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Association between device-measured stepping behaviors and cardiometabolic health markers in middle-aged women: The Australian Longitudinal Study on Women's Health

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The associations between different types and contexts of stepping behaviors and cardiometabolic (CM) health markers are unclear. This study aimed to examine the associations of daily total, walking, stair, incidental and purposeful steps with cardiometabolic risk. A total of 943 women (mean age ± SD = 44.1 ± 1.6 years) from the Australian Longitudinal Study on Women's Health (ALSWH) were included in this cross-sectional study. Daily total, walking, stair, incidental, and purposeful steps were measured using thigh-worn accelerometry. Outcomes comprised of CM markers of adiposity, blood pressure, resting heart rate, lipids, glycaemia, and the composite CM score. We used generalized linear modeling and multiple linear regression to assess the associations. We observed that all stepping behaviors were beneficial to CM health, for example, compared to the lowest quartile (Q1), the change of the composite CM score across low to high quartile of purposeful steps was −0.12 (Q2, 95% CI: −0.41, 0.17), −0.16 (Q3, −0.46, 0.14), and −0.36 (Q4, −0.66, −0.05). Stair steps showed linear associations with blood pressure and adiposity biomarkers, for example, the change of quartile of waist circumference was −1.45 cm (Q2, −4.35, 1.44), −3.56 cm (Q3, −6.52, −0.60), and −7.08 cm (Q4, −10.31, −3.86). Peak 30-min walking intensity showed independent association with adiposity biomarkers (p linear < 0.001 and p = 0.002 for waist circumference and BMI, respectively). Our study showed that all stepping forms were beneficial to CM health. Higher stair steps and peak 30-min walking cadence were associated with a steep decline of adiposity biomarkers. Purposeful steps showed more consistent associations with CM biomarkers than incidental steps.

KEYWORDS
accelerometry, epidemiology, intensity, physical activity, stair, walking

Gita D Mishra and Emmanuel Stamatakis: Joint Senior Authorship.

Section III: Health, Disease, and Physical Activity.

1 | INTRODUCTION

Cardiovascular diseases (CVDs) are the leading cause of death worldwide and a major contributor to disability. There were 523 million prevalent cases of total CVD and 18.6 million deaths from CVD in 2019.[1] The regular physical activity (PA), whether performed in low or high volumes, could help prevent CVDs.[2] Stepping, as the fundamental unit of human ambulatory performance physical activity, has the advantage of being an intuitive and relatively easy metric to measure objectively.[3] Stepping behavior consists of movement accumulated as walking steps, running steps, and stair steps. Meanwhile, movement stepping can be accumulated as purposeful (planned) steps (moving from A to B) or incidental steps (ambulating/shuffling).

To date, a large number of studies have shown that the daily total steps have been consistently associated with all-cause and CVD mortality and morbidity.[3-7] A large systematic review including 17 prospective studies involving over 30 000 adults demonstrated consistent evidence that daily steps are associated with all-cause mortality, CVD mortality, and morbidity, but showed inconsistent evidence for dysglycemia outcomes.[5] Existing studies have used waist/hip-worn accelerometry to measure total steps but did not take into account the diversity of stepping behavior (walking, running, stair climbing). Waist/hip-worn accelerometry cannot distinguish or provide accuracy in detecting different postures and activity types; however, this limitation can be overcome by thigh-worn accelerometry, which allows the study of different stepping behaviors.[8] Thigh placement enables highly accurate detection of specific PA types (e.g., sitting/lying, standing, walking, running, stair climbing, and cycling).[9,10] No population-level study has examined the independent association of type-specific stepping behavior measured with accelerometers and CM health markers.

A study has researched the association between step intensity, which is indicated by the peak 30-min cadence, and CM health in women after adjusting for step volume.[6] However, no studies have focused on peak 30-min cadence within walking behavior. Existing studies using waist/hip-worn accelerometers were unable to detect walking behavior and were unable to calculate the peak 30-min walking cadence. Other studies used self-reported data to measure walking pace or intensity. For example, a pooled analysis of 50 225 participants from 11 British population cohorts showed that walking pace has an independent association with CVD health.[11] However, the limitations to using self-report measurement to assess PA are well documented; for instance, participants may misinterpret the questions being asked or have difficulty measuring the intensity of PA.[12]

The association of purposeful movement steps (≥40 steps/min) and incidental steps (<40 steps/min)[3] with CM health is not clear. A recent study found no association of time spent for purposeful steps with all-cause mortality after adjusting for step volume.[3] It is unclear how sporadic incidental steps which has low intensity are associated with CM health and how this association differs from that of purposeful steps.

It is well-recognized that women are at higher risk of developing CVD after menopause.[13] PA could be an important early preventative intervention before women enter postmenopausal stage. Premenopausal and postmenopausal women may react differently to the effects of PA, due to differences in endogenous hormonal state.[14] However, few studies concentrate on how PA is associated with CM health markers in early to mid-40 year old women, and none of them focused specifically on device-measured walking type. Focusing on women entering menopausal transition provides evidence for building up early prevention for CM risk.

This study aimed to examine the hypothesis that the device-measured stepping behaviors (type, context) have differential associations with CM health markers in middle-aged women.

2 | MATERIALS AND METHODS

2.1 | Sample

This cross-sectional analysis was based on the Menarche-to-Pre-Menopause substudy (M-PreM) of the Australian Longitudinal Study on Women's Health (ALSWH). ALSWH is a national prospective study of biological and mental health, social and lifestyle factors, and health services among women.[13,15,16] Participants from the 1973 to 1978 cohort were asked to join the M-PreM study and those who responded positively were invited. The ethical approval was provided by the Metro South Health and Health Services Human Research Ethics Committee (reference number: HREC/2019/QMS/52052) and ratified by the University of Newcastle and the University of Queensland Human Research Ethics Committees.

2.2 | Measurement

2.2.1 | Exposure variables

Participants who attended a study site were fitted with thigh-worn triaxial accelerometers (activPAL3 micro and activPAL4 micro devices; PAL Technologies). If they could not attend a study site, they were mailed an accelerometer

with instructions. The accelerometers were attached to the middle of the anterior surface of the right thigh and worn continuously for 8 days.[13] Walking, running, and stair climbing were detected using ActiPASS software, which is based on a validated activity classification and step detection algorithm.[17,18] Notably, walking, running, and stair climbing are mutually exclusive. Stair climbing is distinct behavior from walking and running. We defined steps with a stepping rate <40 per minute as incidental and those with a stepping rate ≥40 per minute as purposeful steps.[3] In the context of free-living environment, step accumulation patterns observed over 1 min (i.e., cadence) can effectively distinguish incidental movements and purposeful movements which lead up to more persistent patterns.[19,20] We calculated each participant's average daily total, walking, stair, incidental and purposeful steps through dividing the number of steps foeach stepping behavior by the number of corresponding accelerometer-wearing days. We then categorized mean daily steps of each exposure into quartiles, with quartile 1 (Q1) indicating the lowest portion of steps and quartile 4 (Q4) indicating the highest portion. Since only 4% of participants had running steps in each outcome-specific sample, we dichotomized the participants as running (any running steps) and non-running. We used peak 30-min walking step cadence as a proxy of walking step intensity. Peak 30-min cadence is the mean steps per minute recorded for the 30 highest, but not necessarily, consecutive minutes in a day, representing participants' highest habitual efforts.[21]

2.2.2 | Confounders

The confounders in our study included age, occupation (No paid job, skill level 1 and 2, skill level 3 and 4, skill level 5),[22] education (less than year 12, trade/apprentice/certificate/diploma, college/university degree or above), diet (defined as servings of fruit and vegetable per day),[23] smoking status (current smoker, non-smoker), alcohol (never drink, less than once a week, drink on 1–4 days per week, above 1–4 days per week), sleep duration, self-rated health (excellent, very good, good, fair, poor), and daily sitting time. In addition, non-walking and non-stair steps were calculated by subtracting walking/stair steps from total steps (that also included running steps).

2.2.3 | Outcomes

The M-PreM study conducted anthropometric measures, blood pressure (BP) measurement and collection of blood.[13] BMI was derived as body weight (kg) divided by squared height (m^2). We divided waist circumference by hip circumference to derive the waist-hip ratio. Systolic (SBP), diastolic (DBP) blood pressure and resting heart rate were measured via triplicate measurements using an automated blood pressure monitor. Non-fasting blood samples were collected and analyzed for HbA1c (mmoL/moL), high-density lipoprotein (HDL) (mmoL/L), and triglycerides (TG) (mmoL/L). The details of the measurements were described in the M-PreM study cohort profile.[13] We divided total cholesterol by HDL to calculate the total-to-HDL cholesterol ratio. We used existing methods[24,25] to develop a composite CM risk score based on waist circumference, averaged BP, resting heart rate, total-to-HDL ratio and HbA1c. Waist circumference and average BP were used as an index for adiposity and hemodynamic outcomes, respectively. We selected the total-to-HDL cholesterol ratio to represent lipid outcomes, as this may be the most informative cholesterol-related index.[26] HbA1c was used to represent glycaemic outcomes. After z-score conversion (z=[value−mean]/SD) of 5 CM variables, the z-scores were summed and then divided by 5 to compile the composite CM risk score.

2.3 | Statistical analysis

All analyses were performed using R studio (version 1.4) software. We examined the associations between daily steps of each stepping behavior (totals steps, walking steps, stair steps, incidental steps, purposeful steps) and each CM biomarker or the composite CM risk score using generalized linear models and multiple linear regression. Generalized linear model coefficients indicate mean difference between the reference quartile (Q1, representing the lowest level of steps) and each of the higher quartile (Q2, Q3, Q4). The linear trend was examined using multiple linear regression. The statistical significance of the linear associations was based on 2-sided probability ($p < 0.05$). We observed no evidence of multicollinearity among exposures and covariates, as indicated by a variance inflation factor (VIF); for example, in the analysis of the waist circumference sample, the range of VIF for covariates was from 1.3 to 3.0. Because of the large number of data, we only present results for two models. In Model 1, we adjusted for demographic confounders (age, occupation and education), diet, smoking, alcohol, mean sleep time per day, self-rated health, and mean sitting time per day and additionally adjusted daily non-walking steps, non-stair steps, incidental steps, purposeful steps according to which explanatory variable we are examining. For triglycerides outcome, we further adjusted fasting time as it may affect the level of triglycerides. In model 2, we additionally adjusted walking intensity (approximated by peak 30-min walking cadence) to specifically examine the independent association of walking steps volume with CM biomarkers. In addition, we examined the independent association of peak 30-min walking intensity with CM

biomarkers. The coefficients for running were examined through generalized linear model with age, occupation, education, diet, smoking, alcohol, self-rated health, mean sleep time per day, mean sitting time per day, and non-running steps as confounders.

3 | RESULTS

3.1 | Sample characteristics

Figure 1 describes the derivation of the study sample. 943 participants had valid accelerometry data and were considered for inclusion in the outcome-specific analyses. The core sample consisted of 678 participants for waist circumference (Table 1). Table 1 presents the characteristics of participants by quartile of the mean steps per day. The mean age was 44.1 years (±1.6), and 68.4% had a college degree and above. The mean total steps per day were 10 103 (±3124) across the sample. The mean walking and stair steps per day were 9408 (±2825, 93.1% of the total) and 623 (±450, 6.2% of the total), respectively. The mean purposeful and incidental steps per day were 6870 (±2676, 68.0% of the total) and 3233 (±862, 32.0% of the total). Participants who took more steps were more likely to report better self-rated health and less sitting time.

3.2 | Association of each stepping behavior with CM biomarkers and the composite CM risk score (based on model 1)

3.2.1 | Total steps

Figure 2, Figure S1, Table S1 present the associations between total steps and CM health markers and the composite CM risk score. The results showed that higher daily total steps were associated with lower adiposity biomarkers (Figure 2A–C), BP (Figure 2D,E), resting heart rate (Figure 2F), total-to-HDL cholesterol ratio (Figure S1b), CM risk score (Figure S1f), and higher HDL (Figure S1a). The total steps did not show association with triglycerides (Figure S1c), HbA1c (Figure S1d) and glucose (Figure S1e).

3.2.2 | Walking steps

As shown in Figure 3, Table 2, we found an association between walking steps and waist-hip ratio, and the corresponding change of waist-hip ratio across low-to-high quartile of walking steps was: Q2, (−0.011 [−0.029, 0.006]); Q3, (−0.017 [−0.036, −0.0008]); Q4, (−0.014 [−0.033, 0.005]; *p*-linear = 0.134) (Figure 3C). Walking steps had an inverse

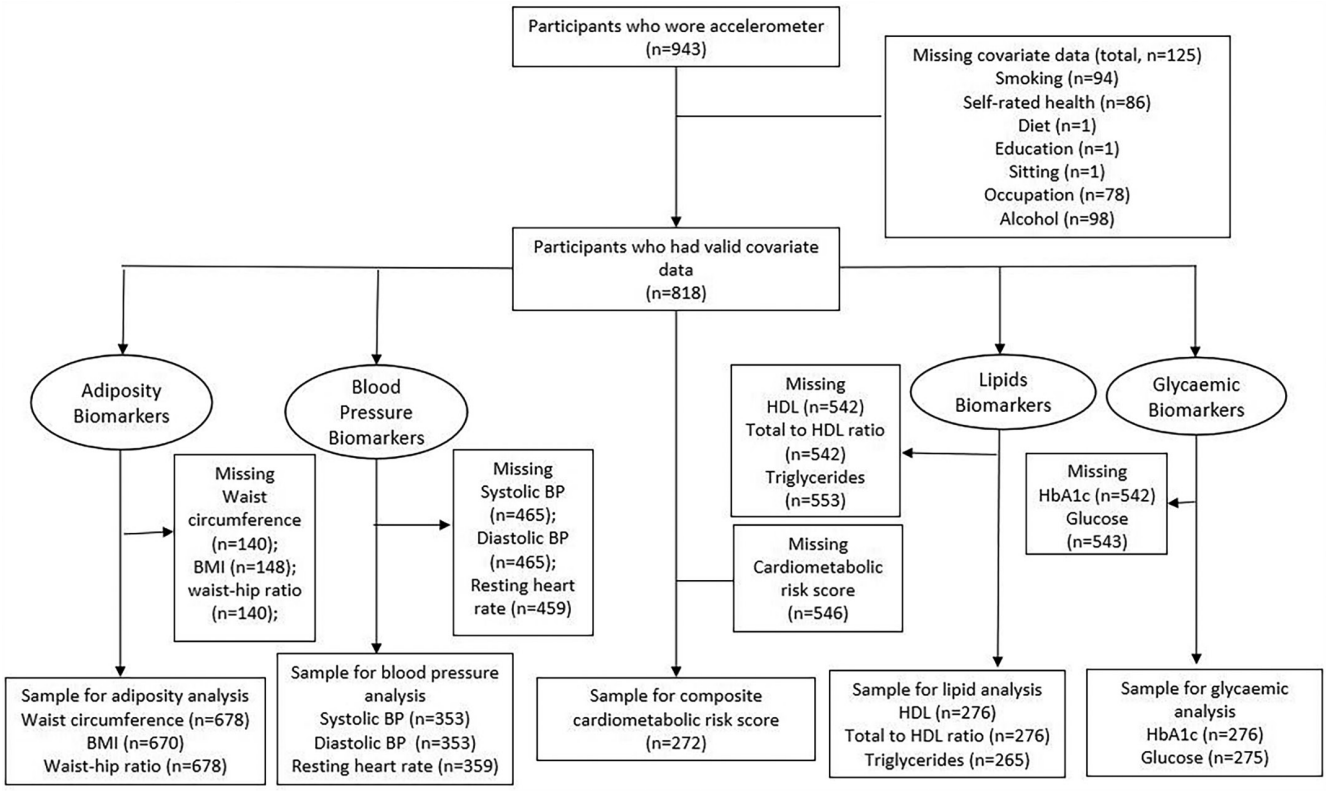

FIGURE 1 Participants flowchart.

TABLE 1 Baseline characteristics of waist circumference sample participants by quartiles of mean steps per day[a].

Characteristics	Overall	Quartile of the mean steps per day			
		Bottom quartile	2nd quartile	3rd quartile	Top quartile
Total *n*	678	169	169	171	169
Waist circumference, cm	88.4 (14.5)	94.7 (16.8)	89.7 (14.7)	86.3 (12.3)	83.1 (10.9)
Age, years	44.1 (1.6)	44.0 (1.7)	43.8 (1.6)	44.1 (1.6)	44.2 (1.6)
Occupation, *n* (%)[b]					
No paid job	78 (11.5)	25 (14.8)	18 (10.7)	20 (11.7)	15 (8.9)
Skill level 5	21 (3.1)	3 (1.8)	8 (4.7)	1 (0.6)	9 (5.3)
Skill level 3 and 4	137 (20.2)	43 (25.4)	35 (20.7)	30 (17.5)	29 (17.2)
Skill level 1 and 2	442 (65.2)	98 (58.0)	108 (63.9)	120 (70.2)	116 (68.6)
Education, *n* (%)					
Below year 12	20 (2.9)	9 (5.3)	3 (1.8)	5 (2.9)	3 (1.8)
Trade/apprenticeship or certificate/diploma	194 (28.6)	64 (37.9)	45 (26.6)	41 (24.0)	44 (26.0)
College/university or above	464 (68.4)	96 (56.8)	121 (71.6)	125 (73.1)	122 (72.2)
Diet[c]	3.14 (1.63)	2.80 (1.02)	3.01 (1.01)	3.32 (1.01)	3.44 (1.00)
Current smokers, *n* (%)	38 (5.4)	14 (8.3)	7 (4.1)	9 (5.3)	7 (4.1)
Alcohol, *n* (%)					
More than 4 days per week	269 (39.7)	63 (37.3)	65 (38.5)	74 (43.3)	67 (39.6)
1–4 days per week	63 (9.3)	6 (3.6)	16 (9.5)	24 (14.0)	17 (10.1)
Less than once per week	278 (41.0)	82 (48.5)	76 (45.0)	62 (36.3)	58 (34.3)
Never drink alcohol	68 (10.2)	18 (10.7)	12 (7.1)	11 (6.4)	27 (16.0)
Self-rated health, *n* (%)					
Excellent	112 (16.5)	21 (12.4)	19 (11.2)	24 (14.0)	48 (28.4)
Very good	311 (45.9)	70 (41.4)	79 (46.7)	86 (50.3)	76 (45.0)
Good	199 (29.4)	54 (32.0)	54 (32.0)	51 (29.8)	40 (23.7)
Fair	47 (6.9)	21 (12.4)	15 (8.9)	7 (4.1)	4 (2.4)
Poor	9 (1.3)	3 (1.8)	2 (1.2)	3 (1.8)	1 (0.6)
Sleep time (mins) per day	384.4 (61.2)	394.8 (71.6)	393.8 (64.1)	377.4 (52.6)	371.5 (49.2)
Sitting time (mins) per day	445.7 (102.2)	322.5 (47.7)	409.8 (19.2)	473.8 (18.9)	575.8 (58.1)
Non-walking steps per day	695 (573)	323 (197)	550 (297)	746 (403)	1156 (809)
Non-stair steps per day	9480 (2882)	5961 (1085)	8397 (654)	10 307 (705)	13 247 (1661)
Total steps per day	10 103 (3124)	6273 (1147)	8917 (618)	11 004 (638)	14 206 (1813)
Walking steps per day	9408 (2825)	5948 (1089)	8367 (664)	10 258 (709)	13 049 (1683)
Stair steps per day	623 (450)	312 (195.0)	521 (279)	698 (362)	959 (583)
Incidental steps per day	3233 (862)	2497 (587)	3102 (674)	3453 (699)	3876 (820)
Purposeful steps per day	6870 (2676)	3775 (973)	5815 (790)	7552 (856)	10 330 (1810)
Peak 30-min walking step cadence	118.4 (4.8)	115.7 (4.1)	117.5 (4.1)	119.4 (4.2)	121.1 (5.0)

[a]Values represent mean (SD), unless specified otherwise.

[b]Occupation groups were based on five skill levels in Australian Standard Classification of Occupations (ASCO) Second Edition: skill level 1 (bachelor degree or higher or at least 5 years relevant experience); skill level 2 (diploma or higher, or at least 3 years relevant experience); skill level 3 (Australian Qualification Framework (AQF) Certificate III or IV, or at least 3 years relevant experience); skill level 4 (AQF certificate II or at least 1 year relevant experience); skill level 5 (compulsory secondary education or an AQF certificate I).

[c]Fruit and vegetable servings/day.

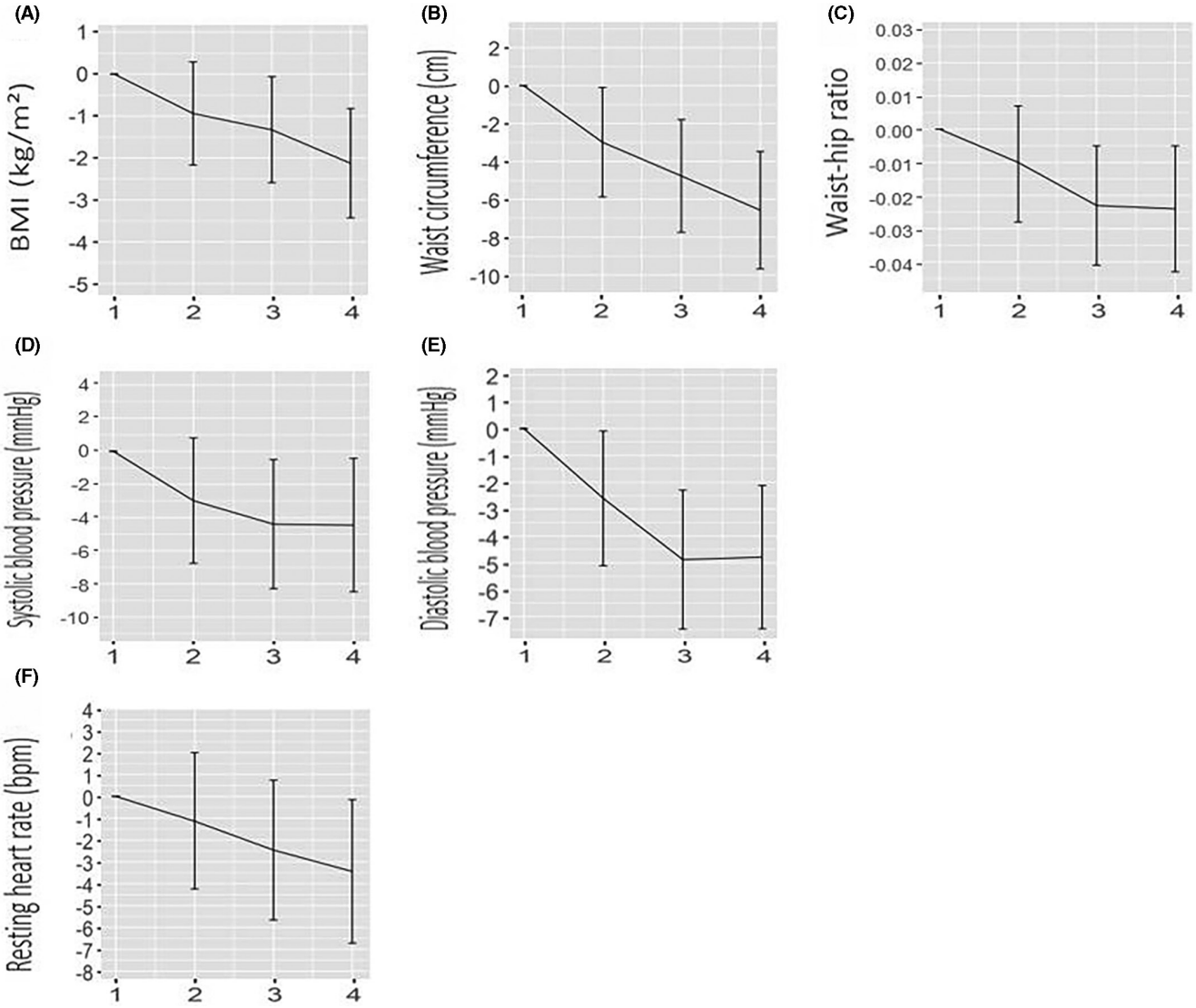

FIGURE 2 Associations of Daily Total Steps with Cardiometabolic Markers of Adiposity, Blood Pressure and Resting Heart Rate. *Note:* The multivariable-adjusted means and the corresponding 95% CIs of the relative change of each quartile of daily total steps compared to quartile 1 were presented for each biomarker in this figure (1 is bottom quartile, 2 is 2nd quartile, 3 is 3rd quartile, 4 is top quartile). *P*-values for linear trend between the mean daily total steps and each CM biomarker were: (A) BMI, $n = 670$, $p = 0.001$; (B) Waist circumference, $n = 678$, $p < 0.001$; (C) Waist-hip ratio, $n = 678$, $p = 0.005$; (D) Systolic blood pressure, $n = 353$, $p = 0.026$; (E) Diastolic blood pressure, $n = 353$, $p < 0.001$; (F) Resting heart rate, $n = 359$, $p = 0.031$. Models were adjusted for age, occupation, education, diet, smoking, alcohol consumption, self-rated health, sleep time per day, and sitting time per day.

association with DBP: Q2, (−1.64 [−4.17, 0.89]); Q3, (−3.54 [−6.22, −0.86]; Q4, −3.22 [−5.96, −0.48]; *p*-linear = 0.013) (Figure 3E). We did not find association of walking with BMI (Figure 3A), waist circumference (Figure 3B), SBP (Figure 3D), resting heart rate (Figure 3F), lipids (Figure S2a–c), glycaemia biomarkers (Figure S2d,e), and cardiometabolic risk score (Figure S2f).

3.2.3 | Stair steps

As shown in Figure 4, Figure S3, Table S2, stair steps showed the most evident beneficial association with BMI, waist circumference and BP than other stepping behaviors. The corresponding change of BMI was (Q2, −0.87 [−2.07, 0.34]; Q3, −2.47 [−3.71, −1.23]; Q4, −3.64 [−4.99, −2.31]); *p*-linear < 0.001 (Figure 4A). The change of waist circumference was (Q2, −1.45 [−4.35, 1.44]; Q3, −3.56 [−6.52, −0.60]; Q4, −7.08 [−10.31, −3.86]; *p*-linear < 0.001) (Figure 4B); The change of BP biomarkers was: SBP, Q2, −2.55 [−6.36, 1.27]; Q3, −4.92 [−8.64, −1.19]; Q4, −6.79 [−10.84, −2.74]; *p*-linear < 0.001 (Figure 4D); DBP, Q2, −0.70 [−3.24, 1.84]; Q3, −3.19 [−5.67, −0.71]; Q4, −4.00 [−6.70, −1.30]; *p*-linear < 0.001 (Figure 4E). We did not find association of stair-stepping with resting heart rate (Figure 4F), lipids (Figure S3a–c),

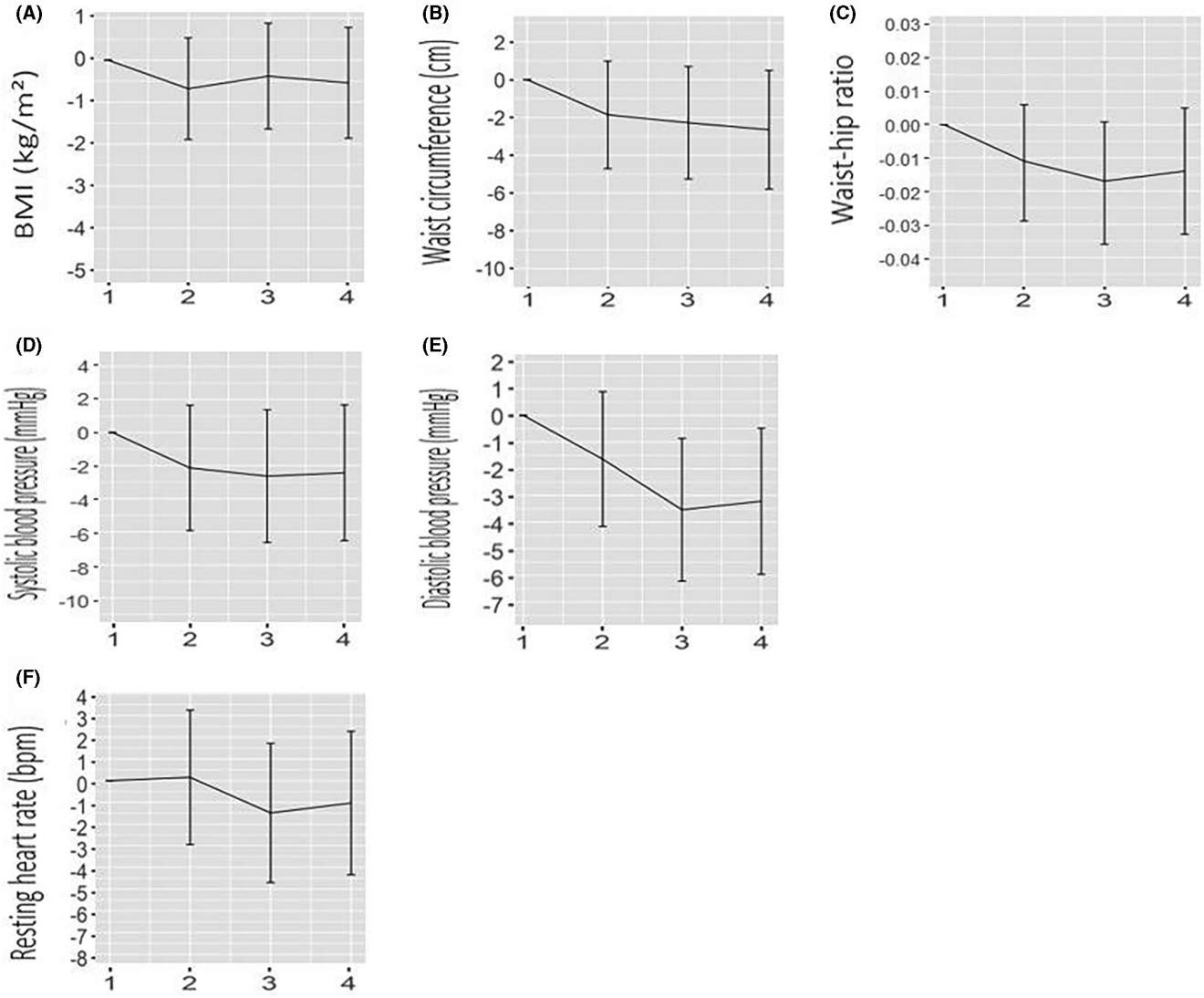

FIGURE 3 Associations of Daily Walking Steps with Cardiometabolic Markers of Adiposity, Blood Pressure and Resting Heart rate. *Note:* Multivariable-adjusted means and the corresponding 95% CIs of the relative change of each quartile of daily walking steps compared to quartile 1 were presented for each biomarker in this figure (1 is bottom quartile, 2 is 2nd quartile, 3 is 3rd quartile, 4 is top quartile). *P*-values for linear trend between the mean walking steps per day and each biomarker were: (A) BMI, $n = 670$, $p = 0.561$; (B) Waist circumference, $n = 678$, $p = 0.107$; (C) Waist-hip ratio, $n = 678$, $p = 0.134$; (D) Systolic blood pressure, $n = 353$, $p = 0.256$; (E) Diastolic blood pressure, $n = 353$, $p = 0.013$; (F) Resting heart rate, $n = 359$, $p = 0.400$. Models were adjusted for age, occupation, education, diet, smoking, alcohol consumption, self-rated health, sleep time per day, sitting time per day, and non-walking steps per day.

glycemic (Figure S3d,e) biomarkers and the cardiometabolic risk score (Figure S3f).

3.2.4 | Incidental steps

As shown in Figure 5, Figure S4, Table S3, the incidental steps were associated with DBP (Figure 5E): Q2, (−1.03 [−3.53, 1.48]); Q3, (−0.87 [−3.46, 1.72]); Q4, −3.44 [−6.35, −0.52]; *p*-linear = 0.040 (Figure 3E). The highest quartile of incidental steps was associated with the cardiometabolic risk score (Figure S4f): Q2, (−0.108 [−0.368, 0.171]); Q3, (0.100 [−0.191, 0.392]); Q4, −0.333 (−0.658, −0.008), *p*-linear = 0.185. The incidental steps did not show associations for adiposity (Figure 5A–C), SBP (Figure 5D), resting heart rate (Figure 5F), lipids (Figure S4a–c), and glycaemic outcomes (Figure S4d,e).

3.2.5 | Purposeful steps

As shown in Figure 6, Figure S5, Table S4. Purposeful steps showed consistent favorable associations with adiposity biomarkers (Figure 6A–C), BP (Figure 6D,E), resting heart rate (Figure 6F), HDL (Figure S5a), total-to HDL ratio (Figure S5b), and cardiometabolic risk score

TABLE 2 Associations of walking steps with cardiometabolic markers (Model 1 and Model 2)*.

Cardiometabolic health markers	Quartile 1 (lowest)	Relative change of each quartile comparing to quartile 1 (95% confident interval)			*p*-value (linear trend)
		Quartile 2	Quartile 3	Quartile 4 (highest)	
BMI (kg/m^2) ($n=670$)					
Model 1	Reference	−0.68 (−1.89, 0.53)	−0.38 (−1.64, 0.88)	−0.54 (−1.86, 0.78)	0.561
Model 2	Reference	−0.43 (−1.64, 0.77)	0.06 (−1.22, 1.34)	0.20 (−1.18, 1.59)	0.658
Waist Circumference (cm) ($n=678$)					
Model 1	Reference	−1.86 (−4.71, 0.98)	−2.28 (−5.26, 0.70)	−2.65 (−5.79, 0.49)	0.107
Model 2	Reference	−1.17 (−4.00, 1.67)	−1.06 (−4.06, 1.94)	−0.41 (−3.69, 2.88)	0.846
Waist-hip ratio ($n=678$)					
Model 1	Reference	−0.011 (−0.029, 0.006)	−0.017 (−0.036, −0.0008)	−0.014 (−0.033, 0.005)	0.134
Model 2	Reference	−0.012 (−0.029, 0.006)	−0.018 (−0.037, −0.0004)	−0.015 (−0.036, 0.005)	0.117
Systolic blood pressure (mmHg) ($n=353$)					
Model 1	Reference	−2.14 (−5.93, 1.65)	−2.64 (−6.65, 1.38)	−2.44 (−6.54, 1.67)	0.256
Model 2	Reference	−2.00 (−5.81, 1.81)	−2.33 (−6.44, 1.77)	−1.99 (−6.28, 2.31)	0.383
Diastolic blood pressure (mmHg) ($n=353$)					
Model 1	Reference	−1.64 (−4.17, 0.89)	−3.54 (−6.22, −0.86)	−3.22 (−5.96, −0.48)	**0.013**
Model 2	Reference	−1.52 (−4.07, 1.03)	−3.28 (−6.02, −0.54)	−2.83 (−5.70, −0.03)	**0.036**
Resting heart rate (bpm) ($n=359$)					
Model 1	Reference	0.15 (−2.95, 3.25)	−1.49 (−4.70, 1.72)	−1.03 (−4.34, 2.27)	0.400
Model 2	Reference	0.08 (−3.04, 3.19)	−1.64 (−4.90, 1.62)	−1.28 (−4.71, 2.15)	0.336
HDL Cholesterol (mmoL/L) ($n=276$)					
Model 1	Reference	−0.073 (−0.195, 0.049)	0.083 (−0.049, 0.215)	0.020 (−0.115, 0.154)	0.395
Model 2	Reference	−0.071 (−0.194, 0.052)	0.088 (−0.048, 0.224)	0.026 (−0.114, 0.166)	0.391
Total to HDL cholesterol ratio ($n=276$)					
Model 1	Reference	0.172 (−0.080, 0.425)	−0.009 (−0.264, 0.282)	−0.016 (−0.295, 0.263)	0.649
Model 2	Reference	0.176 (−0.079, 0.430)	0.018 (−0.264, 0.300)	−0.005 (−0.296, 0.285)	0.730
Triglycerides (mmoL/L) ($n=265$)					
Model 1	Reference	0.102 (−0.174, 0.377)	0.063 (−0.236, 0.363)	−0.045 (−0.348, 0.258)	0.686
Model 2	Reference	0.105 (−0.173, 0.382)	0.072 (−0.237, 0.380)	−0.035 (−0.351, 0.281)	0.742
HbA1c (mmoL/moL) ($n=276$)					
Model 1	Reference	−0.671 (−1.757, 0.416)	−0.263 (−1.437, 0.911)	−0.799 (−1.998, 0.400)	0.289
Model 2	Reference	−0.654 (−1.746, 0.438)	−0.215 (−1.424, 0.995)	−0.741 (−1.989, 0.507)	0.349
Glucose (mmoL/L) ($n=275$)					
Model 1	Reference	−0.101 (−0.257, 0.056)	−0.051 (−0.217, 0.115)	−0.116 (−0.287, 0.055)	0.272
Model 2	Reference	−0.099 (−0.256, 0.058)	−0.044 (−0.213, 0.126)	−0.107 (−0.282, 0.069)	0.333
Cardiometabolic risk score ($n=272$)					
Model 1	Reference	−0.092 (−0.372, 0.188)	−0.092 (−0.396, 0.211)	−0.190 (−0.501, 0.121)	0.258
Model 2	Reference	−0.084 (−0.366, 0.197)	−0.071 (−0.383, 0.241)	−0.163 (−0.487, 0.162)	0.218

Note: *Model 1: adjusted for age, occupation and education, diet, smoking, alcohol, mean sleep time per day, mean sitting time per day, self-rated health, and additionally adjusted daily non-walking steps. For triglycerides outcome, we further adjusted fasting time. *Model 2: further adjustments for walking intensity (approximated by peak 30-min walking cadence). The statistical significant p value ($p < 0.05$) for linear trend is highlighted in bold.

(Figure S5f) and have similar patterns with total steps. We did not find association between purposeful steps and triglycerides (Figure S5c), and glycaemic biomarkers (Figure S5d,e).

3.2.6 | Running steps

Table S5 shows findings for running steps. There was a favorable association between running and adiposity biomarkers, resting heart rate, lipids biomarkers, and the cardiometabolic risk score.

3.2.7 | Peak-30 min walking cadence

As shown in Table 2, after adjusting for peak 30-min walking step cadence (model 2), the associations between walking steps and adiposity biomarkers were significantly attenuated. For instance, the *p*-linear trend increased from 0.107 to 0.846 for waist circumference after the adjustment. In Table 3, the independent associations of walking intensity (peak-30 min walking cadence) and CM health markers were examined. The walking step intensity showed a linear association with waist circumference and BMI with *p*-linear < 0.001 and =0.002, respectively.

4 | DISCUSSION

To our knowledge, this is the first study to examine the association between different types and contexts of stepping behavior with comprehensive CM health markers. We observed consistent beneficial associations of total steps with most CM health markers and the composite CM risk score. Walking steps showed beneficial but less pronounced associations than total steps. Peak 30-min walking cadence demonstrated independent associations with most adiposity biomarkers. Stair steps showed the most evident inverse associations with adiposity and BP biomarkers among all types of stepping behavior. Purposeful steps largely drove the associations between total steps and CM biomarkers, and showed more consistently favorable associations than incidental steps.

Total steps showed consistent beneficial associations with CM health markers and the composite CM risk score. A systematic review of prospective studies involving up to 16 741 adults over the age of 18 showed that total steps had consistent beneficial associations with adiposity and BP biomarkers.[5] Although results for glycaemic outcomes were inconsistent, the four largest cohort studies within the review demonstrated favorable associations.[5] Our study showed consistent beneficial associations with adiposity, BP biomarkers, resting heart rate, HDL, total to HDL cholesterol ratio, but not triglycerides and glycemic biomarkers. Owing to our small sample (e.g., *n* for HbA1c was 276), wide CI may have made the detection of the associations difficult.

We found favorable associations of walking steps with waist-hip ratio and DBP, supporting findings on the associations of walking with adiposity and BP from previous meta-analysis of randomized control trials (RCT).[27,28] Because our study is a cross-sectional analysis and we have a relatively small outcome-specific sample size (e.g., approximately 285 for glycemic biomarkers), thus may limit the ability to observe the association with glucose biomarkers. Our study showed that peak 30-min walking cadence was found to have an independent association with adiposity biomarkers (waist circumference and BMI). In a cross-sectional study of NHANES involving 3388 participants, higher step cadence was beneficially associated with CM health markers, including adiposity, lipids, and glycemic biomarkers.[6] Although we only observed the association of peak 30-min walking cadence with adiposity biomarkers, our study may still support increasing the intensity of walking as an early intervention to decrease CVD risk in women at a later age. The participants in our study are premenopausal women in their 40 s before experiencing a dramatic decline in factors such as estrogen and leptin. Such decline may lead to abdominal and visceral fat accumulation in women after menopause, thus affecting CM health.[29] As they age, visceral fat mass gain[30,31] with the added risk of obesity may happen if the lifestyle has not changed when entering the menopause stage.[32] If people cannot control body weight before menopause, it is likely that higher CVD risk may happen at postmenopausal age. Therefore, early intervention in increasing walking intensity may be an effective method to help women lower their CVD risk when they enter the menopausal transition or postmenopause age. In addition, for those women who lack time to increase their walking volume, increasing walking intensity to reduce BMI and body weight could be an efficient way. Further prospective intervention study on walking intensity and postmenopausal women is warranted.

Our findings suggest that stair climbing, despite its relatively low daily volume (all participants in our sample recorded stair steps, with an average of 623 steps/day), may be a promising intervention for CM health. In our study, stair steps had the most evident linear associations with BMI, waist circumference, and BP biomarkers. Previous randomized controlled trials have found that stair steps protocol had beneficial effects on CM health, although a large sample (8874 men) prospective analysis from Harvard Alumni Health Study found no evidence for

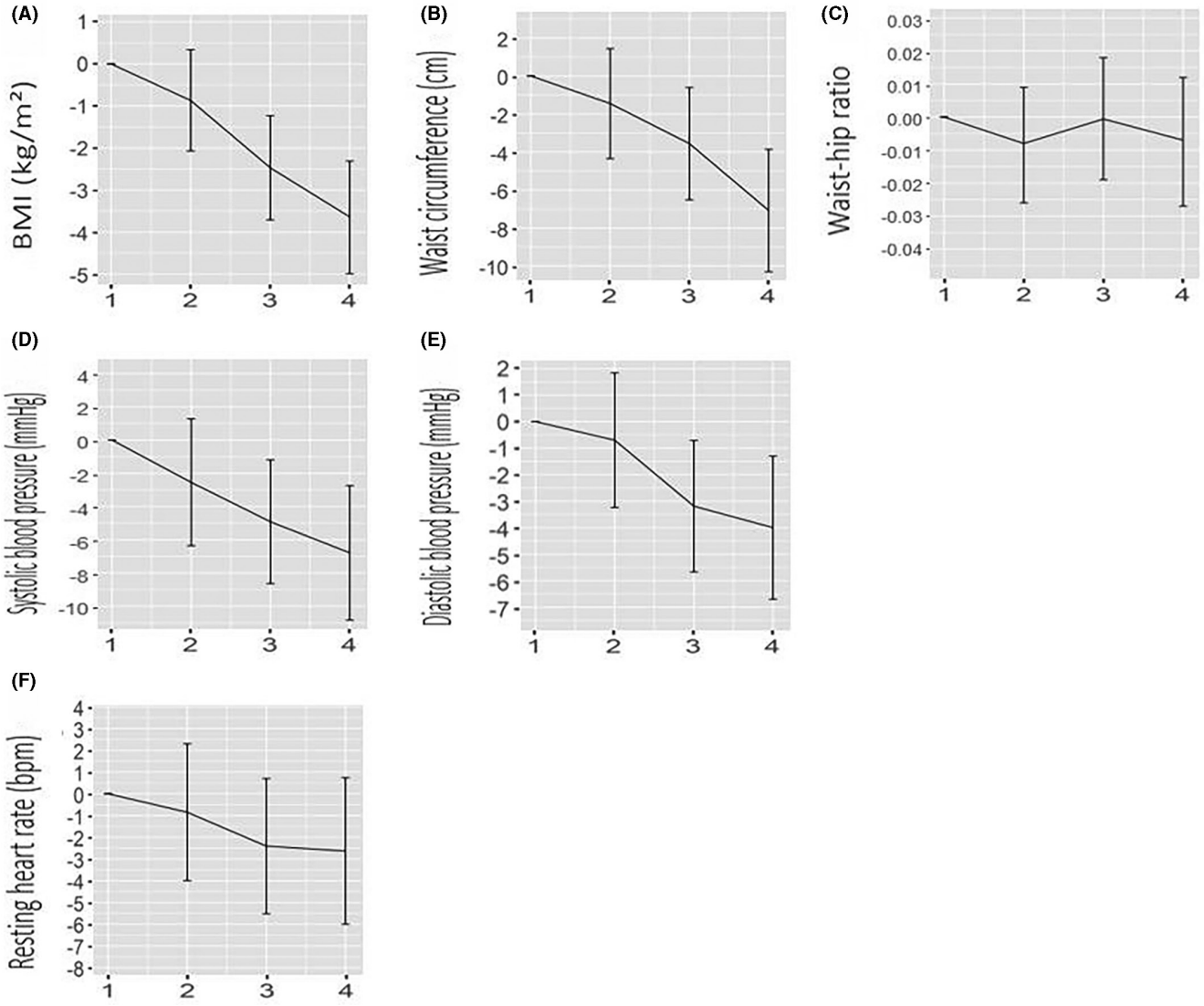

FIGURE 4 Associations of Daily Stair Steps with Cardiometabolic Markers of Adiposity, Blood Pressure and Resting Heart rate. *Note:* Multivariable-adjusted means and the corresponding 95% CIs of the relative change of each quartile of daily stair steps compared to quartile 1 were presented for each biomarker in this figure (1 is bottom quartile, 2 is 2nd quartile, 3 is 3rd quartile, 4 is top quartile). *P*-values for linear trend between the mean stair steps per day and each biomarker were: (A) BMI, $n = 670$, $p < 0.001$; (B) Waist circumference, $n = 678$, $p < 0.001$; (C) Waist-hip ratio, $n = 678$, $p = 0.687$; (D) Systolic blood pressure, $n = 353$, $p < 0.001$; (E) Diastolic blood pressure, $n = 353$, $p < 0.001$; (F) Resting heart rate, $n = 359$, $p = 0.127$. All Models were adjusted for age, occupation, education, diet, smoking, alcohol consumption, self-rated health, sleep time per day, sitting time per day, and non-stair steps per day.

an association between self-reported stair floors climbed and CVD mortality risk.[34] Our study using thigh-worn accelerometry, which provided accurate stair steps detection, seems to not support this finding due to the evident linear association with adiposity detected in our study. As adipose tissue accumulates excessively, the individual's cardiac structure and function undergo a variety of adaptations and changes. Being overweight/obese increases the risk of various CVDs, such as coronary heart disease, through its effect on the cardiovascular system.[35] Stair climbing may be an effective early intervention for mid-age women to control their weight and reduce their CVD risk. Stair climbing is a time-efficient form of physical activity that could be embedded into our daily lives. For example, for office workers, taking the stairs instead of the lift is a potentially effective method to enhance CM health. Having more stair steps is also an effective way for those who are unable to keep a fast-walking pace. In the future, dose–response analysis in prospective studies is warranted to help us determine the clinically significant stair step volume to adequately reflect the change in CM health, which would be helpful in informing intervention design.

A large-scale UK biobank study of 78 500 adults showed that higher purposeful steps (a cadence of ≥40

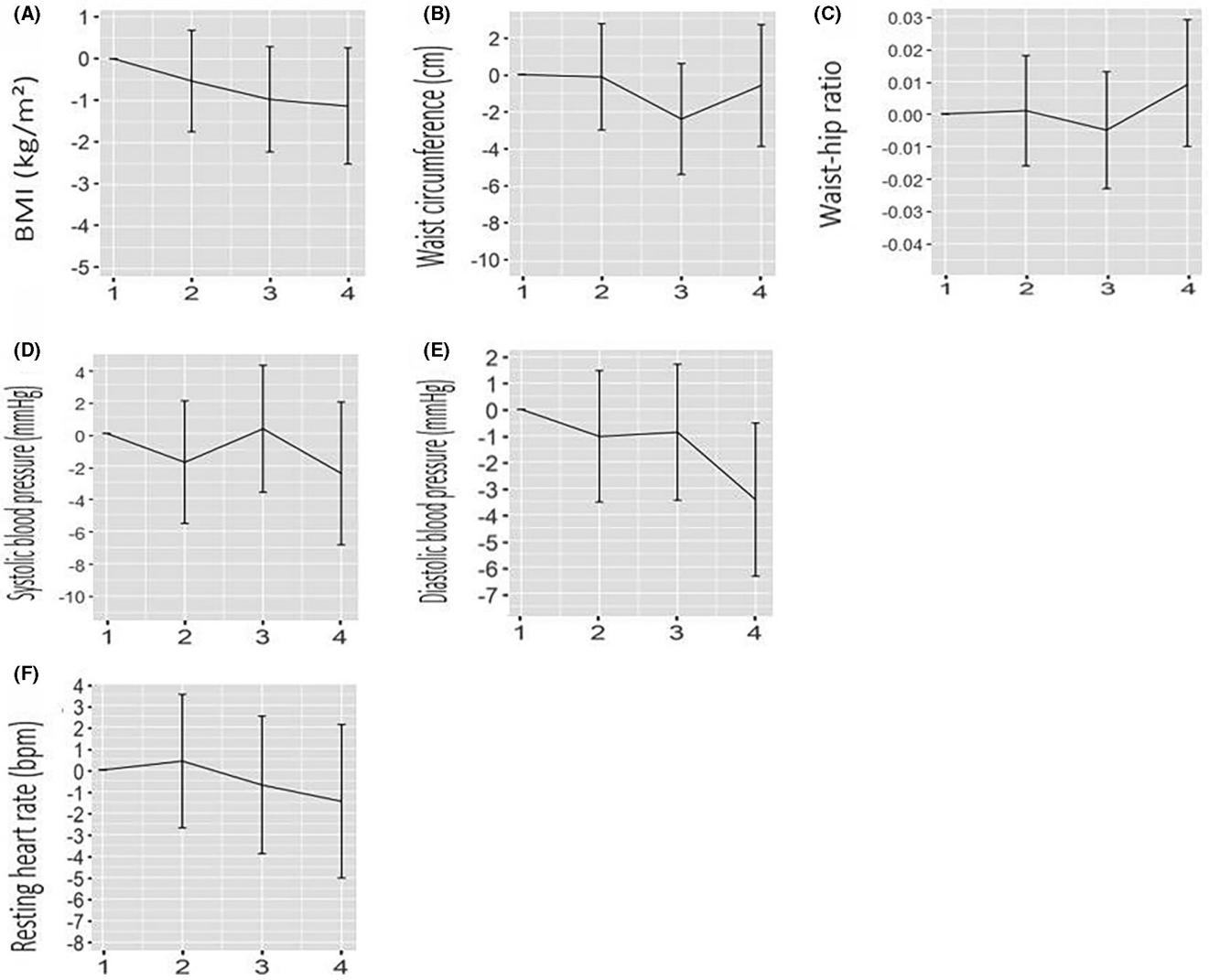

FIGURE 5 Associations of Daily Incidental Steps with Cardiometabolic Markers of Adiposity, Blood Pressure and Resting Heart rate. *Note:* Multivariable-adjusted means and the corresponding 95% CIs of the relative change of each quartile of daily incidental steps compared to quartile 1 were presented for each biomarker in this figure (1 is bottom quartile, 2 is 2nd quartile, 3 is 3rd quartile, 4 is top quartile). *P*-values for linear trend between mean incidental steps per day and each biomarker were: (A) BMI, $n = 670$, $p = 0.088$; (B) Waist circumference, $n = 678$, $p = 0.421$; (C) Waist-hip ratio, $n = 678$, $p = 0.545$; (D) Systolic blood pressure, $n = 353$, $p = 0.492$; (E) Diastolic blood pressure, $n = 353$, $p = 0.040$; (F) Resting heart rate, $n = 365$, $p = 0.424$. All Models were adjusted for age, occupation, education, diet, smoking, alcohol consumption, self-rated health, sleep time per day, sitting time per day, non-incidental steps (purposeful steps) per day.

steps per minute) and incidental steps were associated with a lower risk of CVD morbidity and mortality.[36] Our study supports these findings as we observed consistent beneficial associations between purposeful steps and CM risk factors. Apart from the reason that purposeful steps accounted for a large proportion of total step volume (67% of total steps), the step intensity is perhaps another reason, as purposeful steps may involve higher step intensity since it was defined as ≥40 steps/min. We observed beneficial associations between incidental steps and DBP, which supported the WHO 2020 PA and sedentary behavior guidelines affirming that some physical activity is better than none.[37] More prospective studies are warranted regarding the dose–response association of purposeful and incidental steps with CM health in the free-living environment.

Our study has numerous strengths. Using thigh-worn accelerometry, we were able to calculate walking steps and stair steps objectively. This is the first study, to our knowledge, to examine the associations of device-measured stair steps and peak 30-min walking cadence with CM biomarkers in a free-living environment. Rare studies have done research on the associations of a wide range of PA stepping forms (types and context) with CM biomarkers in the age of women entering menopause transition. Moreover, our accelerometry study was embedded in a

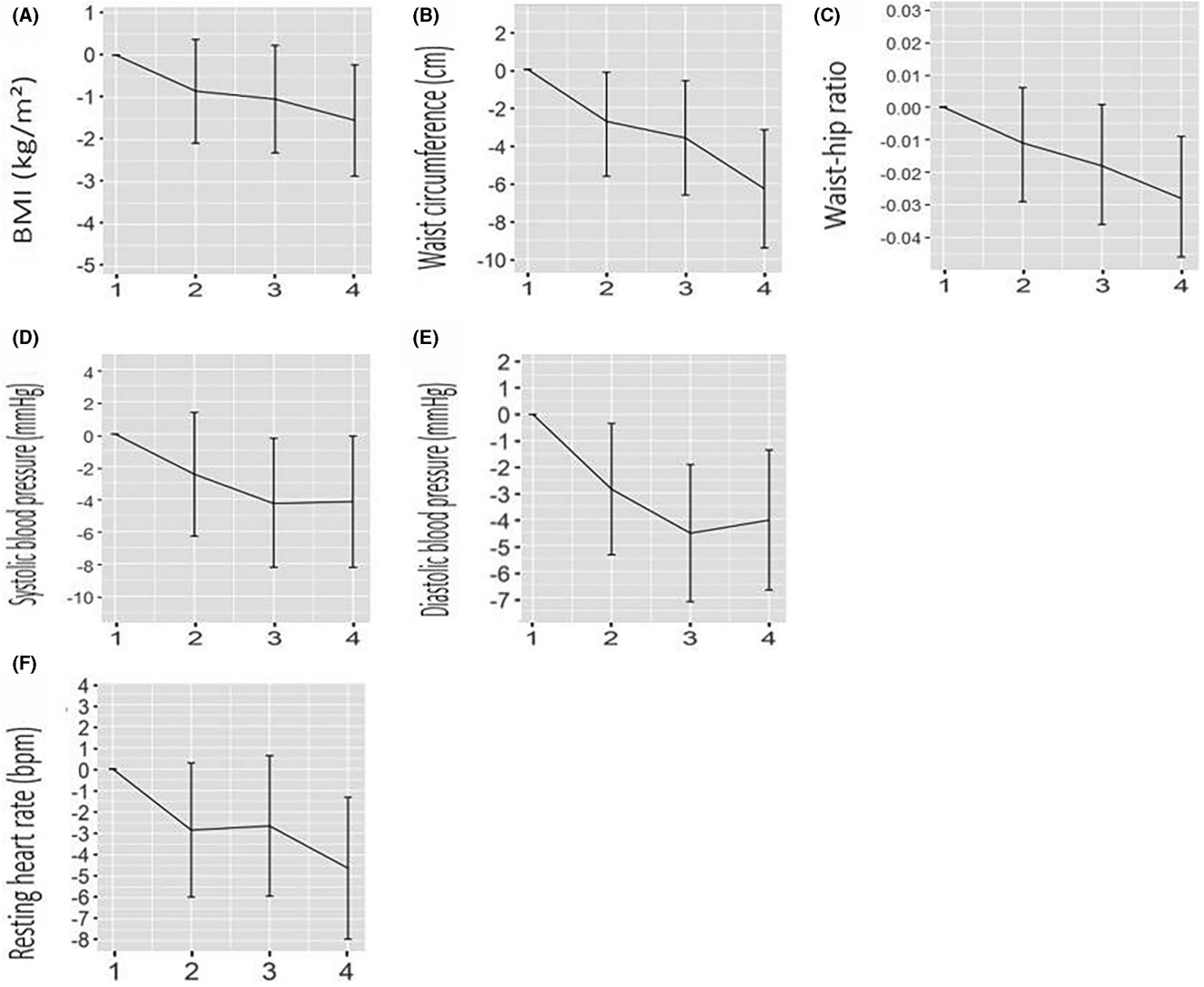

FIGURE 6 Associations of Daily Purposeful Steps with Cardiometabolic Markers of Adiposity, Blood Pressure and Resting Heart Rate. *Note:* Multivariable-adjusted means and the corresponding 95% CIs of the relative change of each quartile of daily purposeful steps compared to quartile 1 were presented for each biomarker in this figure (1 is bottom quartile, 2 is 2nd quartile, 3 is 3rd quartile, 4 is top quartile). *P*-values for linear trend between mean purposeful steps per day and each biomarker were: (A) BMI, $n = 670$, $p = 0.026$; (B) Waist circumference, $n = 678$, $p < 0.001$; (C) Waist-hip ratio, $n = 678$, $p = 0.004$; (D) Systolic blood pressure, $n = 353$, $p = 0.035$; (E) Diastolic blood pressure, $n = 353$, $p = 0.002$; (F) Resting heart rate, $n = 359$, $p = 0.007$. All Models were adjusted for age, occupation, education, diet, smoking, alcohol consumption, self-rated health, sleep time per day, sitting time per day, non-purposeful steps (incidental steps) per day.

national representative cohort (1973–1978 birth cohort) from ALSWH. Our study also has some limitations. The cross-sectional design limits the ability to infer causal relationships. The sample size of lipids and glycaemic biomarkers is small (outcome-specific sample size from 265 to 276), which may have limited our ability to observe the associations. Only 4% of the total sample record any running step, which may lead to spurious associations between running and CM biomarkers. In addition, our study only examined the linear trend of each physical activity with CM health markers but not the non-linear trend as we used categorical exposure to do the analysis of associations. The average step count in our study is relatively high, which may differentiate our results from other studies which have lower average steps.

5 | PERSPECTIVES

Total daily steps, walking steps, and purposeful steps had consistent beneficial associations with CM health markers. Peak 30-min walking cadence demonstrated independent associations with adiposity biomarkers. Despite the low volume of stair steps, our study suggested that

TABLE 3 Associations of peak 30-min walking cadence with cardiometabolic markers.

Cardiometabolic health markers	*p*-value (linear trend)
Waist Circumference (cm) ($n = 678$)	**<0.001**
BMI (kg/m^2) ($n = 670$)	**0.002**
Waist-hip ratio ($n = 678$)	0.684
Systolic blood pressure (mmHg) ($n = 353$)	0.481
Diastolic blood pressure (mmHg) ($n = 353$)	0.364
Resting heart rate (bpm) ($n = 359$)	0.583
HDL cholesterol (mmoL/L) ($n = 276$)	0.755
Total to HDL cholesterol ratio ($n = 276$)	0.788
triglycerides (mmoL/L) ($n = 265$)	0.825
HbA1c (mmoL/moL) ($n = 276$)	0.739
Glucose (mmoL/L) ($n = 275$)	0.660
Cardiometabolic risk score ($n = 272$)	0.552

Note: The statistical significant *p*-value ($p < 0.05$) for linear trend ishighlighted in bold.

stair steps had the most evident linear associations with adiposity and BP biomarkers. Our findings supported that increasing walking intensity and stair climbing might be a promising and time-effective early intervention for women's CM health. Purposeful steps drove the associations between total steps and CM biomarkers and showed a more consistent association with CM health markers than incidental steps. These findings suggest that step intensity plays an important role in adiposity, which could inform physical activity interventions for CM health.

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no competing interests.

DATA AVAILABILITY STATEMENT

Data are available upon reasonable request. Access to the M-PreM dataset requires approval from the Australian Longitudinal Study on Women's Health (ALSWH) Data Access Committee. More information can be found at the ALSWH website: https://alswh.org.au/for-data-users/.

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SUPPORTING INFORMATION

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

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