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Effects of Commuter Cycling on Physical Activity, Cardiometabolic Health and Body Composition

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ABSTRACT

The aim of this study was to evaluate effects of a 10-week commuter cycling intervention on physical activity (PA), cardiometabolic health and body composition. A randomised controlled trial was conducted in healthy males and females ($n = 26$, BMI ≤ 30, ≥ 20 years ≤ 55 years). The intervention group (CYC) cycle commuted (148 ± 38 min.wk^{-1}). The control group (CON) received public transport or petrol vouchers. $\dot{V}O_{2max}$ increased in CYC ($10.5 \pm 16.2\%$), decreased in CON ($-2.8 \pm 12.3\%$) ($p = 0.03$). HR_{rest} decreased in CYC ($-5.4 \pm 6.8\%$), increased in CON ($1.7 \pm 9.5\%$) ($p = 0.02$) as did diastolic blood pressure ($-1.2 \pm 7.5\%$, $11.9 \pm 16.5\%$, respectively, $p = 0.02$). Weekly logbooks indicated no group difference in total PA (Group $p = 0.15$) or change over time ($p = 0.18$). CYC conducted more moderate and vigorous PA combined ($p = 0.008$). No changes in body mass were observed (CYC: wk0 78.5 ± 9.0, wk10 78.7 ± 9.0, CON: wk0 69.8 ± 6.7, wk10 70.3 ± 6.7 ($p = 0.17$), or difference between groups ($p = 0.61$). Body fat (sum of 4 skinfolds) was maintained similarly in both groups ($p = 0.95$). Body fat (DXA) was $29.4 \pm 9.7\%$ before and $29.5 \pm 9.8\%$ after in CYC ($p = 0.97$). The intervention did not alter C-reactive protein, HDL, LDL, or total cholesterol, fasting glucose, insulin or HOMA-IR ($p > 0.05$). In conclusion, some cardiovascular benefits can occur with commuter cycling even if total PA and body composition are not altered. The increase in more intensive PA is likely responsible for the enhanced cardiovascular fitness.

Trial Registration: The study was registered with the Australian New Zealand Clinical Trials Registry (ANZTCR:12617000123347)

1 | Introduction

A trend for increased obesity and sedentary-related diseases (e.g. cardiovascular diseases and diabetes) exists in nations where physical activity (PA), including active transport, is decreasing (Saunders et al. 2013). Epidemiological evidence indicates that physically active modes of transport can reduce the risk of cardiovascular disease, type-2 diabetes (Honda et al. 2022; Kuwahara et al. 2022) and all-cause mortality (Dinu et al. 2019; Oja et al. 2011; Peterman et al. 2021). Most studies, however, were prospective cohort with many combining walking and cycling. Cycling is performed at an intensity that generally supports greater cardiovascular benefits than walking (Oja et al. 1991; Hoevenaar-Blom et al. 2011). Intervention studies are limited and whether incorporating commuter cycling (cycling to and from work) into daily life results in

Summary

- Commuter cycling positively impacts cardiovascular risk factors: increased maximal aerobic capacity ($\dot{V}O_{2max}$), decreased diastolic blood pressure and resting heart rate.
- Improved cardiovascular indices can occur even without changes in total physical activity level or body composition.
- A greater amount of moderate—vigorous physical activity observed with commuter cycling is likely responsible for enhanced cardiovascular fitness.

cardiometabolic benefits and whether these are due to increased PA amount and/or intensity is unclear (Oja et al. 2011; de Geus et al. 2008; Møller et al. 2011).

Among the limited cycle intervention studies de Geus et al. (2008) found improvements in several variables associated with cardiovascular risk including cardiorespiratory fitness and diastolic blood pressure. However, no baseline data were presented and, thus, it is unknown if total PA increased or not, although PA levels in the intervention group were greater than in the control group. Møller et al. (2011) found, in their cycle commuting study, that cardiorespiratory fitness increased to a greater extent in their intervention group, but participants were asked to maintain other physical activities at the same level as prior to the trial (unreported). In another cycle commuting intervention, Hendriksen et al. (2000) also found that cardiorespiratory fitness increased only in males in their intervention group. However, males cycled a greater distance than females and there were more than twice as many male participants than female, thus, the study may have been underpowered for females. No information on other activities was provided. Lastly, Reich et al. (2020) reported that maximal power increased through a cycle commuting intervention, and although the total PA was stated to have increased, it was not significant. No information on activities outside of cycling was provided.

Robust evidence that the health benefits gained from commuter cycling are because of increased PA is lacking due to methodological differences in previous studies. As delineated above, most studies asked that, outside of the commuter cycling, other physical activities not be altered during the intervention (Oja et al. 2011; de Geus et al. 2008; Møller et al. 2011). Thus, whether incorporating commuter cycling into daily life enhances overall PA levels, or replaces other activities, and the consequent impact on health are unknown. A systematic review investigating whether active transport displaces other PA was inconclusive (Wanjau et al. 2023) and the one RCT included did not differentiate active commuting from other activities.

Therefore, the specific aims of this study were to determine if incorporating cycling to and from work into the daily routine (1) increases overall physical activity (PA), (2) enhances cardiovascular ($\dot{V}O_{2max}$, resting heart rate, blood cholesterol, triglycerides, C-reactive protein and blood pressure) and metabolic (fasting glucose, insulin and HOMA-IR) health and (3) improves body composition (skin fold thickness, DXA) amongst healthy men and women. The hypotheses were that commuter cycling would increase PA and improve the measured parameters of cardiometabolic disease associated with sedentary behaviour.

2 | Methods

2.1 | Study Design and Recruitment

A randomised controlled study was undertaken to evaluate effects of a 10-week commuter cycling intervention on PA, cardiometabolic health parameters and body composition. Flyers and emails were distributed through the local university, businesses and city council to recruit potential participants. Prospective participants were asked to complete online questionnaires to assess PA readiness and lifestyle factors associated with their current travel and PA habits. If answers were in accordance with inclusion and exclusion criteria participants came to the lab for a preliminary pre-intervention session in which measurement of height and mass, skin folds and cycling $\dot{V}O_{2max}$ were conducted. The preliminary testing session took place between 14 and 8 days before the intervention. At least 2 days before this session, participants were informed of the testing procedures and preparedness for the test (i.e., appropriate clothing for exercise, hydration, no meals within 2 h of testing, abstain from vigorous or otherwise exhausting exercise for 24 h prior to testing). Exclusion criteria were smoking, already actively commuting, being unemployed or working from home, BMI > 30, < 20 years or > 55 years, participating in a structured training programme, training to compete in sport, people with chronic disease (e.g. cardiovascular disease, diabetes, cancer) or having contraindications to exercise as defined in the Physical Activity Readiness Questionnaire (PAR-Q) (Thomas et al. 1992). Inclusion criteria included currently travelling to work by motor vehicle. If all inclusion and exclusion criteria were met a second pre-intervention testing session was conducted within 7 days prior to the intervention. Participants were tested in the morning ≥ 48 h after the last bout of moderate or high intensity exercise, ≥ 24 h after any exercise, ≥ 24 h fast from alcohol and 12 h fast from food and caffeinated beverages. Upon arrival to the laboratory, body mass was measured, and participants were then fitted with a recordable HR monitor and seated to complete a physical activity questionnaire, followed by rest in the supine position. Blood collection consumables were hidden from participants' view until BP and HR measures were collected. While participants remained supine, blood collection was performed. Upon completion of testing, participants were provided with breakfast and were instructed on procedures for completing the PA log book. Ninety-six people completed the screening questionnaire, 33 met inclusion criteria and underwent pre-intervention testing and 28 completed pre-intervention testing and were available for the time needed to be able to complete the study.

2.2 | Intervention

The 28 participants (14 males, 14 females) were quasi-randomised into cycling (CYC) or control (CON) groups. To control for varying levels of cardiorespiratory fitness each participant was

paired with one other participant with a similar $\dot{V}O_{2max}$ (± 3 mL $\dot{V}O_2 \cdot kg \cdot min^{-1}$) and randomly allocated to CYC or CON. This was done because $\dot{V}O_{2max}$ was a key criterion measure of cardiorespiratory fitness, and magnitude of improvement is, in general, greater in those with a lower initial $\dot{V}O_{2max}$. Randomisation was performed separately for males and females to ensure equal representation in each group. Participants in CYC were given bicycles, high-visibility wet-weather clothing, lights and repair kits, and were encouraged to accumulate at least 150 min.week^{-1} of commuter cycling for 10 consecutive weeks. A minimum ride time of 100 min.week-^{1}, accumulated on three or more days, was necessary to remain in the study.

Prior to beginning, CYC participants met individually with the researcher to discuss road rules regarding bicycle use and common hazards and were provided with an information pack. Potential route choices were discussed, and an action plan created for the days they intended to cycle as well as a backup plan if a scheduled active commute was missed. Strategies for managing weather, clothing choices and transport of work materials were also discussed and questions answered. During the third week of the intervention, two bicycle maintenance clinics were held.

CON participants were asked to maintain existing PA and dietary habits and were followed over the same 10-week period as CYC. CON were provided with $75 of public transport or petrol vouchers. All participants were contacted weekly to ensure adherence and completion of intermediate measures (e.g. PA logbooks and questionnaires) throughout the intervention.

2.3 | Physical Activity Assessment

The International Physical Activity Questionnaire (IPAQ-short form) was administered the week prior to the intervention (week 0) and on weeks 4, 8 and 10 (Booth 2000). Moderate level of PA was defined as 30 min of moderate-intensity PA on most days per week, including three or more days of vigorous intensity activity and/or walking of at least 30 min per day, or five or more days of moderate intensity activity and/or walking of at least 30 min per day, or five or more days of any combination of walking, moderate-intensity or vigorous-intensity activities achieving a minimum total physical activity of at least 600 MET-min per week. High PA level was defined as approximately one hour of PA per day, or more, of at least a moderate intensity, including vigorous intensity activity on at least three days, achieving a minimum total PA of at least 1500 MET-min per week, or seven or more days of any combination of walking, moderate-intensity or vigorous-intensity activities achieving a minimum total PA of at least 3000 MET-min per week. Low PA level was defined as not meeting the requirements for moderate or vigorous categories.

Participants were also provided with a logbook to record all PA that was performed for ≥ 5 min. The log was kept daily from the week before the intervention began (week 0) and throughout the intervention. Logbooks included definitions and examples of activities classed as moderate and vigorous intensity, which were adapted from the validated IPAQ and they were asked to rate the intensity of their activities accordingly. The total minutes of PA in each intensity category per week was then calculated. These logbooks were also used to quantify the commuter cycling time in CYC to confirm minimum requirement to remain in the study.

2.4 | Maximal Oxygen Consumption ($\dot{V}O_{2max}$)

Prior to the intervention beginning (8–14 days), an incremental exercise test to exhaustion was performed on a cycle ergometer (Velotron Elite, RacerMate Inc., Seattle, Washington, USA) with respiratory gas analysis (Cosmed Cardio Pulmonary Exercise Testing, CosmedSrl, Rome, Italy) averaged over 30 s blocks to determine $\dot{V}O_{2max}$.

The $\dot{V}O_{2max}$ protocol started at 100 W and increased in 50 W increments every 3 minutes until a heart rate (HR) of 165 beats·min^{-1} (bpm) was achieved. Above 165 bpm, stages increased in 25 W increments until exhaustion, defined by plateau in $\dot{V}O_2$ with increased workload. If a plateau was not observed, exhaustion was defined as inability to pedal greater than 60 rpm in addition to one of the following criteria: RER of ≥ 1.1 or maximal age-predicated HR (±10 bpm). If participants were unable to complete the $\dot{V}O_{2max}$ protocol, a second attempt was permitted before exclusion from the study. Two females completed the test on second attempt with lower start wattage and smaller increments.

2.5 | Heart Rate Sampling

CYC were instructed to wear a HR monitor (Polar RS400, Polar Electro Inc., Kempele, Finland) on week four and eight. Heart rate data for commuting activities were downloaded to determine the duration and relative intensity (percentage $\dot{V}O_{2max}$) of commuter cycling and rate of oxygen consumption. Week four data were calculated relative to the baseline $\dot{V}O_{2max}$, whereas week eight data were calculated relative to the week 10 $\dot{V}O_{2max}$.

2.6 | Resting Blood Pressure

Systolic and diastolic blood pressure (BP) were measured supine after 15 min rest (within 7 days) before and (within 7 days) after the intervention. Measures were performed in duplicate with a mercury sphygmomanometer (Nihon Seimitsu Sokki Co. Ltd., Gunma, Japan) and stethoscope by the same qualified technician for all participants during pre- and post-intervention testing.

2.7 | Resting Heart Rate

Resting heart rate (HR_{rest}) was measured with a portable HR monitor (Polar RS400, Polar Electro Inc., Kempele, Finland) throughout 15 min of supine rest (within 7 days) before and (within 7 days) after the intervention. Data were averaged over 15 s blocks, with the lowest value recorded as HR_{rest}.

2.8 | Blood Measures of Cardiometabolic Health

Plasma samples for fasting insulin, glucose, triglycerides, cholesterol (HDL and LDL), and C-reactive protein (CRP) were collected from an antecubital vein in EDTA tubes (BD New Zealand, Auckland, New Zealand) (within 7 days) before and (within 7 days) after the intervention). These were collected 48 h after the last bout of moderate or high intensity exercise, ≥ 24 h from any exercise and ≥ 4 h fast from alcohol and 12 h fast from food and caffeine. Samples were stored at −80C until post-intervention samples were collected and biochemical analyses were conducted.

C-reactive protein, total cholesterol, HDL cholesterol and triglycerides were analysed with a COBAS Mira Plus analyser (Roche Diagnostic, Basel, Switzerland). LDL cholesterol was determined by the Friedewald equation (Friedewald et al. 1972). Glucose was analysed in duplicate with a Cobas c 111 (Roche Instrument Centre, Rotkreuz, Switzerland) and insulin with the electrochemiluminescence method using analyser Elecsys2010 (Roche/Hitachi, Tokyo, Japan). Homeostatic model assessment for insulin resistance (HOMA-IR) was calculated from fasting insulin and glucose. The coefficient of variation (CV) for glucose was (1.6%), insulin (1.6%), total cholesterol (1.7%), HDL cholesterol (4.7%), triglycerides (1.2%) and CRP (6.7%).

2.9 | Body Mass and Composition

Body mass was measured (within 7 days before the intervention) after a 12 h fast. Participants were instructed to void and remove outer layers of clothing before being measured to the nearest 100 g on electronic scales (Model 770, Seca alpha, Hamburg, Germany). Skinfold thickness was measured at four sites (triceps, biceps, sub-scapular and supra-iliac) to the nearest 0.2 mm with callipers (John Bull, British Indicators Ltd., St Albans, England). Measures were performed in duplicate and measures with variability over 1 mm were repeated a third time and the closest two measures used. After group allocation was performed, CYC participants underwent a DXA scan (Lunar Prodigy, GE Medical Systems Lunar, Madison, Wisconsin) (within 7 days) before and (within 7 days) after the intervention. CON did not undertake DXA scans due to financial constraints. Lean and fat masses were determined for the whole body, as well as for legs, arms, trunk, waist and hips (Taylor et al. 1998). Hip and waist circumferences were also determined with DXA.

2.10 | Statistical Analyses

Results are presented as means ± SD, unless otherwise specified. Maximal oxygen consumption ($\dot{V}O_{2max}$) was chosen as the primary outcome variable, as it is the best measure of aerobic fitness and is highly correlated with reduced cardiovascular disease risk and reduced morbidity (Kodama et al. 2009). Thus, a sample size calculation was performed on this variable and expected change over this timeframe. A paired-sample sample size calculation was conducted using Minitab (v16.1.1) assuming an increase in $\dot{V}O_{2max}$ of 14%, standard deviation of 15% (Kukkonen-Harjula et al. 1998) and a power of 0.80, and indicated a sample size of 13 in each group was necessary.

SPSS (Version 27, IBM, New York) was used for statistical analyses, with significance set at $p < 0.05$. Linear mixed models, including a random participant effect, were used to detect any group effects and time-by-group interactions with measures collected in both groups at three or more time points (PA measures) which were analysed as differences from baseline (wk 0) with age, gender and BMI as covariates. General linear model ANOVA were performed for data collected at two time points (e.g., cardiovascular and metabolic parameters) and paired *t*-tests were performed for measures analysed from CYC only (e.g. DXA). Effect sizes were determined by partial eta squared η_p^2 (Ben-Shachar et al. 2020).

3 | Results

3.1 | Compliance

Twenty-seven participants completed intervention testing. Three CON participants (2 female, 1 male) did not complete the logbooks and IPAQ at weeks 4 and 8. Two of these participants completed post-intervention testing and one female withdrew due to recurring illness. All 14 CYC participants completed the intervention. However, one female CYC participant was excluded from analysis upon admission that she was commuter cycling prior to the intervention. Those in the final analyses who completed the intervention met our criteria to remain in the study (i.e. a minimum ride time of 100 min.week^{-1}, accumulated on three or more days, as indicated in logbooks). Participants cycled 148 ± 38 min.wk^{-1}, with a range of 105—248 min.wk^{-1}. Females cycled 168 ± 59 min.wk^{-1} and males cycled 131 ± 49 min.wk^{-1}; no differences were detected between sexes ($p = 0.13$) or over time ($p = 0.90$).

3.2 | Participant Characteristics and Body Composition

Mean age was 39.0 ± 7.0 years (CYC) and 34.5 ± 7.0 years (CON), range 24–52 years and 23–45 years, respectively. Fasted body mass was greater ($p = 0.01$) in CYC than CON at baseline and throughout the study but both groups maintained their mass (Table 1). Fitness and age were similar between groups. No changes in body composition over time (skinfolds and DXA), or between groups (skinfolds) were observed (Table 1). Body fat, as determined by DXA, was 29.4 ± 9.7% in CYC, prior to, and 29.5 ± 9.8% ($p = 0.97$, $\eta_p^2 < 0.001$) after the intervention. Waist to hip ratio as determined by DXA, was similarly unaltered (0.85 ± 0.09 before, 0.84 ± 0.09 after) ($p = 0.90$, $\eta_p^2 = 0.001$).

3.3 | Physical Activity

3.3.1 | International Physical Activity Questionnaire

Median and quartiles of physical activity at various intensities as determined by IPAQ are displayed in Table 2. Most participants

TABLE 1 | Physical characteristics (mean ± SD) for cycling and control groups at baseline (week 0) and after the 10-week cycling intervention.

	Cycling		Control			
	week 0 (n = 13)	**week 10 (n = 13)**	**week 0 (n = 13)**	**week 10 (n = 13)**	***p***	η_p^2
Age (yr)	39.0 ± 7.0		34.5 ± 7.0			
Body mass (kg)	78.5 ± 9.0	78.7 ± 9.0	69.8 ± 6.7	70.3 ± 6.7	0.61	0.011
BMI	26.1 ± 2.4	26.2 ± 2.2	24.2 ± 2.3	24.4 ± 2.4	0.61	0.011
Skin-folds (mm)	76 ± 36	76 ± 35	62 ± 26	63 ± 24	0.95	< 0.001
$\dot{V}O_{2max}$ (L/min)	2.83 ± 0.83	3.05 ± 0.73	2.66 ± 0.68	2.60 ± 0.69	0.047	0.154
$\dot{V}O_{2max}$ (mL/kg/min)	36 ± 9	39 ± 7	39 ± 10	37 ± 10	0.03	0.188

Note: p determined by general linear model ANOVA for between group % change week 0 to week 10.
Abbreviations: BMI, body mass index; $\dot{V}O_{2max}$, maximal oxygen consumption.

TABLE 2 | Median (upper and lower quartiles) physical activity per week reported from the International Physical Activity Questionnaire in control (CON) and commuter cycling (CYC) groups at baseline (week 0), weeks 4, 8 and 10 of the intervention.

	week 0		week 4		week 8		week 10	
	CYC	**CON**	**CYC**	**CON**	**CYC**	**CON**	**CYC**	**CON**
MVPA (min)	150 (50,308)	90 (0.225)	200 (132,330)	140 (0.266)	165 (0.248)	68 (5150)	156 (105,310)	30 (0.135)
MPA (min)	40 (15,165)	30 (0.150)	100 (30,145)	90 (0.200)	105 (20,120)	50 (0.150)	90 (35,150)	30 (0.120)
VPA (min)	60 (0.128)	0 (0.60)	120 (25,220)	30 (0.60)	75 (40,179)	0 (0.45)	60 (0.175)	0 (0.0)

TABLE 3 | Mean (±SD) physical activity per week reported from the International Physical Activity Questionnaire in control (CON) and commuter cycling (CYC) groups at baseline (week 0), weeks 4, 8 and 10 of the intervention.

	week 0		week 4		week 8		week 10	
	CYC	**CON**	**CYC**	**CON**	**CYC**	**CON**	**CYC**	**CON**
MVPA[a] (min)	160 ± 120	169 ± 262	255 ± 163	173 ± 164	185 ± 100	109 ± 123	201 ± 114	68 ± 87
MPA[b] (min)	75 ± 82	142 ± 257	111 ± 106	124 ± 156	81 ± 55	91 ± 110	111 ± 101	61 ± 83
VPA[c] (min)	85 ± 100	28 ± 36	144 ± 117	49 ± 74	104 ± 90	18 ± 24	91 ± 95	7 ± 17

Note: Mixed linear model of differences from baseline between CYC and CON: [a]p = 0.33, [b]p = 0.29, [c]Data distribution invalidated analysis.
Abbreviations: MPA, moderate-intensity physical activity; MVPA, moderate- and vigorous-intensity physical activity combined; VPA, vigorous-intensity physical activity.

had moderate levels of physical activity at week 0 (CYC n = 10, 77%; CON n = 9, 70%). In both groups, 15% (n = 2) had high PA levels and 1 CYC and 2 CON participants were in the low category. No group differences were observed at baseline (p = 0.91) (Tables 2 and 3).

From the IPAQ data no statistical difference was observed between groups for vigorous PA, but there was a significant change over time (Group: p = 0.53, η_p^2 = 0.12, Time: p = 0.01 = 0.20, Interaction: p = 0.92, η_p^2 < 0.001). There was also no observed difference between groups for moderate PA (Group: p = 0.29, η_p^2 = 0.04, Time: p = 0.35, η_p^2 = 0.04, Interaction p = 0.18, η_p^2 = 0.08) or moderate and vigorous combined PA, but a significant change over time in the latter (Group: p = 0.33, η_p^2 = 0.10, Time: p = 0.003, η_p^2 = 0.24, Interaction: p = 0.21, η_p^2 = 0.07) (Table 3).

Total PA was not calculated because of low compliance for recording walking data.

3.3.2 | Logbooks

Groups were similar at week zero for mean total PA calculated from logbooks and there was no consistent change in total PA over time or difference between groups over the 10-week period (Figure 1) (Group p = 0.15, η_p^2 = 0.08, Time p = 0.18, η_p^2 = 0.06 Interaction p = 0.45, η_p^2 = 0.04). However, there was a greater increase in time spent in moderate PA in CYC compared to CON (Figure 2) (Group p = 0.02, η_p^2 = 0.24, Time p = 0.11, η_p^2 = 0.07, Interaction p = 0.56, η_p^2 = 0.04) as well as in moderate and vigorous PA combined (Group p = 0.008, η_p^2 = 0.30, Time p = 0.29, η_p^2 = 0.15. Interaction p = 0.52, η_p^2 = 0.04). No differences were observed in light PA (Group p = 0.55, η_p^2 = 0.02, Time p = 0.43, η_p^2 = 0.04, Interaction p = 0.81, η_p^2 = 0.02). Because of the distribution of data, vigorous PA could not be analysed for statistical significance.

3.3.3 | Cycle Commuting

Participants cycled 65 ± 38 min per round trip, that is, the total time of cycling to and from work. Mean round trip duration was similar (p = 0.51) between wk 4 (66 ± 39 min) and wk 8 (64 ± 38 min). Mean cycle intensity was 56 ± 11% $\dot{V}O_{2max}$.

Mean heart rate was similar at weeks 4 (119 ± 12 bpm) and 8 (121 ± 19 bpm, p = 0.39) as was oxygen consumption (wk 4: 1.6 ± 1.0, wk 8: 1.6 ± 1.4, L.min^{-1}, p = 0.54).

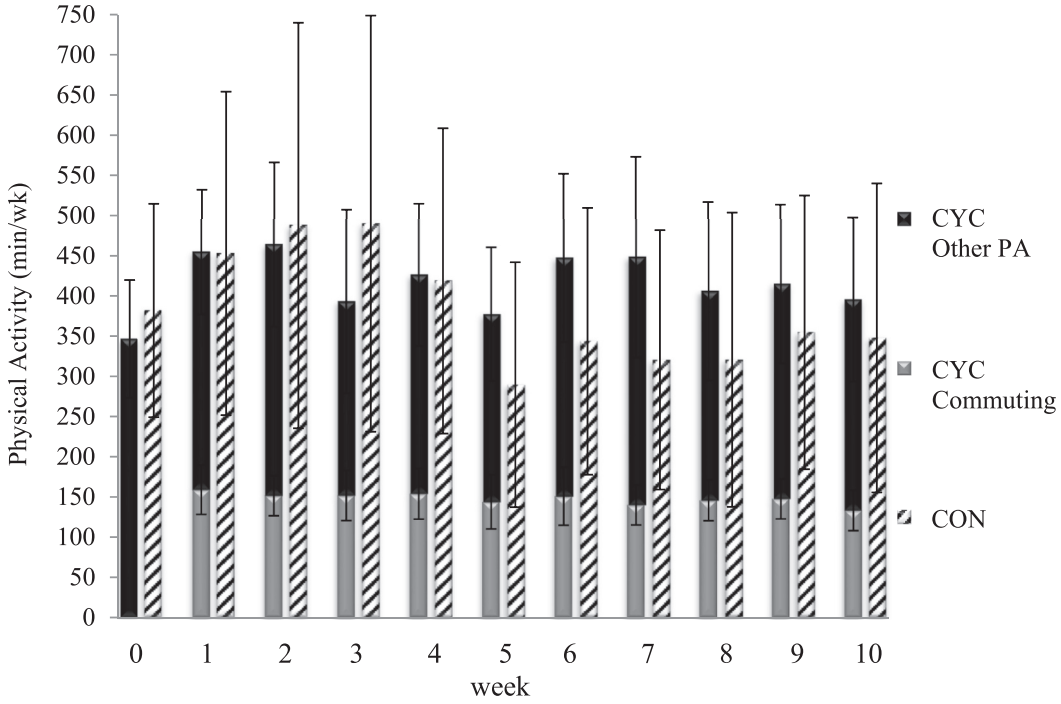

FIGURE 1 | Total physical activity (PA) per week from logbooks (mean ± SD) in control (CON) ($n = 13$) and commuter cycling (CYC) ($n = 13$) groups, with cycle commuting and other physical activities differentiated in CYC. (Mixed linear model differences from wk 0: Total PA Group $p = 0.15$, Time $p = 0.18$, Interaction $p = 0.45$).

3.3.4 | Non-Cycle Commuting Physical Activity

Weekly PA unrelated to commuter cycling did not appear to change over time and there was no difference between groups (Group $p = 0.61$, $\eta_p^2 = 0.03$, Time $p = 0.30$, $\eta_p^2 = 0.05$, Interaction $p = 0.35$, $\eta_p^2 = 0.05$) (Figure 1).

3.4 | Aerobic Capacity

Groups were similar in absolute $\dot{V}O_{2max}$ ($l \cdot min^{-1}$) ($p = 0.56$) and relative to body mass ($ml \cdot kg \cdot in^{-1}$) ($p = 0.48$) at baseline (Table 1). Relative $\dot{V}O_{2max}$ increased by 10.5 ± 16.2% after 10 weeks of commuting in CYC and decreased in CON by 2.8 ± 12.3% ($p = 0.03$, η_p^2 0.188) (Table 1).

3.5 | Resting Heart Rate

Groups had similar resting heart rates at baseline ($p = 0.33$). At 10 weeks, resting heart rate decreased (−5.4 ± 6.8%) in CYC compared to an increase (1.7 ± 9.5%) in CON ($p = 0.02$, $\eta_p^2 = 0.168$) (Table 4).

3.6 | Resting Blood Pressure

Groups were similar at baseline for systolic ($p = 0.176$) and diastolic blood pressure ($p = 0.08$). No effect of commuter cycling on systolic BP was detected (Table 4). Diastolic BP decreased, −1.2 ± 7.5%, in CYC compared to a 11.9 ± 16.5% increase in CON ($p = 0.02$, $\eta_p^2 = 0.223$) (Table 4).

3.7 | Cardiometabolic Blood Parameters

One CYC participant was excluded from C-reactive protein (CRP) analysis due to elevated CRP levels, indicating an underlying ailment. Another CYC participant was excluded from glucose, insulin and homeostatic model assessment—insulin resistance (HOMA-IR) analysis due to questionable insulin concentration, possibly not having been fasted at baseline, and was 81% greater at baseline than at follow-up. No group differences were observed at baseline for total cholesterol, HDL, LDL, triglycerides, CRP, fasting plasma glucose, insulin or HOMA-IR and no significant effects of commuter cycling on any blood parameters were observed (Table 4).

4 | Discussion

The main findings from the present study are that commuter cycling ~150 min/wk for just 10 weeks can improve cardiorespiratory fitness, resting heart rate, and diastolic blood pressure, all known markers of cardiovascular health. Unexpectedly, these occurred without measurable changes in total amount of PA or body composition. The main difference in physical activity was a greater amount of moderate-intensive PA, in contrast to the control group. The enhanced cardiorespiratory fitness observed is likely due to the increase in PA intensity. This is supported by a cross-sectional study comparing walking versus cycling to work, in which health benefits observed with cycling were not observed with walking (Vaara, Vasankari, Fogelholm, Koski, and Kyröläinen 2020), attributed to the increased intensity of cycling (Oja et al. 1991). These findings support the hypothesis that healthy adults can improve cardiovascular disease risk factors simply by incorporating regular

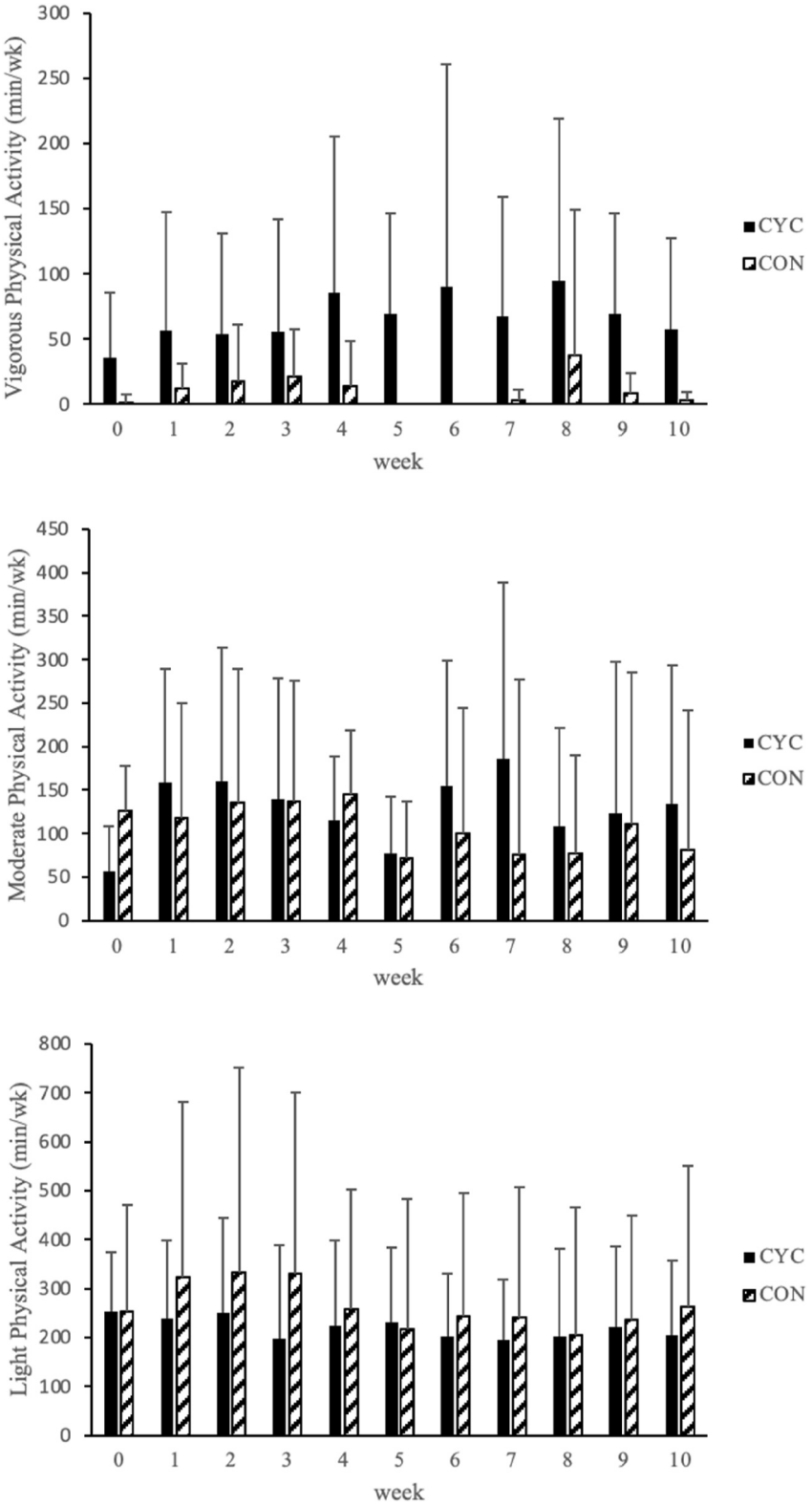

FIGURE 2 | Vigorous, moderate and light physical activity (PA) per week from logbooks (mean ± SD) in control (CON) ($n = 13$) and commuter cycling (CYC) groups ($n = 13$) groups. (Mixed linear model differences from wk 0: moderate PA Group $p = 0.02$, Time $p = 0.11$ Interaction $p = 0.56$; light PA Group $p = 0.55$, Time $p = 0.43$, Interaction $p = 0.81$). Data distribution invalidated vigorous PA analysis.

TABLE 4 | Physiological and biochemical measures (mean ± SD) at baseline (week 0) and after 10 weeks of commuter cycling (CYC) and in a control group (CON).

	week 0		week 10		
	CYC	CON	CYC	CON	*p*
Systolic BP (mmHg)	120 ± 14	116 ± 8	113 ± 10	114 ± 12	0.17
Diastolic BP (mmHg)	75 ± 9	74 ± 6	68 ± 9	76 ± 8	0.02
Heart $rate_{rest}$ ($b \cdot min^{-1}$)	61 ± 11	57 ± 8	58 ± 10	59 ± 9	0.02
Total Chol (mmol/L)	4.56 ± 0.88	5.39 ± 1.05	4.70 ± 0.79	5.12 ± 1.05	0.64
HDL (mmol/L)	0.95 ± 0.32	1.15 ± 0.29	0.95 ± 0.34	1.20 ± 0.31	0.32
LDL (mmol/L)	3.20 ± 0.59	3.72 ± 1.03	3.17 ± 0.64	3.42 ± 0.97	0.25
Trig (mmol/L)	1.61 ± 1.69	1.14 ± 0.63	1.57 ± 1.13	1.07 ± 0.57	0.94
CRP (mg/dL)[a]	0.74 ± 0.72	0.85 ± 0.97	0.99 ± 0.68	0.52 ± 0.68	0.06
Glucose (mmol/L)[a]	5.20 ± 0.30	5.46 ± 0.54	5.19 ± 0.29	5.27 ± 0.47	0.20
Insulin (uU/mL)[a]	6.79 ± 3.04	5.94 ± 2.43	7.00 ± 3.07	5.55 ± 2.91	0.44
HOMA-IR[a]	1.58 ± 0.71	1.47 ± 0.69	1.63 ± 0.76	1.33 ± 0.83	0.30

Note: p determined by General Linear Model repeated measures ANOVA for group * time interaction.
Abbreviations: BP, blood pressure; CRP, C-reactive protein; HDL, high-density lipoprotein; HOMA-IR, homeostatic model assessment for insulin resistance; LDL, low-density lipoprotein; Trig, triglycerides; ; Total Chol, total cholesterol.
[a]$n = 12$ for CYC.

cycle commuting into their lifestyles, without a structured exercise programme.

4.1 | Physical Activity

To our knowledge this is the first study to monitor and report *ad libitum* PA, in addition to that prescribed, in a commuter cycling intervention in healthy, working adults. We primarily used IPAQ data to categorise participants, whereas conclusions about total PA and intensity levels were based on weekly logbook data. Total PA was unaffected by the intervention which contrasts with previous findings from De Geus et al.'s nonrandomised intervention in which diaries were used to record activities (de Geus et al. 2008). In that study PA outside of commuting was also not constrained. They reported greater PA (cycling + leisure PA) in a cycling group than controls after 6 months of commuter cycling, although leisure PA was not reported separately. In another study by Reich et al. (Reich et al. 2020), in which participants in their cycling intervention group were asked to achieve 150 $min.wk^{-1}$ for their commute for 1 year, no significant difference in change in total PA between groups was observed.

In the present study, the lack of significant effects on total PA reported, and noncycle commuting activities, may have been obscured from low resolution of the self-reported data, since activities lasting less than 5 min were not recorded. It may be that short-lasting incidental activities were reduced or that inaccuracies in reporting occurred.

The impact of a cycle commuting intervention on existing PA is largely underreported in the literature. The expected effect on outcome variables with any PA intervention may be influenced by compensatory effects on other activities (King et al. 2007) and, thus, knowing effects of an intervention in which other activities are not constrained is valuable.

Despite the lack of effect on total physical activity in the present study, commuter cycling significantly contributed to a greater proportion of activity being performed at a greater intensity. Growing evidence suggests that vigorous activity confers a greater cardio protective effect than more moderate exercise (Swain and Franklin 2006) and that intensity of PA is associated with reduced risk independent of volume (Tanasescu et al. 2002). This is likely due to cardiorespiratory fitness, more so than physical activity level per se, being associated with reduced cardiovascular disease, although the two are inexorably linked (Han et al. 2022; Fardman et al. 2021).

4.2 | Cardio-Respiratory Fitness

Maximal oxygen consumption ($\dot{V}O_{2max}$) increased, by 10.5%, in CYC while decreasing slightly in CON, which supports previous RCTs that have shown improved $\dot{V}O_{2max}$ with cycle commuting (Oja et al. 1991; Møller et al. 2011; Hendriksen et al. 2000). Previous RCTs of commuter cycling resulted in increases in $\dot{V}O_{2max}$ of 12.5% after 8 weeks (Møller et al. 2011), 7.3% after 10 weeks (Oja et al. 2011, 1991) and 6% after 26 weeks (Hendriksen et al. 2000). In contrast, De Geus et al. observed only a slight increase (1.3%) after 6 months (de Geus et al. 2009). However, only 38% adhered to the directive to cycle commute ≥ 3 times per week. The variability in increase in $\dot{V}O_{2max}$ with a commuter cycling intervention is likely due to the varying load (volume, intensity and energy expenditure) achieved (de Geus et al. 2009). In our study, CON and CYC groups were matched for baseline $\dot{V}O_{2max}$, as fitness level can influence increase in $\dot{V}O_{2max}$. Oja et al. (1991) also attempted to account for baseline fitness by putting half of "low fitness" and half of "high fitness" in each of their control and cycle commuting intervention groups. However, they controlled other PA to prior levels during the intervention. Our study not only had a balanced participation (for sex and fitness) in control and intervention groups but

also allowed ad libitum PA in addition to the prescribed commuter cycling. Thus, our study might be considered more ecologically valid. Our findings provide evidence that cardiorespiratory fitness can be significantly increased with commuter cycling, even if total PA is not increased. The decreased resting heart rate observed in CYC is also indicative of enhanced fitness.

4.3 | Blood Pressure

Diastolic blood pressure (DBP) decreased in CYC compared to CON but systolic blood pressure (SBP) was not altered. This is similar to de Geus et al. (de Geus et al. 2008) who found only DBP to be reduced over a 1-year cycling intervention. That systolic blood pressure (SBP) was unaffected supports findings from other commuter cycling interventions (de Geus et al. 2008; Møller et al. 2011). Møller et al. (2011) observed decreases in both SBP and DBP with 8 weeks of a commuter cycling intervention, but this was not different from the decrease observed in their control group. We suspect that effects on blood pressure were a result of the increased proportion of higher intensity PA in our intervention group. In Swain and Franklin's review (Swain and Franklin 2006) they found that PA at greater intensities was associated with a reduction in diastolic blood pressure than PA at lower intensities, with no intensity effect on systolic blood pressure.

4.4 | Body Composition

No effect of cycle commuting on body composition was observed in the present study.

In contrast, in a large cross-sectional study in men by Vaara, Vasankari, Fogelholm, Koski, and Kyröläinen (2020), differences in body composition (lower body mass, BMI and waist circumference) between cycle commuters and passive commuters was observed. However, because of the cross-sectional nature of that study, it cannot be determined whether the cycle commuting caused the reduction or whether those having a lower body mass and, possibly greater muscle to fat ratio, were more likely to commute by bike. It may also be that the duration of the present study was not long enough for a significant change in body composition to occur and/or the energy expenditure of cycling was compensated by increasing dietary intake and/or decreasing other short, incidental physical activities. Our findings also contrast one other RCT of commuter cyclists by Møller et al. (2011) in which a decrease in skin-fold thickness was observed after 8 weeks. An explanation for the difference may lie in the fact that their participants were told that "prior levels of leisure time physical activity should be maintained", in addition to the prescribed 20 min day^{-1} of commuter cycling. Additionally, Møller et al. (2011) had more than twice the number of males as females and weight loss as a result of increased exercise is more common in males (Ballor and Keesey 1991). This is most likely because the absolute energy requirements are greater for most males than females when exercising for a given period of time at the same relative intensity (Donnelly and Smith 2005; de Geus et al. 2007). The amount of PA performed in Moller et al.'s study is unknown, as they measured cycling in kilometres, which does not offer insight into duration or intensity. It is unknown if participants in the present study cycled less than those in Møller et al. (2011), as in the present study cycling was measured by time and perceived intensity. Nevertheless, the $\dot{V}O_{2max}$ increase, without a change in body mass or composition, is important as greater cardiorespiratory fitness is associated with a reduction in all-cause mortality (Barry et al. 2014).

4.5 | Cardiometabolic Blood Parameters

4.5.1 | Cholesterol Fractions

Similar to our findings, Oja et al. (1991) did not observe significant effects of a 10-week commuter cycling intervention on cholesterol; however, there was a trend towards increased HDL cholesterol. In contrast, Peterman et al. (2019) observed an increase in HDL cholesterol with a 4-week intervention of workstation cycling. Their participants averaged 1.77 h of cycling per day versus 1.08 h in the present study. de Geus et al. (2008) also observed positive changes in cholesterol after 6 months and 1 year of cycle commuting. It appears that a greater load and/or duration of intervention (Oja et al. 2011) than that in the present study are necessary to achieve significant blood lipid changes.

4.5.2 | CRP

In our study no effect of cycle commuting on CRP was observed, despite a systematic review of physical activity and atherosclerosis finding PA was inversely correlated with CRP (Palmefors et al. 2014). Although 17 studies were included, only four were high quality and three medium quality. All of these were clinical populations with cardiovascular disease, obesity or hypercholesterolaemia, two did not find an effect of PA on CRP. In a lower quality study cited with healthy (sedentary) 25–40-year-olds (Reed et al. 2010) no effect on CRP was observed from a running/energy restriction intervention (4x/week over 4 months). In another study of 30–64 year-olds with PA and/or low fat diet intervention (Camhi et al. 2010), only diet, in women with metabolic syndrome, had an effect and higher baseline CRP was also associated with a greater decrease in CRP. This may explain our lack of change in CRP as our participants had baseline CPR of < 1.0 $mg.L^{-1}$, whereas in most other interventions the baseline was > 1.0 $mg.L^{-1}$. Our study was also shorter than many of the other interventions, but in one study at 3 months of a cycle commuting intervention, in obese and overweight, a decrease in CRP was observed (Gram et al. 2017), however, their baseline was > 1.0 $mg.L^{-1}$. It is hypothesised that the initial metabolic state and CRP are largely responsible for the lack of CRP change in our study population.

Others have also observed that weight (fat) loss plays a greater role than PA in CRP decrease in those with elevated CRP (Church et al. 2010), and may enhance any effect of PA on CRP (Fedewa et al. 2016). The exercise dose also affects the response. In a large ($n = 6208$) cross-sectional study, active commuting ≥ 45 $min.day^{-1}$ resulted in lower CRP (−16.8%), with a smaller,

nonsignificant response (−7.4%) when adjusted for covariables, with 15–29 min.day^{-1} of active commuting (Allaouat et al. 2023). Our study was at the upper end of the low dose but, more importantly, the normal initial CRP levels, healthy metabolic state, body composition, and lack of change in the latter, likely explain our lack of change in CRP.

4.5.3 | Glucose, Insulin and HOMA-IR

Numerous studies have shown positive acute and chronic effects of PA on glucose tolerance and insulin resistance (Richter et al. 2021). In a prospective cohort study over ~ 14 years, cycle commuting was associated with reduced type 2 diabetes risk, more so than walking (Honda et al. 2022). In meta analyses the risk reduction for type 2 diabetes associated with 11.25 and 22.5 MET-hours.week^{-1} of active commuting was 15% and 30%, respectively (Raza et al. 2020). Based upon cycle commuting using ~4–6.8 METs (Herrmann et al. 2024) and that CYC commuted for ~150 min per week, ~10–17 MET-h cycle commuting was conducted per week in the present study. Nevertheless, we did not observe an effect of 10 weeks of cycle commuting on glucose regulation (HOMA-IR). One previous 12-week cycling intervention did positively impact HOMA-IR (AminiLari et al. 2017); however, this was in insulin resistant, type 2 diabetics. The fact that the participants in the present study, although inactive, were healthy with normal insulin and glucose levels, may contribute to the lack of effect. In another intervention with inactive but otherwise healthy individuals, with varying modes and intensities of active commuting, a significant change in insulin sensitivity (hyperinsulinaemic euglycemic clamp) was observed after 6 months but not 3 months of cycle commuting (Bruhn et al. 2021). The duration of our intervention may have been too short, and HOMA-IR not sensitive enough, to observe a change in healthy individuals.

4.6 | Limitations

The relatively small sample size and limited duration of the intervention, make it difficult to draw firm conclusions on the effectiveness of cycle commuting to increase overall PA level or affect body composition, when activities outside of commuting are ad libitum. These limitations, as well as the fact that our population was healthy, and with a limited age range, should also be considered when interpreting, in particular cardiometabolic responses. The self-report measure of PA is also a limitation. To verify the present findings future study with more objective measures of all PA or energy expenditure would be valuable.

5 | Conclusions

From current literature it is unclear if incorporating cycling to and from work increases overall physical activity levels and enhances cardiometabolic fitness. We observed, in healthy adults, ~150 min/week of commuter cycling for 12 weeks is sufficient to enhance $\dot{V}O_{2max}$, resting heart rate and diastolic blood pressure, all predictors of cardiovascular health. These changes occurred without measurable changes to total amount of physical activity, body composition or mass. The amount of moderate to intensive physical activity increased and was likely responsible for the enhancement in cardiovascular fitness observed. Although limited in duration and sample, this study contributes to the growing body of literature indicating that intensity of exercise is important to cardiovascular fitness and that by incorporating cycle commuting into one's regular activities the proportion of more intensive exercise can be increased.

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Ethics Statement

Ethical approval was obtained from the local Ethics Committee (10/153) and written informed consent was obtained from participants.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

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

References

Allaouat, S., J. I. Halonen, J. J. Jussila, et al. 2023. "Association Between Active Commuting and Low-Grade Inflammation: A Population-Based Cross-Sectional Study." *European Journal of Public Health* 34, no. 2: 292–298. https://doi.org/10.1093/eurpub/ckad213.

AminiLari, Z., M. Fararouei, S. Amanat, et al. 2017. "The Effect of 12 Weeks Aerobic, Resistance, and Combined Exercises on Omentin-1 Levels and Insulin Resistance Among Type 2 Diabetic Middle-Aged Women." *Diabetes & Metabolism Journal* 41, no. 3: 205. https://doi.org/10.4093/dmj.2017.41.3.205.

Ballor, D., and R. E. Keesey. 1991. "A Meta-Analysis of the Factors Affecting Exercise-Induced Changes in Body Mass, Fat Mass and Fat-free Mass in Males and Females." *International Journal of Obesity* 15, no. 11: 717–726.

Barry, V. W., M. Baruth, M. W. Beets, J. L. Durstine, J. Liu, and S. N. Blair. 2014. "Fitness vs. Fatness on All-Cause Mortality: A Meta-Analysis." *Progress in Cardiovascular Diseases* 56, no. 4: 382–390. https://doi.org/10.1016/j.pcad.2013.09.002.

Ben-Shachar, M., D. Lüdecke, and D. Makowski. 2020. "Effectsize: Estimation of Effect Size Indices and Standardized Parameters." *Journal of Open Source Software* 5, no. 56: 2815. https://doi.org/10.21105/joss.02815.

Booth, M. 2000. "Assessment of Physical Activity: An International Perspective." *Research Quarterly for Exercise & Sport* 71, no. 2: 114–120. https://doi.org/10.1080/02701367.2000.11082794.

Bruhn, L., R. Kjøbsted, J. S. Quist, et al. 2021. "Effect of Exercise Training on Skeletal Muscle Protein Expression in Relation to Insulin Sensitivity: Per-protocol Analysis of a Randomized Controlled Trial (GO-ACTIWE)." *Physiological Reports* 9, no. 10: e14850. https://doi.org/10.14814/phy2.14850.

Camhi, S. M., M. L. Stefanick, P. M. Ridker, and D. R. Young. 2010. "Changes in C-Reactive Protein From Low-Fat Diet And/or Physical Activity in Men and Women With and Without Metabolic Syndrome." *Metabolism* 59, no. 1: 54–61. https://doi.org/10.1016/j.metabol.2009.07.008.

Church, T. S., C. P. Earnest, A. M. Thompson, et al. 2010. "Exercise Without Weight Loss Does Not Reduce C-Reactive Protein: The INFLAME Study." *Medicine & Science in Sports & Exercise* 42, no. 4: 708–716. https://doi.org/10.1249/mss.0b013e3181c03a43.

de Geus, B., S. De Smet, J. Nijs, and R. Meeusen. 2007. "Determining the Intensity and Energy Expenditure During Commuter Cycling." *British Journal of Sports Medicine* 41, no. 1: 8–12. https://doi.org/10.1136/bjsm.2006.027615.

de Geus, B., J. Joncheere, and R. Meeusen. 2009. "Commuter Cycling: Effect on Physical Performance in Untrained Men and Women in Flanders: Minimum Dose to Improve Indexes of Fitness." *Scandinavian Journal of Medicine & Science in Sports* 19, no. 2: 179–187. https://doi.org/10.1111/j.1600-0838.2008.00776.x.

de Geus, B., E. Van Hoof, I. Aerts, and R. Meeusen. 2008. "Cycling to Work: Influence on Indexes of Health in Untrained Men and Women in Flanders. Coronary Heart Disease and Quality of Life." *Scandinavian Journal of Medicine & Science in Sports* 18, no. 4: 498–510. https://doi.org/10.1111/j.1600-0838.2007.00729.x.

Dinu, M., G. Pagliai, C. Macchi, and F. Sofi. 2019. "Active Commuting and Multiple Health Outcomes: A Systematic Review and Meta-Analysis." *Sports Medicine* 49, no. 3: 437–452. https://doi.org/10.1007/s40279-018-1023-0.

Donnelly, J. E., and B. K. Smith. 2005. "Is Exercise Effective for Weight Loss With Ad Libitum Diet? Energy Balance, Compensation, and Gender Differences." *Exercise and Sport Sciences Reviews* 33, no. 4: 169–174. https://doi.org/10.1097/00003677-200510000-00004.

Fardman, A., G. D. Banschick, R. Rabia, et al. 2021. "Cardiorespiratory Fitness Is an Independent Predictor of Cardiovascular Morbidity and Mortality and Improves Accuracy of Prediction Models." *Canadian Journal of Cardiology* 37, no. 2: 241–250. https://doi.org/10.1016/j.cjca.2020.05.017.

Fedewa, M. V., E. D. Hathaway, and C. L. Ward-Ritacco. 2016. "Effect of Exercise Training on C Reactive Protein: A Systematic Review and Meta-Analysis of Randomised and Non-randomised Controlled Trials." *British Journal of Sports Medicine* 51, no. 8: 670–676. https://doi.org/10.1136/bjsports-2016-095999.

Friedewald, W. T., R. I. Levy, and D. S. Fredrickson. 1972. "Estimation of the Concentration of Low-Density Lipoprotein Cholesterol in Plasma, Without Use of the Preparative Ultracentrifuge." *Clinical Chemistry* 18, no. 6: 499–502. https://doi.org/10.1093/clinchem/18.6.499.

Gram, A. S., E.-M. Bladbjerg, J. S. Quist, M. B. Petersen, M. Rosenkilde, and B. Stallknecht. 2017. "Anti-inflammatory Effects of Active Commuting and Leisure Time Exercise in Overweight and Obese Women and Men: A Randomized Controlled Trial." *Atherosclerosis* 265: 318–324. https://doi.org/10.1016/j.atherosclerosis.2017.06.923.

Han, M., R. Qie, X. Shi, et al. 2022. "Cardiorespiratory Fitness and Mortality From All Causes, Cardiovascular Disease and Cancer: Dose–Response Meta-Analysis of Cohort Studies." *British Journal of Sports Medicine* 56, no. 13: 733–739. https://doi.org/10.1136/bjsports-2021-104876.

Hendriksen, I. J. M., B. Zuiderveld, H. C.G. Kemper, and P. D. Bezemer. 2000. "Effect of Commuter Cycling on Physical Performance of Male and Female Employees." *Medicine & Science in Sports & Exercise* 32, no. 2: 504. https://doi.org/10.1097/00005768-200002000-00037.

Herrmann, S. D., E. A. Willis, and B. E. Ainsworth. 2024. "The 2024 Compendium of Physical Activities and its Expansion." *Journal of Sport & Health Science* 13, no. 1: 1–2. https://doi.org/10.1016/j.jshs.2023.09.008.

Hoevenaar-Blom, M. P., G. C. W. Wendel-Vos, A. M. W. Spijkerman, D. Kromhout, and W. Verschuren. 2011. "Cycling and Sports, but Not Walking, Are Associated With 10-year Cardiovascular Disease Incidence: The MORGEN Study." *European Journal of Cardiovascular Prevention & Rehabilitation* 18, no. 1: 41–47. https://doi.org/10.1097/hjr.0b013e32833bfc87.

Honda, T., Y. Hirakawa, J. Hata, et al. 2022. "Active Commuting, Commuting Modes and the Risk of Diabetes: 14-year Follow-up Data From the Hisayama Study." *Journal of Diabetes Investigation* 13, no. 10: 1677–1684. https://doi.org/10.1111/jdi.13844.

King, N. A., P. Caudwell, M. Hopkins, et al. 2007. "Metabolic and Behavioral Compensatory Responses to Exercise Interventions: Barriers to Weight Loss." *Obesity* 15, no. 6: 1373–1383. https://doi.org/10.1038/oby.2007.164.

Kodama, S., K. Saito, S. Tanaka, et al. 2009. "Cardiorespiratory Fitness as a Quantitative Predictor of All-Cause Mortality and Cardiovascular Events in Healthy Men and Women: A Meta-Analysis." *JAMA* 301, no. 19: 2024–2035. https://doi.org/10.1001/jama.2009.681.

Kukkonen-Harjula, K., R. Laukkanen, I. Vuori, et al. 1998. "Effects of Walking Training on Health-Related Fitness in Healthy Middle-Aged Adults–a Randomized Controlled Study." *Scandinavian Journal of Medicine & Science in Sports* 8, no. 4: 236–242. https://doi.org/10.1111/j.1600-0838.1998.tb00198.x.

Kuwahara, K., S. S. Sawada, H. Noma, et al. 2022. "Commuter Cycling and Risk of Type 2 Diabetes: A Cohort Study in Japan." *Diabetes Care* 45, no. 12: e179–e180. https://doi.org/10.2337/dc22-1267.

Møller, N. C., L. Østergaard, J. R. Gade, J. L. Nielsen, and L. Bo Andersen. 2011. "The Effect on Cardiorespiratory Fitness After an 8-week Period of Commuter Cycling–a Randomized Controlled Study in Adults." *Preventive Medicine* 53, no. 3: 172–177. https://doi.org/10.1016/j.ypmed.2011.06.007.

Oja, P., A. Mänttäri, A. Heinonen, et al. 1991. "Physiological Effects of Walking and Cycling to Work." *Scandinavian Journal of Medicine & Science in Sports* 1, no. 3: 151–157. https://doi.org/10.1111/j.1600-0838.1991.tb00288.x.

Oja, P., S. Titze, A. Bauman, et al. 2011. "Health Benefits of Cycling: A Systematic Review." *Scandinavian Journal of Medicine & Science in Sports* 21, no. 4: 496–509. https://doi.org/10.1111/j.1600-0838.2011.01299.x.

Palmefors, H., S. DuttaRoy, B. Rundqvist, and M. Börjesson. 2014. "The Effect of Physical Activity or Exercise on Key Biomarkers in Atherosclerosis–A Systematic Review." *Atherosclerosis* 235, no. 1: 150–161. https://doi.org/10.1016/j.atherosclerosis.2014.04.026.

Peterman, J. E., D. R. Bassett, W. H. Finch, et al. 2021. "Associations Between Active Commuting and Cardiovascular Disease in the United States." *Journal of Physical Activity and Health* 18, no. 12: 1525–1531. https://doi.org/10.1123/jpah.2021-0245.

Peterman, J. E., K. L. Morris, R. Kram, and W. C. Byrnes. 2019. "Cardiometabolic Effects of a Workplace Cycling Intervention." *Journal of Physical Activity and Health* 16, no. 7: 547–555. https://doi.org/10.1123/jpah.2018-0062.

Raza, W., B. Krachler, B. Forsberg, and J. N. Sommar. 2020. "Health Benefits of Leisure Time and Commuting Physical Activity: A Meta-Analysis of Effects on Morbidity." *Journal of Transport & Health* 18: 100873. https://doi.org/10.1016/j.jth.2020.100873.

Reed, J. L., M. J. D. Souza, and N. I. Williams. 2010. "Effects of Exercise Combined With Caloric Restriction on Inflammatory Cytokines." *Applied Physiology Nutrition and Metabolism* 35, no. 5: 573–582.

Reich, B., D. Niederseer, M. Loidl, et al. 2020. "Effects of Active Commuting on Cardiovascular Risk Factors: GISMO—A Randomized Controlled Feasibility Study." *Scandinavian Journal of Medicine & Science in Sports* 30, no. S1: 15–23. https://doi.org/10.1111/sms.13697.

Richter, E. A., L. Sylow, and M. Hargreaves. 2021. "Interactions Between Insulin and Exercise." *Biochemical Journal* 478, no. 21: 3827–3846. https://doi.org/10.1042/bcj20210185.

Saunders, L. E., J.M. Green, M. P. Petticrew, R. Steinbach, and H. Roberts. 2013. "What Are the Health Benefits of Active Travel? A Systematic Review of Trials and Cohort Studies." *PLoS One* 8, no. 8: e69912. https://doi.org/10.1371/journal.pone.0069912.

Swain, D. P., and B. A. Franklin. 2006. "Comparison of Cardioprotective Benefits of Vigorous versus Moderate Intensity Aerobic Exercise." *American Journal of Cardiology* 97, no. 1: 141–147. https://doi.org/10.1016/j.amjcard.2005.07.130.

Tanasescu, M., M. F. Leitzmann, E. B. Rimm, W. C. Willett, M. J. Stampfer, and F. B. Hu. 2002. "Exercise Type and Intensity in Relation to Coronary Heart Disease in Men." *JAMA* 288, no. 16: 1994–2000. https://doi.org/10.1001/jama.288.16.1994.

Taylor, R. W., D. Keil, E. J. Gold, S. M. Williams, and A. Goulding. 1998. "Body Mass Index, Waist Girth, and Waist-To-Hip Ratio as Indexes of Total and Regional Adiposity in Women: Evaluation Using Receiver Operating Characteristic Curves." *American Journal of Clinical Nutrition* 67, no. 1: 44–49. https://doi.org/10.1093/ajcn/67.1.44.

Thomas, S., J. Reading, and R. J. Shephard. 1992. "Revision of the Physical Activity Readiness Questionnaire (PAR-Q)." *Canadian Journal of Sport Sciences* 17, no. 4: 338–345.

Vaara, J. P., T. Vasankari, M. Fogelholm, H. Koski, and H. Kyröläinen. 2020. "Cycling but Not Walking to Work or Study Is Associated With Physical Fitness, Body Composition and Clustered Cardiometabolic Risk in Young Men." *BMJ Open Sport & Exercise Medicine* 6, no. 1: e000668. https://doi.org/10.1136/bmjsem-2019-000668.

Wanjau, M. N., Y. Dalugoda, M. Oberai, et al. 2023. "Does Active Transport Displace Other Physical Activity? A Systematic Review of the Evidence." *Journal of Transport & Health* 31: 101631. https://doi.org/10.1016/j.jth.2023.101631.