll et al. 2000). Data from the SphygmoCor® applanation tonometry were downloaded to assess PWV, a surrogate indicator of arterial stiffness (Vlachopoulos et al. 2010), using SphygmoCor® XCEL software (AtCor Medical Holdings Ltd, Australia). Non-sinus cardiac cycles were excluded from the ECG data that were downloaded and analysed using Medilog Darwin V2 software (Schiller AG, Switzerland). The R–R intervals for all sinus beats (N–N intervals) along with the corresponding time co-ordinates (determined from the time at the beginning of each N–N interval) were imported into a customised software package designed using LabVIEW software (LabVIEW 2016; National Instruments, UK). As previously reported (Kingsley et al. 2005), a 4 Hz sampling frequency was used to re-sample the RR interval data to provide uniformly sampled data, before being de-trended and windowed using a Hanning window followed by Fast Fourier Transformation of 1 min segments to provide an estimate of the power spectral density in HF bandwidth (0.15–0.40 Hz) and LF bandwidth (0.04–0.15 Hz). The recommendations of the Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology (Cam et al. 1996) were followed to calculate frequency domain (LF, HF LF/HF power) and time domain (NNmean, NNSD, RMSSD NN50, pNN50) parameters.

Statistical analyses were carried out using IBM SPSS for Macintosh (V25 software; IBM Corp, Armonk, US). One-way repeated measures ANOVAs were performed to compare trial effects. Where appropriate, Bonferroni corrections were applied to account for multiple comparisons. A paired samples t test was conducted to evaluate participants’ preference for the exercise trials. Tests were deemed statistically significant at alpha ≤0.05. Unless otherwise stated, all data are reported as mean ± standard deviation or mean difference (95% confidence interval). Small 0.01–0.05, medium 0.06–0.13, and large >0.14 magnitude of effects were reported using partial eta² (Cohen 1988).

![Fig. 1 Study flow of participants during this three-arm randomised controlled, cross-over trial. ACC accumulated, CONT continuous, NOEX no exercise](image-url)
Results

Ten adults (m = 8, f = 2 postmenopausal) completed all aspects of the study; their baseline characteristics are at Table 1. Participants were free of any diagnosed cardio-metabolic disorder. From the IPAQ, only two participants reported they undertook moderate-intensity leisure-time exercise (for 80 min and 100 min per week respectively), and zero participants reported completing vigorous intensity exercise. Mean speed and treadmill incline for the ACC trial was 5.4 ± 0.8 km h⁻¹ and 7.7 ± 2.9% respectively, and for the CONT trial 5.1 ± 0.6 km h⁻¹ and 6.4 ± 1.9% respectively. Participants were provided with the same individualised meal plans for each trial week comprising 230 ± 54 g day⁻¹ carbohydrate, 114 ± 18 g day⁻¹ protein, and 88 ± 19 g day⁻¹ fat for a mean daily energy content of 9072 ± 1205 kJ day⁻¹. Overall physical activity (step count) was not different between trials (NOEX 58,039 ± 14,585, CONT 61,732 ± 15,462, ACC 64,644 ± 13,253, p = 0.268, partial η² = 0.338). Participants did not express a preference for either CONT (82 ± 19) or ACC (83 ± 18; t(9) = 2.26, p = 0.885) exercise trials.

Fasting glucose and fasting insulin were not different between the trials (Table 2). There were large intervention effects for glucose AUC (F(2,8) = 4.21, p = 0.010, partial η² = 0.40; Fig. 2a) and insulin AUC (F(2,8) = 5.29, p = 0.057, partial η² = 0.27; Fig. 2b). Glucose AUC following CONT (917 ± 142 mmol L⁻¹ 2 h⁻¹) was not different from ACC (931 ± 191 mmol L⁻¹ 2 h⁻¹; p = 0.671). However, glucose AUC following NOEX (1037 ± 151 mmol L⁻¹ 2 h⁻¹) was higher than CONT (p = 0.025) and higher than ACC (p = 0.016). Insulin AUC was lower following ACC (51,313 ± 13,037 pmol L⁻¹ 2 h⁻¹) than NOEX (70,328 ± 17401 pmol L⁻¹ 2 h⁻¹; p = 0.007). However, insulin AUC following CONT (66,150 ± 19,185 pmol L⁻¹ 2 h⁻¹) was not different to that for NOEX (70,328 ± 17,401 pmol L⁻¹ 2 h⁻¹; p = 0.627). There was a large trial effect for insulin sensitivity that did not reach statistical significance (SISI: F(2,8) = 2.61, p = 0.114; partial η² = 0.225, Table 2).

A large intervention effect was observed for PWV (F(2,8) = 2.91, p = 0.047; partial η² = 0.29). Pairwise comparisons indicated a difference between CONT (6.9 ± 1.4 m s⁻¹) and ACC (6.0 ± 0.8 m s⁻¹; p = 0.031), but not between NOEX (6.5 ± 1.2 m s⁻¹) and CONT (p = 0.265) or NOEX and ACC (p = 0.151).

The exercise completed in these trials (CONT and ACC) did not result in a systematic change in HRV over the 24-h measurement period when compared to no-exercise. The 24-h HRV data for the time and frequency domains were not systematically different between the three trials (Table 3).

Discussion

The key finding from this study was that five days of moderate-intensity walking completed as three separate 10-min bouts after breakfast, lunch, and dinner compared to a single 30-min bout after dinner were more effective at reducing insulin requirements and pulse wave velocity in insufficiently active, apparently healthy adults. Both exercise prescriptions were equally as effective at reducing postprandial

| Variable | Measure | NOEX | CONT | ACC | Partial η² | p |
|----------|---------|------|------|-----|------------|---|
| Age (year) | 50 ± 12.6 | 29.0 ± 5.4 | 129 ± 13 | 91.3 ± 15.8 | 106.1 ± 9.3 | 0.9 ± 0.1 | 31.9 ± 7.1 | 5.5 ± 0.2 | 6.1 ± 1.1 | 1.3 ± 0.2 | 3.9 ± 0.6 | 2.2 ± 2.4 |
| BMI (kg m⁻²) | | | | | | | | | |
| Systolic blood pressure (mm Hg) | | | | | | | | | |
| Diastolic blood pressure (mm Hg) | | | | | | | | | |
| Waist (cm) | | | | | | | | | |
| Hip (cm) | | | | | | | | | |
| Waist/Hip ratio | | | | | | | | | |
| VO₂peak, (mL min⁻¹ kg⁻¹) | | | | | | | | | |
| HbA1c (%) | 5.5 ± 0.2 | | | | | | | | | | |
| Total cholesterol (mmol L⁻¹) | 6.1 ± 1.1 | | | | | | | | | | |
| HDL-C (mmol L⁻¹) | 1.3 ± 0.2 | | | | | | | | | | |
| LDL-C (mmol L⁻¹) | 3.9 ± 0.6 | | | | | | | | | | |
| Triglycerides (mmol L⁻¹) | 2.2 ± 2.4 | | | | | | | | | | |

Values are mean ± SD

BMI body mass index, HbA1c glycated haemoglobin, HDL-C high density lipoprotein cholesterol, LDL-C low density lipoprotein cholesterol

Blood samples taken at 30-min intervals for 2 h following consumption of an OGTT solution. Values are mean ± SD

ACC accumulated, AUC area under the curve, mmol L⁻¹ mmol per litre, CONT continuous, NOEX no exercise, OGTT oral glucose tolerance test, pmol L⁻¹ picamol per litre, ISI insulin sensitivity index

 Springer
glucose concentrations compared to a no-exercise control. Furthermore, ACC (but not CONT) resulted in a lower insulin requirement than NOEX, even with similar reductions in glucose. It was also determined that PWV was lower for ACC compared to CONT. This is an important finding as studies involving the effects of exercise on arterial stiffness have generally focused on longer duration continuous exercise bouts of 30 min or more. Taken together, these novel data suggest that accumulating exercise in multiple bouts throughout the day might be more beneficial for cardiometabolic health than a single bout of similar total duration after the evening meal only. However, whether these results would occur if exercise was completed prior to meal consumption was not assessed.

In the current study, only the ACC trial was associated with a reduced insulin requirement to facilitate a reduction in glucose. Elevated blood glucose has been demonstrated to increase arterial stiffness (Salomaa et al. 1995). As both the ACC and CONT trials experienced a reduction in glucose AUC, it might be inferred that the reduced insulin requirement following accumulated exercise in this study drove the reduction in arterial stiffness. This hypothesis is consistent with other research investigating the effects of increased insulin concentration on arterial stiffness. In a cross-sectional study of people with T2DM or prediabetes, Salomaa et al. (1995) reported that increases in fasting insulin were positively associated with increased arterial stiffness. This might be due to the residual effects of the insulin released following meal consumption during the separate exercise bouts having a cumulative effect greater on PWV than that from the single 30-min bout.

**Fig. 2** Two-hour oral glucose tolerance test. Fasted blood draw at Time = 0. Blood drawn at 30 min intervals following ingestion of oral glucose tolerance test solution for measurement of a glucose and b insulin. ACC accumulated, CONT continuous, NOEX no exercise.

**Table 3** Measures of heart rate variability and vascular compliance

| Variable | NOEX | CONT | ACC | Partial eta² | p |
|----------|------|------|-----|--------------|---|
| NN50 (n) | 4828 ± 3016 | 5147 ± 2998 | 6068 ± 4324 | 0.065 | 0.546 |
| PNN50 (%) | 4.5 ± 3.5 | 5.0 ± 3.3 | 5.9 ± 4.5 | 0.069 | 0.525 |
| RMSSD (ms) | 24.2 ± 5.7 | 24.1 ± 6.6 | 26.6 ± 8.2 | 0.099 | 0.390 |
| RNSD (ms) | 37 ± 1 | 38 ± 1 | 42 ± 1 | 0.150 | 0.232 |
| RRmean (ms) | 770 ± 9 | 759 ± 9 | 790 ± 7 | 0.128 | 0.293 |
| VLFpower (m s⁻¹) | 510 ± 307 | 526 ± 278 | 624 ± 301 | 0.128 | 0.293 |
| LFpower (m s⁻¹) | 889 ± 463 | 882 ± 579 | 1089 ± 742 | 0.131 | 0.283 |
| HFpower (m s⁻¹) | 200 ± 98 | 204 ± 106 | 263 ± 231 | 0.090 | 0.428 |
| LF/HF | 4.4 ± 0.9 | 4.7 ± 1.4 | 4.5 ± 1.2 | 0.046 | 0.654 |
| PWV (m s⁻¹) | 6.55 ± 1.2 | 6.9 ± 1.4 | 6.0 ± 0.8 | 0.288 | 0.047 |

Heart rate variability measures obtained from 24-h ambulatory, five-lead ECG. Pulse Wave Velocity measures obtained from SphygmoCor® applanation tonometry.

Values are mean ± SD

ACC accumulated, CONT continuous, NOEX no exercise, n number, NN50 number of RR intervals differing by more than 50 ms, PNN50 percentage of RR intervals differing by more than 50 ms, RMSSD root mean squared difference of successive RR intervals, RNSD standard deviation of RR intervals, RRmean mean RR interval, VLF power very low frequency power, LFpower low frequency power, LF/HF low frequency, high frequency ratio, PWV pulse wave velocity.
Previous research has shown that the risk of cardiovascular events is reduced by 12-14% for every 1 m s⁻¹ reduction in PWV (Vlachopoulos et al. 2010). In the current study, PWV was 0.9 m s⁻¹ lower when exercise was accumulated throughout the day compared to a single continuous bout, suggesting the result is likely clinically significant. In a systematic review and meta-analysis, Ashor et al. (2014) reported that aerobic exercise improved PWV noting that greater improvements were observed at higher exercise intensities and in trials of 10 weeks or more without noting whether the exercise was continuous or accumulated. Two 15-min bouts of cycling separated by 20 min of rest acutely improved PWV compared to a resting control group but the absence of another group undertaking a single 30-min bout of exercise render it difficult to make any comparison (Kobayashi et al. 2018). Although there has been minimal investigation of the effect of accumulating exercise on arterial stiffness, Okamoto et al. (2018) demonstrated that 30 min of treadmill walking, comprising five sets of 3 min at 30% VO₂max and five sets of 3 min at 70% VO₂max, resulted in a more persistent reduction in PWV in healthy adults when compared to a single bout of continuous walking for 30 min at 50% VO₂max. The results from Okamoto et al. (2018) suggest that interval exercise might be better than continuous exercise for reducing PWV. Further research should investigate the effects of habitual accumulation of exercise compared to continuous exercise in order to allow a better determination of which method might be more efficacious in the long-term.

The findings from the current study confirm that exercise is beneficial for improving arterial stiffness. However, this study extends the findings of Zheng et al. (2015), as the results suggest that following multiple days of exercise, changes in PWV can be observed for at least 12 h after the final exercise bout. Zheng et al. (2015) investigated the acute effects of single sessions of 30 min continuous exercise bouts or two 15-min bouts separated by 20 and 60 min respectively on arterial stiffness using the cardio-ankle vascular index (CAVI), measured immediately and 60 min after the trials. All exercise trials improved CAVI when measured immediately after the exercise had finished. However only the accumulated exercise with the bouts separated by 20 min showed a reduction in arterial stiffness when measured 60 min after the exercise had finished (Zheng et al. 2015). Therefore, it is possible that repeated bouts of exercise have an additive, accumulated effect on arterial function/compliance that is further enhanced if the exercise is accumulated in short bouts throughout the day on multiple consecutive days.

The current study and that by Zheng et al. (2015) both detected changes in PWV but used different measurement techniques that might make it difficult to directly compare the results. The CAVI is derived from a stiffness parameter (β) determined from the time and distance of pulses from the heart valve, popliteal, brachial, and ankle pulses. Blood-pressure cuffs with sensors are placed on both ankles, right knee, and upper arms. A phonocardiogram is placed at the second intercostal space on the sternal border and electrocardiogram leads placed on the wrists. In contrast the applanation tonometry technique of the Sphygmocor® utilises a cuff on the femoral artery and a tonometer placed over the carotid artery to determine the femoral–carotid pulse transit time. When comparing different techniques used to assess arterial stiffness Huck et al. (2007) suggested that the requirement to place various sensors and cuffs might have contributed to the greater variance in readings from CAVI technique compared to applanation tonometry measured PWV. Therefore, although both this study and that of Zheng et al. (2015) demonstrated that accumulating exercise had a beneficial effect on arterial stiffness, further research using similar exercise methodologies and techniques to measure arterial stiffness are required in order to confirm or refute the results.

In the current study, there was no evidence to suggest that 5 days of completing 30 min of moderate-intensity aerobic exercise, whether undertaken as a single bout or accumulated in multiple bouts, was sufficient to systematically influence HRV throughout the 24-h period of measurement that included exercise trials with the same overall volume and intensity in both the CONT and ACC trials but also a no-exercise control. In a previous study of healthy young males completing 60 min of moderate-intensity aerobic exercise while consuming standardised meals, positive HRV changes were reported when collected under controlled resting conditions (Pober et al. 2004). In the current study HRV data was collected over a 24-h period to ensure any changes in HRV resulting from the different exercise trials were captured that might have dissipated had the data been collected the following morning only. Interpretation of HRV during exercise is difficult as measures of sympathovagal activity at rest behave differently during exercise (Sandercock and Brodie 2006). Therefore, despite the inherent risks of introducing high levels of variance, it might be preferable to consider HRV data gathered over longer durations that embrace exercise as this reflects normal life activities. In the current study there was a high degree of variance in all measurements of HRV recorded, possibly as a result of the largely free-living conditions under which the participants took part in the study and also the apparently good health of the participants. Understanding how trials impact on free-living people is important, as research outcomes in well-controlled experiments might not be replicable beyond the well-controlled conditions of the laboratory. Furthermore, insights might be gained in how exercise can be used to reduce the risks of healthy people developing adverse cardiometabolic outcomes.
Although the results from this study suggest that postprandial exercise can reduce the risk of developing cardiometabolic health conditions, there are some limitations which should be considered. Only the effects of exercise completed 30 min after meals were assessed in this study. Future research should consider whether exercising sooner or later than 30 min after meals, and also before meals, might have different outcomes. Walking might not affect lipids or lipoproteins as neither were reported to change following 12 weeks of walking three days per week either accumulated as two 10-min walks, or one 20-min walk in healthy adults (Murtagh et al. 2005). Furthermore, accumulated exercise and single-bout exercise might be equally as effective at attenuating postprandial lipaemia (Murphy et al. 2009). Therefore, we did not assess the effects of walking on lipid profiles in this study but measuring it in future might be useful to add to the limited evidence base. While all participants consumed the same individually prepared diet for all trials, no attempt was made to match energy intakes or macronutrient content between participants or relative to body mass. Neither was there any attempt to control how much energy participants expended beyond the laboratory other than recording their steps with an accelerometer and asking them to refrain from any exercise they did not normally undertake throughout their involvement in the study. Analysis of blood gases were not undertaken as part of this study as no changes were anticipated due to the exercise intensity (Burton et al. 2004). Blood gas analysis should be considered in future studies involving higher intensity exercise or participants with diabetes or other cardiometabolic disorders that might impact on the acid–base balance or gas partial pressures during exercise. Power was not calculated a priori for HRV, therefore differences might exist, but the study was possibly insufficiently powered to detect them.

Conclusion

This study of insufficiently active, apparently healthy adults found that 30 min of postprandial moderate-intensity aerobic walking accumulated in three 10-min bouts after meals significantly improved arterial stiffness while lowering insulin requirements in comparison to a single 30-min bout after the evening meal alone. There was no difference between the accumulated or continuous exercise prescriptions for 2-h glucose AUC, but both trials were different from the no-exercise control. Therefore, accumulating exercise in multiple bouts throughout the day might be more beneficial than a single bout for reducing the risk of developing cardiometabolic diseases such as diabetes and cardiovascular disease.

Acknowledgements The authors would like to acknowledge the participants who committed their time to participate in this study, and the undergraduate and post-graduate students who helped in the data collection. This study was made possible by funding received from the La Trobe University Sport Exercise and Rehabilitation Research Focus Area. Philip Shambrook was supported by an Australian Government Research Training Programme Scholarship.

Author contributions PS, MK and BG conceived and designed the study. CW analysed the food diaries and prepared the individual food plans. MK developed the software to undertake the HRV analyses. PS, DW and BG conducted the experiments, PS, MK, NT and BG analysed the data and PS wrote the manuscript. All authors edited and approved the final manuscript.

Compliance with ethical standards

Conflict of interest The authors have no competing interests to declare.

References

Ashor AW, Lara J, Siervo M, Celis-Morales C, Mathers JC (2014) Effects of exercise modalities on arterial stiffness and wave reflection: a systematic review and meta-analysis of randomized controlled trials. PLoS ONE 9(10):e110034. https://doi.org/10.1371/journal.pone.0110034

Asikainen TM, Milunpalo S, Kukkonen-Harjula K, Nenonen A, Pasanen M, Rinne M, Uusi-Rasi K, Oja P, Vuori I (2003) Walking trials in postmenopausal women: effect of low doses of exercise and exercise fractionization on coronary risk factors. Scand J Med Sci Sports 13(5):284–292. https://doi.org/10.1034/j.1600-0838.2003.00331.x

Australian Government Department of Health (2014) Australia’s physical activity and sedentary behaviour guidelines. http://www.health.gov.au/internet/main/publishing.nsf/Content/health-pubhlth-strat-phys-act-guidelines. Accessed 2 June 2017

Bally L, Zueger T, Buehler T, Dokumaci AS, Speck C, Pasi N, Ciller C, Paganini D, Feller K, Loher H (2016) Metabolic and hormonal response to intermittent high-intensity and continuous moderate-intensity exercise in individuals with type 1 diabetes: a randomised crossover study. Diabetologia 59(4):776–784. https://doi.org/10.1007/s00125-015-3854-7

Baynard T, Franklin RM, Gouloudoulou S, Carhart R, Kanaley JA (2005) Effect of a single vs multiple bouts of exercise on glucose control in women with type 2 diabetes. Metabolism 54(8):989–994. https://doi.org/10.1016/j.metabol.2005.02.015

Benichou T, Pereira B, Mermillod M, Tauveron I, Pfabigan D, Maq-dasy S, Dutheil F (2018) Heart rate variability in type 2 diabetes mellitus: a systematic review and meta-analysis. PLoS ONE 13(4):e0195166. https://doi.org/10.1371/journal.pone.0195166

Borg GA (1982) Psychophysical bases of perceived exertion. Med Sci Sports Exerc 14(5):377–381. https://doi.org/10.1249/00005768-19820500-00012

Burton DA, Stokes K, Hall GM (2004) Physiological effects of exercise. BJ A Educ 4(6):185–188. https://doi.org/10.1093/bjaeduo/ mik050

Camm AJ, Malik M, Bigger JT, Breithardt G, Cerutti S, Cohen RJ, Coumel P, Fallen EL, Kennedy HL, Kleiger R (1996) Heart rate variability: standards of measurement, physiological interpretation and clinical use. Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. Circulation 93(5):1043–1065. https://doi.org/10.1111/j.1542-474x.1996.tb00275.x

Cohen J (1988) Statistical power analysis for the behavioral sciences. 2nd edn. Lawrence Erlbaum, Abingdon

Cohen J (1988) Statistical power analysis for the behavioral sciences. 2nd edn. Lawrence Erlbaum, Abingdon
