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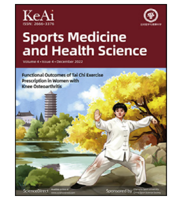

Habitual sedentary time and stationary time are inversely related to aerobic fitness

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A R T I C L E I N F O

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A B S T R A C T

A one metabolic-equivalent-of-task increase in peak aerobic fitness (peak MET) is associated with a clinically relevant improvement in survival risk and all-cause mortality. The co-dependent impact of free-living physical behaviours on aerobic fitness are poorly understood. The purpose of this study was to investigate the impact of theoretically re-allocating time spent in physical behaviours on aerobic fitness. We hypothesized that substituting sedentary time with any physical activity (at any intensity) would be associated with a predicted improvement in aerobic fitness. Peak volume rate of oxygen uptake ($\dot{V}O_2$peak) was assessed via indirect calorimetry during a progressive, maximal cycle ergometer protocol in 103 adults (52 females; [38 ± 21] years; [25.0 ± 3.8] kg/m^2; $\dot{V}O_2$peak: [35.4 ± 11.5] ml·kg^{-1}·min^{-1}). Habitual sedentary time, standing time, light- (LPA), moderate- (MPA), and vigorous-physical activity (VPA) were assessed 24-h/day via thigh-worn inclinometry for up to one week (average: [6.3 ± 0.9] days). Isotemporal substitution modelling examined the impact of replacing one physical behaviour with another. Sedentary time ($\beta = -0.8$, 95% *CI*: [-1.3, −0.2]) and standing time ($\beta = -0.9$, 95%*CI*: [−1.6, −0.2]) were negatively associated with $\dot{V}O_2$peak, whereas VPA was positively associated with relative $\dot{V}O_2$peak ($\beta = 9.2$, 95%*CI*: [0.9, 17.6]). Substituting 30-min/day of VPA with any other behaviour was associated with a 2.4–3.4 higher peak MET. Higher standing time was associated with a lower aerobic fitness. As little as 10-min/day of VPA predicted a clinically relevant 0.8–1.1 peak MET increase. Theoretically, replacing any time with relatively small amounts of VPA is associated with improvements in aerobic fitness.

Introduction

Cardiorespiratory or aerobic fitness represents the greatest amount of oxygen that can be delivered and extracted from inspired air while performing dynamic exercise involving a large proportion of total body muscle mass. The gold standard assessment of aerobic fitness involves determination of the maximum or peak volume rate of oxygen consumption ($\dot{V}O_2$peak) via indirect calorimetry. Regular aerobic physical activity and exercise are associated with a reduced risk and improved management of most major chronic diseases,[1] with a greater disease risk reduction among persons with higher aerobic fitness.[2,3] Specifically, 1 metabolic equivalent of task (MET; multiple of resting oxygen consumption) increase in aerobic fitness may confer a 12%–35% improvement in survival risk and 15% risk reduction of all-cause mortality, as reviewed by Ross et al. (2016).[3] Aerobic fitness is largely influenced by activity-related factors (e.g., exercise), as well as body composition, sex, and genetics.[4,5] There is a strong argument that aerobic fitness should be included as the sixth vital sign in clinical settings.[3] Investigating the impact of specific physical behaviours on aerobic fitness may provide insight into pragmatic strategies for improving cardiovascular health.

Higher levels of objectively measured moderate-vigorous physical activity and lower levels of objectively measured sedentary time are associated with higher aerobic fitness levels.[6,7] However, the correlational approach implemented in these reports does not consider the co-dependent nature of habitual activity, in that increased time spent in one activity displaces another (e.g., more physical activity time may displace sedentary time). Isotemporal substitution modelling examines the theoretical impact of replacing time spent in one behaviour versus another, within the parameters of a finite day.[8,9] This analytical approach

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Abbreviations

CI	confidence interval
DBP	diastolic blood pressure
HR	heart rate
kg	kilogram
LPA	light-intensity physical activity
MET	metabolic equivalent of task
min	minute(s)
ml	millilitre
MPA	moderate-intensity physical activity
MVPA	moderate-vigorous-intensity physical activity
SBP	systolic blood pressure
$\dot{V}O_2$peak	peak volume rate of oxygen consumption
VPA	vigorous-intensity physical activity

is useful in evaluating the impact of replacing discouraged physical behaviours (i.e., sedentary time) with encouraged behaviours (i.e., physical activity). Activity monitors provide an objective measure of habitual activity. Unlike monitors worn on the waist or wrist, accelerometers positioned on the thigh can differentiate sedentary time from standing.[10] Accordingly, thigh-monitors provide greater detail of the time spent in different postures and can be used to inform the relationship between habitual standing and sedentary times with clinical or health outcomes.

Results from the Maastricht study demonstrated that replacing time spent sedentary with higher (> 110 step/min) or lower (< 110 step/min) intensity activity was associated with greater estimated maximum cycling power outputs.[11] While peak aerobic power may provide an index of cardiorespiratory fitness, $\dot{V}O_2$peak was not directly assessed. Therefore, their predicted improvements in aerobic fitness, as well as the clinical interpretation of these potential benefits are less clear. Furthermore, the dichotomization into higher and lower activity based on a step rate threshold provides poor activity intensity resolution compared to time spent in light (LPA), moderate (MPA) or vigorous (VPA) aerobic physical activity; particularly when MPA ranges from ~80 to 130 step/min.[12,13] Accordingly, questions regarding the impact of replacing a physical behaviour with another on aerobic fitness remain.

The purpose of the present study was to examine the impact of theoretically allocating time spent in one behaviour (sedentary time, standing time, LPA, MPA, VPA) with the same duration of another on $\dot{V}O_2$peak. It was hypothesized that substituting sedentary time with any physical activity (LPA, MPA and VPA) would be associated with a predicted improvement in aerobic fitness.

Materials & methods

Participants

103 participants (52 females) were included in the present study. Some activPAL data have been previously published in a sub-sample of 73 (37 females) that evaluated the impact of habitual activity on peripheral vascular function[14] and the influence of sedentary activity on baroreflex sensitivity.[15] However, the current purpose and statistical analyses (i.e., comparison with aerobic fitness) are independent from these previous reports. Based on a moderate-large effect size ($f^2 = 0.25$) and 5 predictor variables (sedentary time, standing time, LPA, MPA and VPA), a sample size calculation estimated that a minimum of 58 participants were needed assuming a two-tailed, $\alpha = 0.05$ and $\beta = 80\%$ power (G*Power, v3.1[16]). All participants had a resting blood pressure < 140/90 mm of mercury and were not prescribed medications known to interfere with the cardiovascular system. All older females ($n = 22$) were post-menopausal and not on hormone replacement therapy, younger females were naturally menstruating ($n = 15$) or using oral contraceptive pills ($n = 15$).

Ethical approval statement

Participants were informed of the methods and procedures of determining aerobic fitness and habitual activity verbally and in writing before providing written informed consent. All protocols and procedures conformed to the Declaration of Helsinki and were approved by the Dalhousie University Health Sciences Research Ethics Board.

Experimental design

Participants reported to the laboratory three times. The first visit involved measurements of height and body mass, assessment of aerobic fitness, and to receive the activity monitor. The second visit involved the determination of systemic hemodynamics. The third brief visit consisted of returning the monitor ~7-days following the first visit.

Anthropometrics, systemic hemodynamics, and aerobic fitness

Height and weight were measured using a calibrated stadiometer and physician's scale (Health-*O*-Meter, McCook IL, USA) to the nearest 0.5 cm and 0.1 kg, respectively. An incremental and maximal effort exercise test on an electromagnetically braked cycle ergometer (Lode Excalibur Sport, Groningen, The Netherlands) was administered to determine $\dot{V}O_2$peak via a mixing chamber-based commercial metabolic system (TrueOne 2400, Parvo Medics Inc., Sandy, UT, USA). A cycle ergometer-based test was selected over a treadmill-based test for safety reasons. Heart rate (HR) was determined throughout the test via a chest-strap monitor (Polar H9, Kempele, FI).

Resting HR was determined via cardiac intervals obtained from lead II of a standard bipolar limb lead electrocardiogram. Beat-by-beat resting systolic (SBP) and diastolic (DBP) blood pressures were measured using finger photoplethysmography (Portapres; Finapres Medical Systems, Amsterdam, The Netherlands). These pressures were then used to calculate mean arterial pressure using the equation $^1/_3$ SBP + $^2/_3$ DBP. Left upper arm measurements of SBP and DBP were also recorded by an automated vital signs monitor (Carescape v100, General Electric Healthcare, Mississauga, ON, Canada) and used to correct the SBP and DBP values from the Portapres waveform to the brachial artery. The Portapres and electrocardiogram recordings were sampled continuously using a PowerLab (PL3508 PowerLab 8/53, ADInstruments, Sydney, Australia) data acquisition system at 200 Hz and 1000 Hz, respectively. Recordings were displayed in real-time and analyzed offline using LabChart software (Version 8, ADInstruments, Sydney, Australia). At least 5 min of resting beat-by-beat hemodynamic data were averaged to represent baseline values.

Following a 5-min warm-up period of light-intensity cycling (30–50 W), the workload was set at 1 W·kg^{-1} body mass and gradually increased by 15 W· min^{-1} (older adults) or set at 70 W and increased incrementally by 20 W ·min^{-1} (younger adults) until voluntary exhaustion. Strong verbal encouragement was provided throughout the test. Upon completion of the test, the workload was immediately reduced to the warm-up level for a 5-min cool-down period. The final workload achieved was recorded as peak aerobic power (in watts). Relative $\dot{V}O_2$ data (millilitre of oxygen ml·kg^{-1}·min^{-1}) were averaged over 15-s intervals for the duration of the test. $\dot{V}O_2$peak was considered as the greatest consecutive 30 s average and was defined as the highest $\dot{V}O_2$ value attained if two of the following criteria were observed: 1) a respiratory exchange ratio ≥ 1.10, 2) a rating of perceived exertion (6–20 scale) > 17, or 3) a peak heart rate ≥ 95% age-predicted maximum (220 – age). Most achieved either the respiratory exchange ratio ($n = 93$), ratings of perceived exertion ($n = 96$), or peak HR criterion ($n = 64$).

To confirm a high inter-day reliability for relative $\dot{V}O_2$peak, a sub-sample of the participants (3 younger females, 6 older males, and 3 older females) completed an additional maximal aerobic fitness test either 6 weeks (older adults) or 12 weeks (younger adults) following their initial test. A high correlation ($r = 0.91$, $p < 0.001$), no significant difference between testing days (via paired *t*-test; $p = 0.40$), a 6.5% coefficient of variation, a low mean difference ([0.8 ± 3.1] ml·kg^{-1}·min^{-1}), and a low mean absolute difference ([2.4 ± 1.9] ml·kg^{-1}·min^{-1}) were observed.

Objective habitual physical and sedentary activity monitoring

The activPAL inclinometer (Pal Technologies Ltd., Glasgow, UK) is a valid measure of habitual stepping,[17] standing,[18] and sedentary time.[10] Participants wore an activPAL 24-h/day for up to 7-days. All participants had a minimum 5 days of valid data, including at least 1 weekend day (average: [6.3 ± 0.9] days), consistent with monitoring guidelines.[10,19] The activPAL was waterproofed and secured using a nitrile finger cot and transparent medical dressing (Tegaderm™, 3 M, London, ON, Canada) to the midline of their right thigh, one-third of the way between the hip and the knee. Participants self-reported their waking hours (excluding all sleeping) to assist with activPAL analysis.

ActivPAL data were analyzed using a customized LabVIEW program (LabVIEW 2013; National Instruments, Austin, TX, USA) that confirmed waking hours and summarized daily averages of time spent awake, standing, sitting/lying down.[15] This program also reported the number and duration of various sedentary patterns (i.e., total time spent in bouts > 60 min and the number sedentary breaks/waking hour).[15] Physical activity intensity (LPA, MPA, VPA) was determined using step rate thresholds that were determined using cross-validated curvilinear cadence-intensity equations individualized for height (younger adults) or body mass index (older adults) that are more accurate than the default activPAL settings in determining physical activity intensity.[13,17,20] The method of using stepping cadence to derive physical activity intensity is described in more detail elsewhere.[21]

Statistical analysis

Descriptive statistics for continuous and categorical variables were presented as means ± standard deviations and frequencies, respectively. Statistical significance was accepted as $p < 0.05$. All statistics were completed in SPSS Version 27.0 (IBM, NY).

Times spent in each physical behaviour (sedentary time, standing time, LPA, MPA, VPA) were converted from mins/day and standardized into 30-min units (e.g., 8 h of sedentary time = 16 units) for all modelling analyses. The selection of 30 min is the most commonly used magnitude of replacing a physical behaviour with another for isotemporal substitution analysis.[9] Firstly, the individual relationship of each single physical behaviour versus $\dot{V}O_2$peak was determined. Then, partition models were conducted with all physical behaviours simultaneously entered into the model to evaluate the independent relationship between each behaviour with $\dot{V}O_2$peak. Both the unadjusted associations and the models with covariates included are presented. The predicted residuals of all models were confirmed normal via a Shapiro-Wilk test. Multicollinearity was assessed via variance inflation factors, which were less than the standard threshold of 10 (all, < 2.6).[22] Age, sex, and body mass index were added as covariates in the single and partition models.

To determine the effect of replacing 30 min of one behaviour with another on $\dot{V}O_2$peak, isotemporal substitution modelling consisted of removing one physical behaviour variable (replacement variable) and inserting the total physical behaviour time (i.e., sum of sedentary time, standing time, LPA, MPA, VPA) into the model. See Model 1 and Model 2 for an example of replacing sedentary time.

Model 1. Relative $\dot{V}O_2$peak = Intercept + β1Standing + β2LPA + β3MPA + β4VPA + $\underline{\beta\text{5Sedentary Time}}$ + β6Covariates + Error.

Model 2 (replacing sedentary time with total time example). Relative $\dot{V}O_2$peak = Intercept + β1Standing + β2LPA + β3MPA + β4VPA + $\underline{\beta\text{5Total Time}}$ + β6Covariates + Error.

In this example, any statistically significant predictor variable in Model 2 would describe the theoretical impact of replacing sedentary time with that physical behaviour variable on aerobic fitness. Since all variables were standardized to 30-min units, the impact of replacing 30 min of the other physical behaviour variable is determined. As such, the β values of the significant predictors in Model 2 would indicate the magnitude of $\dot{V}O_2$peak change if 30 min were allocated from the replacement variable with another physical behaviour. Incorporating sleep time creates a constant number for the total time variable (i.e., full 24 h), which cannot be used in regression analysis and thus was omitted. All isotemporal models covaried for age, sex, and body mass index. To coincide with a previous study that reported estimated maximum cycling power output,[11] a model is presented for peak aerobic power in Supplemental Table 1 and Supplemental Fig. 1. For direct comparisons with corresponding MET values, relative $\dot{V}O_2$peak outcomes were divided by the standard relative resting $\dot{V}O_2$ value of 3.5 ml· kg^{-1}·min^{-1}. Since all $\dot{V}O_2$ data were divided by a constant value of 3.5, *p*-values for comparisons are identical between the $\dot{V}O_2$peak and peak METs comparisons.

Results

Participant characteristics, systemic hemodynamics, aerobic fitness, and habitual activity are summarized in Table 1.

In the unadjusted single models, standing time was negatively associated, and both MPA and VPA were positively associated with aerobic fitness (all, $p < 0.001$; see Tables 2 and 3). After adjusting for covariates, no activity was univariately associated with aerobic fitness (all, $p > 0.08$;

Table 1
Participant descriptive characteristics, resting systemic hemodynamics, aerobic fitness, habitual physical and sedentary activity.

Variable	Participants ($n = 103$)
Characteristics	
Age (years)	38 ± 21 (19–77)
Age Groups (< 30 years, > 55 years)	67, 34
Sex (males, females)	51, 52
Older Adults (> 55 years; males, females)	12, 22
Younger Adults (< 30 years; males, females)	37, 30
Body Mass Index (kg·m^{-2})	25.0 ± 3.8 (17.7–40.6)
Systemic Hemodynamics	
Resting Heart Rate (beat/min)	66 ± 10 (44–92)
Systolic Blood Pressure (mmHg)	118 ± 11 (107–139)
Diastolic Blood pressure (mmHg)	66 ± 9 (55–89)
Mean Arterial Pressure (mmHg)	84 ± 8 (73–101)
Maximal Aerobic Fitness	
Relative $\dot{V}O_2$peak (ml·kg^{-1}·min^{-1})	35.4 ± 11.5 (12.6–61.1)
Peak METs	10.1 ± 3.3 (3.6–17.5)
Peak Aerobic Power (W)	215 ± 73 (75–390)
Peak Heart Rate (beat/min)	176 ± 20 (128–212)
Peak RER ($\dot{V}CO_2/\dot{V}O_2$)	1.21 ± 0.09 (0.98–1.40)
Habitual Activity	
Step Count (step/day)	10 055 ± 3240 (4409–18 259)
LPA (min/day)	69 ± 25 (11–145)
MPA (min/day)	34 ± 18 (5–89)
VPA (min/day)	5 ± 5 (0–34)
Standing Time (h/day)	4.2 ± 1.5 (0.2–9.4)
Total Sedentary Time (h/day)	9.6 ± 1.7 (4.5–13.2)
Prolonged Sedentary Time (h/day)	2.9 ± 1.5 (0.5–8.6)
Sedentary Breaks (break/waking hour)	2.9 ± 0.8 (1.4–4.8)

Data are presented as means ± standard deviations (range) or as a proportion. 2 male participants were between 30 and 55 years of age. METs, metabolic equivalents of task (1 MET = 3.5 ml· kg^{-1}·min^{-1}); RER, respiratory exchange ratio; $\dot{V}CO_2$, volume rate of carbon dioxide produced; $\dot{V}O_2$, volume rate of oxygen consumed; LPA, light-intensity physical activity; MPA, moderate-intensity physical activity; VPA, vigorous-intensity physical activity; kg, kilogram; m, meter; ml, millilitre; min, minute; mmHg, millimetres of mercury. Prolonged sedentary time was calculated as the time spent engaged in uninterrupted bouts longer than 60 min.

Table 2
Single variable and partition models examining the associations between sedentary time, standing time, and physical activity intensity with relative peak volume rate of oxygen consumption.

Models	Sedentary Time β (95% CI)	Standing Time β (95% CI)	LPA β (95% CI)	MPA β (95% CI)	VPA β (95% CI)
Single Models without Covariates	−0.1 (−0.8, 0.5)	**−1.3 (-2.1, -0.6)**	2.7 (0.0, 5.4)	**6.4 (2.8, 10.0)**	**24.4 (12.8, 36.0)**
Single Models with Covariates	−0.2 (−0.6, 0.2)	−0.2 (−0.7, 0.3)	0.8 (−1.0, 2.5)	−0.5 (−3.2, 2.2)	7.3 (−1.0, 15.6)
Partition Model without Covariates	**−1.2 (-2.0, -0.4)**	**−2.0 (-3.0, -1.1)**	1.4 (−1.1, 4.0)	−0.1 (−4.1, 3.8)	**18.5 (6.9, 30.0)**
Partition Model with Covariates	**−0.8 (-1.3, -0.2)**	**−0.9 (-1.6, -0.2)**	0.6 (1.2, 2.4)	−2.8 (−5.7, 0.1)	**9.2 (0.9, 17.6)**

Data are presented as the unstandardized beta coefficient (β) and 95% confidence intervals (CI). LPA, light-intensity physical activity; MPA, moderate-intensity physical activity; VPA, vigorous-intensity physical activity. Covariates included sex, age, and body mass index. Single models reflect the individual physical behaviour with aerobic fitness. The partition models include all physical behaviours simultaneously. All physical behaviours were normalized from mins/day into 30-min daily units for consistency with previous isotemporal substitution models (e.g., 1 h of LPA = 2 LPA units). Bolded values indicate statistical significance at $p < 0.05$.

Table 3
Single variable and partition models examining the associations between sedentary time, standing time, and physical activity intensity with peak metabolic equivalents of task.

Models	Sedentary Time β (95% CI)	Standing Time β (95% CI)	LPA β (95% CI)	MPA β (95% CI)	VPA β (95% CI)
Single Models without Covariates	0.0 (−0.2, 0.1)	**−0.4 (-0.6, -0.2)**	0.8 (0.0, 1.5)	**1.8 (0.8, 2.9)**	**7.0 (3.7, 10.3)**
Single Models with Covariates	−0.1 (−0.2, 0.0)	−0.1 (−0.2, 0.1)	0.2 (−0.3, 0.7)	−0.1 (−0.9, 0.6)	2.1 (−0.3, 4.4)
Partition Model without Covariates	**−0.3 (-0.6, -0.1)**	**−0.6 (-0.8, -0.3)**	0.4 (−0.3, 1.1)	0.0 (−1.2, 1.1)	**5.3 (2.0, 8.6)**
Partition Model with Covariates	**−0.2 (-0.4, -0.1)**	**−0.3 (-0.5, -0.1)**	0.2 (−0.3, 0.7)	−0.8 (−1.6, 0.0)	**2.6 (0.2, 5.0)**

Data are presented as the unstandardized beta coefficient (β) and 95% confidence intervals (CI). LPA, light-intensity physical activity; MPA, moderate-intensity physical activity; VPA, vigorous-intensity physical activity. Covariates included sex, age, and body mass index. Single models reflect the individual physical behaviour with peak metabolic equivalents of task (METs; 1 MET = 3.5 ml·kg^{-1}·min^{-1}). The partition models include all physical behaviours simultaneously. All physical behaviours were normalized from mins/day into 30-min daily units for consistency with previous isotemporal substitution models (e.g., 1 h of LPA = 2 LPA units). Bolded values indicate statistical significance at $p < 0.05$.

Tables 2 and 3). In the adjusted and unadjusted partition models, independent negative associations with aerobic fitness were observed for both sedentary and standing time (both, $p < 0.01$, Tables 2 and 3). In contrast, VPA was positively associated with aerobic fitness ($p < 0.03$, Tables 2 and 3). Neither LPA nor MPA were independently associated with aerobic fitness (both, $p > 0.06$, Tables 2 and 3).

Substituting 30 min/day of sedentary time, standing time, LPA, or MPA with VPA was associated with an increase in relative $\dot{V}O_2$peak (Fig. 1) and peak METs (Fig. 2; all, $p < 0.04$). Conversely, replacing VPA with any other behaviours was associated with a lower aerobic fitness (all, $p < 0.04$; see Figs. 1 and 2). Replacing time spent in sedentary, standing, LPA, and MPA with each other did not change predicted aerobic fitness levels (all, $p > 0.08$).

Discussion

We examined the impact of theoretically replacing one physical behaviour with another on aerobic fitness. Reallocating time spent in any behaviour (sedentary, standing, LPA or MPA) with VPA was associated with a higher predicted $\dot{V}O_2$peak. In contrast, replacing any physical behaviour with LPA or MPA was not associated with a higher in $\dot{V}O_2$peak. In addition, sedentary time and standing time were independently, negatively associated to aerobic fitness. Using the isotemporal substitution approach that controlled for impactful covariates, we demonstrate the potential favourable impact of lowering stationary (sedentary and standing) time and integrating high intensity activity on aerobic fitness.

Aerobic fitness is inversely associated with cardiovascular disease risk and all-cause mortality.[3] A 5% change in aerobic fitness has been used as a clinically meaningful difference.[6] Alternatively, a 1 unit change in peak METs (or ~3.5 ml· kg^{-1}·min^{-1}) provides a clinically significant shift in disease risk.[3] Based on the average relative $\dot{V}O_2$peak of our cohort ([35.4 ± 11.5] ml·kg^{-1}·min^{-1}), a 1 MET change amounts to ~10%. Our isotemporal substitution modelling indicated that replacing 30 min/day of any other physical behaviour with VPA was associated with a 9–12 ml·kg^{-1}·min^{-1} higher $\dot{V}O_2$peak. A predicted increase of ~3 METs (10.5 ml·kg^{-1}·min^{-1}; see Fig. 2) by engaging in 30 min/day of VPA is quite substantial and represents a major clinically relevant improvement in aerobic fitness and overall cardiovascular health. We have demonstrated that adults engage in an average of 18 min/day at stepping cadences between 120 and 140 step/min (i.e., proxy of VPA) and 3 min/day at cadences > 140 step/min.[21] Given the challenges of implementing 30 min/day VPA (or 210 min/week), it should be acknowledged that even 10 min/day (or 70 min/week) was associated with a predicted 3–4 ml·kg^{-1}·min^{-1} higher aerobic fitness (i.e., ~1 MET). Importantly, VPA is attainable for most populations with heuristic stepping cadence recommendations of VPA being equal to ~130 step/-min,[12] which is within the upper threshold for walking cadences (< 140 step/min).[12,17] For optimal health benefits, the increased VPA may need to be accumulated in bouts of a sufficient length (e.g., ≥ 5 min) to achieve the physiological stress required for cardiovascular adaptation. The World Health Organization recommends a minimum of 75 min per week of VPA for health benefits (e.g., cardiovascular, musculoskeletal health, etc.), with the approach that more activity at any intensity is better than less.[23] However, the minimum bout duration of VPA required to elicit meaningful health outcomes is unclear. Using self-reported activity, a harmonized meta-analysis on the joint effects of sitting time and physical activity indicated that those who sat for < 4 h/day or > 8 h/day had similar rates of all-cause mortality when both groups accumulated > 35.5 MET-hours/week of physical activity.[24] Using objective measures, we did not observe any participant engage in < 4 h/day of sedentary time, despite including healthy adults across a range of low-high aerobic fitness levels (see Table 1). Nevertheless, the observational study[24] supports that time spent in higher-intensity physical activity may offset some of the negative effects of sedentary time. Future studies are encouraged to separate MPA from VPA, rather than a composite MVPA measure, to provide further insight into the potential health benefits of higher physical activity intensities. Specifically, the independent impact of VPA may have been masked by being summed with MPA, which would inherently comprise most of the time spent in the composite MVPA outcome (average MPA = 34 min/day [87% of MVPA], VPA = 5 min/day [13% of MVPA]) (Table 1).

In addition to habitual activity, aerobic fitness is largely influenced by genetics, body composition, and sex factors.[4,5] In models adjusted for impactful covariates, standing and sedentary times were negatively

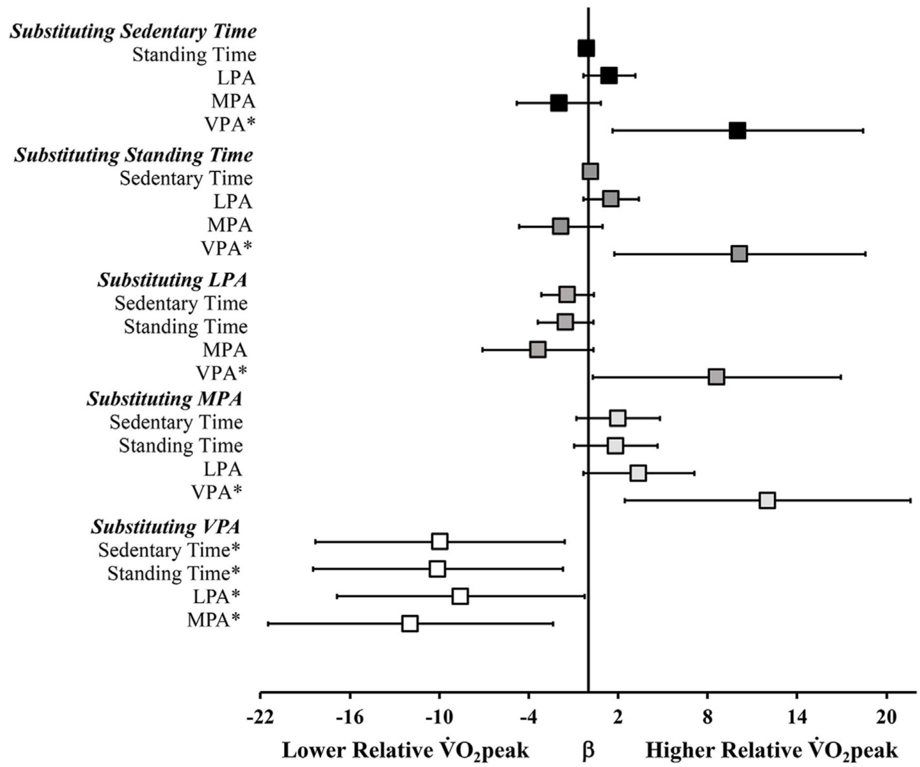

Fig. 1. The results of the isotemporal substation models examining the impact of replacing 30 min of each physical behaviour with another on relative aerobic fitness (V̇O$_2$peak; ml·kg^{-1}·min^{-1}). The beta coefficients ($\beta \pm 95\%$ *CI*) represent the change in relative V̇O$_2$peak predicted by substituting one behaviour with another. LPA, light-intensity physical activity; MPA, moderate-intensity physical activity; VPA, vigorous-intensity physical activity. *$p < 0.05$. The vertical line is set at 0.

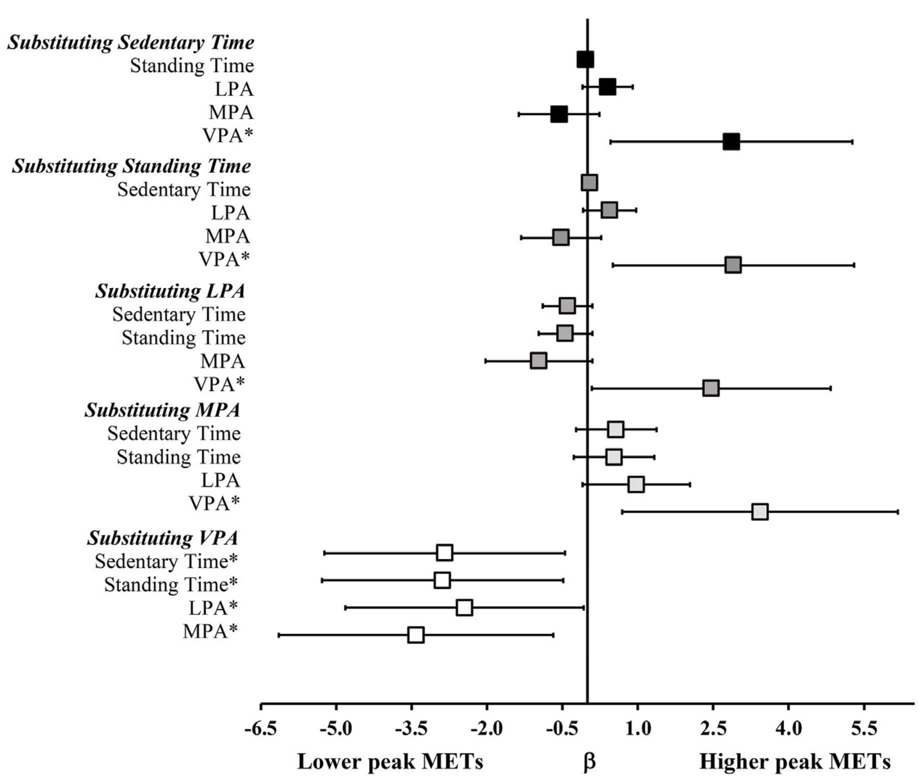

Fig. 2. The results of the isotemporal substation models examining the impact of replacing 30 min of each physical behaviour with another on peak metabolic equivalents of task (peak METs; 1 MET = 3.5 ml·kg^{-1}·min^{-1}). The beta coefficients ($\beta \pm 95\%$ *CI*) represent the change in peak METs predicted by substituting one behaviour with another. LPA, light-intensity physical activity; MPA, moderate-intensity physical activity; VPA, vigorous-intensity physical activity. *$p < 0.05$. The vertical line is set at 0.

associated with aerobic fitness (Table 2). Herein, spending more time in 'stationary' postures instead of moving was associated with lower aerobic fitness. Such observations clearly demonstrate that theoretically replacing sedentary time with standing time is insufficient to improve aerobic fitness (Fig. 1). This is not to indicate that replacing sedentary time with standing time does not have any benefit on other cardiovascular risk factors, with a review of clinical trials on the topic observing small improvements in blood glucose levels and body fat mass, but no effect on blood pressure.[25] Our study adds to the growing debate as to whether inactive standing is a posture that can be categorized as LPA[26] or is associated with null/negative impacts on health outcomes.[27–29] As identified in Ross et al. (2020),[30] the Canadian recommendation of standing is based on low quality evidence consisting exclusively of self-reported standing time.[26] The type (i.e., occupational versus leisure) and pattern by which standing (i.e., intermittent versus prolonged) is accumulated may impact whether standing favourably impacts cardiovascular function.[31] Future high-quality research using objective measures is needed to better characterize standing, aligning with a recent call for better classifications of 'active' versus 'passive' standing.[32]

Our data suggests that the cardiovascular stress associated with habitual LPA and MPA may be insufficient to promote increases in $\dot{V}O_2$peak. This may be due to the smaller cardiovascular responses to LPA or MPA that do not translate to major adaptations in the central (i.e., maximal cardiac output) or peripheral (i.e., oxygen extraction) components of maximal aerobic fitness. Certainly, these findings are specific to a healthy population with preserved cardiovascular function. It is plausible that engaging in LPA or MPA may improve aerobic fitness levels in populations with disease, who are even more sedentary (study average: [9.6 ± 1.7] h/day), and/or are very aerobically unfit. Efforts that promote moving more, and specifically engaging in VPA, might be needed to elicit improvements in aerobic fitness in healthy individuals. This corresponds with recommendations that highlight the importance of short and sporadic bouts of high-intensity incidental physical activity to improve population health.[33] Individuals who have health concerns may require consultation with a qualified exercise and/or health professional prior to beginning very vigorous activity.

The present study is the first to address the theoretical impact of adjusting physical lifestyle factors on cardiorespiratory fitness using a multidisciplinary combination of advanced epidemiological techniques, objectively measured habitual activity, and direct assessment of aerobic fitness. The use of thigh-worn inclinometry permitted the separation between standing and sedentary times,[10] which could not be captured using self-report measures or monitors worn on the wrist or waist. The study sample was relatively healthy and future research evaluating the impact of habitual activity modifications in persons with poor cardiovascular health and exercise intolerance is warranted. Our observation in healthy persons suggests that a greater effect of activity reallocation on aerobic fitness may be observed in less healthy adults. It is plausible that any activity (including LPA or MPA) may increase aerobic fitness in those with worse cardiovascular health. We cannot rule out reverse causality as a contributing factor (i.e., more aerobically fit people engage in more VPA and less sedentary time). Our assessment of aerobic fitness is based on peak, rather than $\dot{V}O_{2max}$ during a maximal exercise test, however older adults ($n = 34/104$) typically do no exhibit a plateau in $\dot{V}O_{2max}$ during tests of maximal aerobic fitness. Nevertheless, an additional confirmation trial to confirm that the highest $\dot{V}O_2$ was achieved could be considered a limitation. This study is cross-sectional in design and therefore longitudinal or cohort studies that include objective measures of habitual activity and maximal aerobic fitness are needed to better establish causality.

More sedentary time and standing time were independently associated with lower aerobic fitness. Theoretically, replacing any physical behaviour with VPA was associated with a clinically relevant higher aerobic fitness in healthy adults. Strategies that promote less stationary time and more high-intensity physical activity may be needed to increase aerobic fitness in healthy adults.

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Ethical approval statement

Participants were informed of the methods and procedures of determining aerobic fitness and habitual activity verbally and in writing before providing written informed consent. All protocols and procedures conformed to the Declaration of Helsinki and were approved by the Dalhousie University Health Sciences Research Ethics Board.

Authors' contributions

MWO drafted the manuscript. All authors contributed to the collection and/or analysis of data. All authors edited the manuscript and approved the final version for submission.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Submission statement

The work has not been published and is not under the consideration for publication elsewhere. The article has been approved by all authors and if accepted, will not be published elsewhere including electronically (regardless of language) without consent of the copyright-holder.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.smhs.2022.10.002.

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