Step-Based Physical Activity Metrics and Cardiometabolic Risk: NHANES 2005–2006

CATRINE TUDOR-LOCKE[1], JOHN M. SCHUNA JR[2], HO HAN[1], ELROY J. AGUIAR[1], MICHAEL A. GREEN[1], MICHAEL A. BUSA[1], SANDRA LARRIVEE[3], and WILLIAM D. JOHNSON[3]

[1]Department of Kinesiology, University of Massachusetts Amherst, Amherst, MA; [2]College of Public Health and Human Sciences, Oregon State University, Corvallis, OR; and [3]Pennington Biomedical Research Center, Louisiana State University, Baton Rouge, LA

ABSTRACT

TUDOR-LOCKE, C., J. M. SCHUNA JR, H. HAN, E. J. AGUIAR, M. A. GREEN, M. A. BUSA, S. LARRIVEE, and W. D. JOHNSON. Step-Based Physical Activity Metrics and Cardiometabolic Risk: NHANES 2005–2006. *Med. Sci. Sports Exerc.*, Vol. 49, No. 2, pp. 283–291, 2017. **Purpose**: This study aimed to catalog the relationships between step-based accelerometer metrics indicative of physical activity volume (steps per day, adjusted to a pedometer scale), intensity (mean steps per minute from the highest, not necessarily consecutive, minutes in a day; peak 30-min cadence), and sedentary behavior (percent time at zero cadence relative to wear time; %TZC) and cardiometabolic risk factors. **Methods**: We analyzed data from 3388 participants, 20+ yr old, in the 2005–2006 National Health and Nutrition Examination Survey with ≥1 valid day of accelerometer data and at least some data on weight, body mass index, waist circumference, systolic and diastolic blood pressure, glucose, insulin, HDL cholesterol, triglycerides, and/or glycohemoglobin. Linear trends were evaluated for cardiometabolic variables, adjusted for age and race, across quintiles of steps per day, peak 30-min cadence, and %TZC. **Results**: Median steps per day ranged from 2247 to 12,334 steps per day for men and from 1755 to 9824 steps per day for women, and median peak 30-min cadence ranged from 48.1 to 96.0 steps per minute for men and from 40.8 to 96.2 steps per minute for women for the first and fifth quintiles, respectively. Linear trends were statistically significant (all $P < 0.001$), with increasing quintiles of steps per day and peak 30-min cadence inversely associated with waist circumference, weight, body mass index, and insulin for both men and women. Median %TZC ranged from 17.6% to 51.0% for men and from 19.9% to 47.6% for women for the first and fifth quintiles, respectively. Linear trends were statistically significant (all $P < 0.05$), with increasing quintiles of %TZC associated with increased waist circumference, weight and insulin for men, and insulin for women. **Conclusions**: This analysis identified strong linear relationships between step-based movement/nonmovement dimensions and cardiometabolic risk factors. These data offer a set of quantified access points for studying the potential dose–response effects of each of these dimensions separately or collectively in longitudinal observational or intervention study designs. **Key Words**: PHYSICAL ACTIVITY, STEPS, INTENSITY, SEDENTARY TIME, CARDIOVASCULAR, METABOLICOPEN-ACCESSTRUE

Steps per day, detected by pedometers (13), accelerometers (21,34), or more contemporary wearable technologies (39), is a widely accepted simple metric for objectively quantifying total daily volume of ambulatory activity. Objectively measured steps per day has been related to indicators of body composition (6,27), blood pressure (6), glucose control (28), higher HDL-cholesterol (27), and lower levels of triglycerides (27). Increasing steps per day decreases body mass index (BMI) (4,23) and improves blood pressure (4) and insulin resistance (42). Pedometer-based interventions demonstrated that increasing steps per day (by approximately 2000 [14] to 2500 steps per day [4,23]) elicits modest weight loss (4,23) and improvements in blood pressure (4). Although steps per day has been associated with time spent in objectively determined moderate intensity physical activity ($r = 0.79$) (35), a simple daily tally of steps taken has been criticized as failing to clearly capture or communicate "quality" of ambulatory activity (7).

Reconsidering cadence (steps per minute) as an indicator of intensity of ambulatory activity has evolved as a result of several controlled studies (based on treadmill, track, or corridor walking) (1,3,18,24,38) that, taken together, demonstrate the correlation between cadence and absolutely defined intensity (measured as METs) is $r = 0.94$ (33). Notably, amid continued disagreements about accelerometer activity counts per minute cut points reflective of moderate intensity thresholds

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(19), there has been remarkable consistency in agreement that >100 steps per minute can be used as a reasonable heuristic value for the same purpose (while still acknowledging individual variation) (1,3,18,24,38). Free-living studies of cadence have also emerged (2,32). On the basis of accelerometry data collected as part of the 2005–2006 National Health and Nutrition Examination Survey (NHANES), we have previously reported that American adults accumulate ≈8.7 h at 1–59 steps per minute (including a range of incidental movements to more purposeful steps), ≈16 min·d^{-1} at 60–79 steps per minute (slow walking), ≈8 min at 80–99 steps per minute (medium walking), ≈5 min at 100–119 steps per minute (brisk walking), and ≈2 min at 120+ steps per minute (considered indicative of all faster locomotor movements, for example, running, dancing, skipping, etc.) (32).

Using these same NHANES data, we have also published the descriptive epidemiology of peak 30-min cadence, a derived variable that captures the average steps per minute recorded for the highest 30 min (not necessarily consecutive) in a day (31). As such, peak 30-min cadence reflects the highest "natural best effort" in a day. Inspiration for this variable grew out of research conducted using the StepWatch Activity Monitor that offers a similar output as one of its summary variables (21). U.S. men and women had an average peak 30-min cadence of 73.7 and 69.6 steps per minute, respectively, and the variable was inversely associated with age and BMI-defined overweight and obesity categories (31).

Steps per day is a metric used to convey daily volume of ambulatory movement events and steps per minute is used to communicate accumulation patterns of these ambulatory movement events indicative of intensity. By contrast, there is growing interest in tracking sedentary time as it has been positively associated with undesirable values for several cardiometabolic biomarkers (i.e., BMI, HDL and LDL cholesterols, triglyceride, fasting plasma glucose, high-sensitivity C-reactive protein, insulin resistance, etc.), independent of physical activity (25,29). Time spent at zero cadence has been used as an indicator of nonmovement and therefore sedentary time (41). Using the NHANES data, we have previously reported that the average U.S. resident accumulates ≈4.8 h·d^{-1} of zero cadence while the accelerometer is worn (32). Because wear time varies with protocol design and participant tolerance, expressing the amount time spent in sedentary time as a percent of time worn at zero cadence (%TZC) is a reasonable metric to facilitate comparisons between studies and individuals.

We have previously advocated that volume, intensity, and an indicator of sedentary behavior could all be inferred from step-based metrics simultaneously quantifying daily human behavior in terms of movement/nonmovement dimensions (37). Building on and extending this early concept, this analysis of the 2005–2006 NHANES accelerometer data catalogs the relationships between these three dimensions and cardiometabolic risk factors. Such an extensive catalog is a necessary first step to illuminating multiple health-related thresholds for each of these objectively monitored movement/nonmovement dimensions.

METHODS

NHANES physical activity monitor. The NHANES continuously assesses the health and nutritional status of civilian U.S. children and adults using a combination of interviews and physical examinations. Databases and details of questionnaires, protocols, and accompanying documentation are located at http://www.cdc.gov/nchs/nhanes.htm. ActiGraph accelerometer (model 7164 manufactured by ActiGraph, of Ft. Walton Beach, FL) data were collected as part of the NHANES physical activity monitor (PAM) component in 2005–2006; however, the step output was only released for the latter cycle. The PAM database includes minute-by-minute data collected from ambulatory participants 6+ yr old who were instructed to wear the waist-worn accelerometer for up to seven consecutive days, removing it only at bedtime and for water-based activities such as showering and bathing. The National Center for Health Statistics ethics review board approved the NHANES survey protocols, and written informed consent was obtained from all participants.

Subjects and data treatment. The National Cancer Institute made a SAS macro publically available (http://riskfactor.cancer.gov/tools/nhanes_pam/) to facilitate standard PAM data analysis, and this was used to identify valid monitored days, defined as ≥10 h of wearing time. The present analysis is limited to 3388 20+ yr olds with at least one valid day (30,34) of NHANES-designated reliable accelerometer data with an average of at least 500 steps per day; complete sex (1725 men and 1663 women), age, race, weight, and BMI data; and at least some data on any of the following cardiometabolic risk factors: waist circumference (1685 men and 1630 women), systolic and diastolic blood pressure (1662 men and 1588 women), glucose (806 men and 741 women), insulin (799 men and 721 women), HDL cholesterol (1667 men and 1583 women), triglycerides (801 men and 728 women), C-reactive protein (1668 men and 1591 women), and glycohemoglobin (1662 men and 1599 women). HOMA-IR was calculated as fasting insulin $\{[(\mu U \cdot mL^{-1}) \times [\text{fasting glucose (mmol·L}^{-1})]]/22.5\}$ for 799 men and 720 women. Because BMI was a focus of this analysis, we also excluded 382 self-reported pregnant women and a single individual with a BMI > 100 kg·m^{-2}.

Initial demographic information, including sex, age, and race, was self-reported. Other categorical variables such as self-reported diabetic and hypertensive status as well as current medication use were collected. Anthropometric measurements, including height, weight, and waist circumference and blood pressure, were directly measured using standardized protocols. Fasting glucose, insulin, HDL cholesterol, triglycerides, and glycohemoglobin levels were collected by using traditional venipuncture techniques and processed at various laboratories according to standardized protocols. Questionnaire and protocol details are available at http://wwwn.cdc.gov/nchs/nhanes/search/nhanes05_06.aspx. Collected data were then used to identify increased cardiometabolic risk defined as follows: waist circumference, ≥102 cm (men) and

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≥88 cm (women); blood pressure, ≥130/≥85 mm Hg, or on blood pressure medication; fasting glucose, ≥100 mg·dL^{-1} (5.55 mmol·L^{-1}), or on diabetes medication; HDL cholesterol, <40 mg·dL^{-1} (1.03 mmol·L^{-1}, men) and <50 mg·dL^{-1} (1.3 mmol·L^{-1}, women), or on medication; and triglycerides, ≥150 mg·dL^{-1} (1.7 mmol·L^{-1}), or on blood lipid–lowering medication (8).

We applied a previously used approach (34) to adjust the NHANES ActiGraph 7164 accelerometer-determined steps per day to a metric more consistent with expected outputs from research-grade pedometers. Specifically, we censored steps by excluding activity occurring at <500 activity counts per minute. Justification, including sensitivity analyses, for this censoring cut point has previously been reported (35,36). Minute-by-minute step data were summed by day and averaged across valid days to obtain steps per day. Minute-by-minute steps per day were also rank ordered (descending) for each day to identify and compute the average steps per minute for the highest 30 min of the day. The resulting value was averaged across valid days to produce peak 30-min cadence as previously described (31). A sedentary time (nonmovement) variable was constructed as a percent of time worn at zero cadence (%TZC), also averaged across valid days (([total wear and nonwear time at zero cadence − nonwear time]/wear time) × 100).

Statistical analysis. Data distributions for steps per day, peak 30-min cadence, and %TZC were cut into quintiles, and each quintile was identified by its median value. Geometric mean values (95% confidence interval [CI]) were computed for the cardiometabolic variables from least square mean values. All geometric mean values were covariate adjusted for age in years and race (except systolic and diastolic blood pressures) and organized by each of the identified movement/nonmovement quintiles.

Descriptive statistics are presented as frequencies (sex and race) and median and mean (and 95% CI) values as appropriate. The geometric mean was used for all continuous variables except age and systolic and diastolic blood pressures. Sex comparisons were performed on the natural log of all the response variables except age and systolic and diastolic blood pressures. Linear trends were evaluated for cardiometabolic variables organized across each of the identified movement/nonmovement indicator quintiles, adjusted for age and race. Spearman rank order correlations were computed to evaluate the effect size of the relationships between cardiometabolic variables and steps per day, peak 30-min cadence, and %TZC. A semilog scatterplot was generated to display the relationships between ln insulin (displayed values are back transformed to microunits per liter) and steps per day, peak 30-min cadence, and %TZC. Quintile bands for each movement/nonmovement variable and their respective geometric mean values (95% CI) were also included on the plots to inform interpretation and observe trends. Multivariable regression was used to evaluate the independent associations of steps per day, peak 30-min cadence, and %TZC with a subset of evaluated cardiometabolic variables (BMI, systolic blood pressure, glucose, insulin, HDL cholesterol, triglycerides, and glycohemoglobin).

RESULTS

Estimated median, mean, and 95% CI for selected variables for the analytic sample are presented in Table 1. Racial composition was 49.6% Caucasian, 23.2% African American, 20.2% Mexican American, and 7.0% Other. Applying recommended thresholds (8), 43.6% of men (and 64.9% of women) had high waist circumferences, 48.3% (and 43.4%) had high blood pressure or were on blood pressure medication, 58.6% (and 47.2%) had fasting blood glucose consistent with metabolic syndrome and prediabetes or were on diabetes medication, 36.3% (and 35.6%) had high cholesterol or were on cholesterol medication, and 37.3% (and 24.6%) had high triglycerides or were on blood lipid–lowering medication. Mean accelerometer wear time was 843 min·d^{-1}, and the mean number of valid days considered was 5.3.

Median censored steps per day by ascending quintile were 2247, 4745, 6762, 9001, and 12,334 for men and 1755,

TABLE 1. Estimated median, mean, and 95% CI for selected variables for male and female 20+ yr old from NHANES 2005–2006.

		Men				Women			
Item	n	Median	Mean[a]	(95% CI)	n	Median	Mean[a]	(95% CI)	P[b]
Age, yr	1725	44.8	46.1	(44.3–47.9)	1663	45.8	47.6	(46.2–49.0)	0.0275
Waist circumference, cm	1685	100.0	100.1	(98.6–101.6)	1630	92.2	93.1	(91.7–94.5)	<0.0001
Weight, kg	1725	85.7	86.8	(85.2–88.5)	1663	71.7	73.2	(71.7–74.8)	<0.0001
BMI, kg·m^{-2}	1725	27.7	28.0	(27.5–28.5)	1663	27.1	27.9	(27.3–28.4)	0.6008
SBP, mm Hg	1670	121.2	123.8	(122.8–124.7)	1598	117.3	121.4	(119.8–122.9)	0.0037
DBP, mm Hg	1662	71.3	71.9	(71.0–72.8)	1588	70.2	70.1	(69.2–70.9)	0.0017
Glucose, mg·dL^{-1}	806	98.9	102.2	(100.1–104.4)	741	95.4	100.2	(98.2–102.2)	0.0592
Insulin, μU·mL^{-1}	799	8.6	9.0	(8.6–9.4)	721	8.0	8.1	(7.3–8.9)	0.0472
HOMA	799	2.2	2.3	(2.1–2.4)	720	1.9	2.0	(1.8–2.2)	0.0254
HDL cholesterol, mg·dL^{-1}	1667	45.6	47.1	(46.4–47.8)	1583	56.9	57.5	(56.2–58.7)	<0.0001
Triglyceride, mg·dL^{-1}	801	125.1	131.2	(125.0–137.7)	728	103.2	107.5	(102.5–112.8)	<0.0001
C-reactive protein, mg·dL^{-1}	1668	0.15	0.16	(0.15–0.17)	1591	0.22	0.21	(0.19–0.23)	<0.0001
Glycohemoglobin, %	1662	5.27	5.41	(5.36–5.47)	1599	5.26	5.40	(5.35–5.45)	0.4764
Uncensored steps per day	1725	10,299	10,737	(10,443–11,031)	1663	8929	9113	(8832–9394)	<0.0001
Censored steps per day	1725	7133	7564	(7282–7847)	1663	5685	5941	(5671–6212)	<0.0001
Peak 30-min cadence, steps per minute	1725	74.2	74.6	(72.7–76.5)	1663	70.5	71.1	(69.2–72.9)	0.0015
Wearing time, min per day	1725	851.4	858.1	(850.7–865.4)	1663	830.0	833.9	(825.7–842.1)	<0.0001

[a]Mean: geometric mean for all the variables except age, SBP, DBP, uncensored, censored steps, and wearing time.
[b]P value: sex comparison conducted on the natural log of all the response variables except age, SBP, DBP, uncensored, censored steps, and wearing time.

3682, 5284, 6766, and 9824 for women. Table 2 presents the mean and 95% CI values for cardiometabolic risk factors across censored steps per day quintiles. Linear trends were statistically significant across all factors besides systolic blood pressure for men.

Median peak 30-min cadences by ascending quintile were 48.1, 62.6, 72.4, 82.3, and 96.0 steps per minute for men and 40.8, 57.0, 67.8, 78.3, and 96.2 steps per minute for women. Table 3 presents the mean and 95% CI values for cardiometabolic risk factors across peak 30-min cadence quintiles. Linear trends were statistically significant across most factors with a few exceptions for men (systolic blood and diastolic blood pressure and glucose) and women (diastolic blood pressure).

Median %TZC by ascending quintiles were 17.6, 26.8, 34.1, 40.6, and 51.0 for men and 19.9, 27.1, 32.9, 39.0, and 47.6 for women. Table 4 presents the mean and 95% CI values for cardiometabolic risk factors across %TZC quintiles. There were statistically significant linear trends for insulin, HOMA-IR, HDL cholesterol, and triglyceride for both sexes. There was also a significant linear trend for weight and waist circumference for men.

Table 5 presents the relationships (Spearman's ρ) between steps per day, peak 30-min cadence, %TZC, and the various cardiometabolic variables. Small to moderate correlations were observed for the majority of variables. Spearman correlations between steps per day and peak 30-min cadence, steps per day and %TZC, and peak 30-min cadence and %TZC were $r_s = 0.81$, -0.61, and -0.35, respectively. In addition, as a single purposive example, a semi-ln scatterplot (Figure, Supplemental Digital Content 1, scatterplot displaying linear trends for insulin, http://links.lww.com/MSS/A764) was generated to display the relationships between ln insulin (displayed values are back transformed to microunits per liter) and steps per day, peak 30-min cadence, and %TZC because of its strong and consistent linear relationships (Tables 2–4) and correlations (Table 5) across all three movement/nonmovement dimensions.

Results of multivariable regression analyses predicting cardiometabolic outcomes from continuous measures of steps per day, peak 30-min cadence, and %TZC are presented in Table 6. Significant associations were observed for steps per day with all evaluated cardiometabolic outcomes in men and fasting blood glucose only in women. Conversely, peak 30-min cadence was associated with all evaluated cardiometabolic outcomes in women and only BMI and glycohemoglobin in men. %TZC was not associated with any evaluated cardiometabolic outcomes in men but was associated with BMI, triglycerides, and glycohemoglobin in women. All variance inflation factors for the evaluated models were <4, indicating no serious multicollinearity problems (9).

DISCUSSION

Although steps per day (6,27) and, more recently, peak 30-min cadence (31) have been previously linked with some cardiometabolic risk factors, we present the most extensive

TABLE 2. Mean (95% CI) for selected variables with steps per day quintiles for male and female 20+ yr old from NHANES 2005–2006.

	Censored Steps per Day Quintiles[a]										
	First Quintile		Second Quintile		Third Quintile		Fourth Quintile		Fifth Quintile		Linear
Men					Mean[b] (95% CI)						
n^c	164–345		149–345		160–345		169–345		156–345		
Waist circumference, cm	104.2	(101.9–106.6)	101.3	(99.3–103.5)	98.9	(95.9–102.0)	99.3	(97.4–101.2)	95.4	(93.2–97.8)	<0.0001
Weight, kg	89.0	(85.5–92.5)	86.6	(84.1–89.1)	84.0	(80.3–87.9)	84.0	(81.7–86.3)	79.6	(76.6–82.8)	<0.0001
BMI, kg·m^{-2}	29.4	(28.4–30.5)	28.7	(27.9–29.6)	27.9	(26.8–29.0)	27.9	(27.1–28.7)	26.8	(26.2–27.5)	<0.0001
SBP, mm Hg	125.0	(123.0–126.9)	126.1	(124.1–128.1)	126.5	(124.2–128.8)	126.3	(124.4–128.3)	122.9	(121.7–124.0)	0.0996
DBP, mm Hg	68.4	(66.0–70.9)	71.9	(69.5–74.2)	73.6	(71.8–75.4)	73.4	(71.6–75.3)	70.7	(68.9–72.5)	0.0481
Glucose, mg·dL^{-1}	108.8	(103.8–114.1)	105.5	(101.4–109.7)	104.6	(101.1–108.2)	105.1	(101.9–108.4)	101.9	(97.5–106.5)	0.0464
Insulin, μU·mL^{-1}	13.5	(11.0–16.6)	11.2	(9.6–13.1)	9.3	(7.9–11.0)	9.3	(7.9–10.9)	7.2	(6.4–8.1)	<0.0001
HOMA-IR^d	3.6	(3.0–4.5)	2.9	(2.5–3.5)	2.4	(2.0–2.8)	2.4	(2.0–2.8)	1.8	(1.6–2.0)	<0.0001
HDL cholesterol, mg·dL^{-1}	43.7	(42.1–45.3)	45.1	(43.4–46.9)	47.5	(45.6–49.5)	48.6	(47.1–50.3)	50.1	(48.3–52.0)	<0.0001
Triglyceride, mg·dL^{-1}	147.7	(123.6–176.6)	144.0	(128.2–161.7)	134.9	(120.8–150.6)	134.0	(118.0–152.2)	112.3	(99.8–126.2)	0.0011
C-reactive protein, mg·dL^{-1}	0.28	(0.25–0.32)	0.21	(0.17–0.26)	0.16	(0.13–0.20)	0.15	(0.13–0.17)	0.14	(0.12–0.16)	<0.0001
Glycohemoglobin, %	5.79	(5.64–5.93)	5.63	(5.54–5.72)	5.59	(5.48–5.71)	5.56	(5.48–5.63)	5.52	(5.43–5.61)	0.0014
Women											
n^c	148–333		147–333		139–332		143–333		143–332		
Waist circumference, cm	99.3	(97.0–101.6)	96.9	(94.7–99.1)	94.7	(91.7–97.8)	91.8	(89.7–93.9)	88.9	(87.5–90.2)	<0.0001
Weight, kg	75.9	(73.7–78.1)	75.7	(73.5–78.0)	73.0	(69.5–76.8)	71.5	(69.5–73.5)	67.8	(66.0–69.6)	<0.0001
BMI, kg·m^{-2}	30.0	(29.3–30.7)	29.7	(28.8–30.5)	28.7	(27.4–30.0)	27.7	(26.9–28.6)	26.4	(25.8–27.0)	<0.0001
SBP, mm Hg	125.2	(121.9–128.5)	124.7	(122.8–126.6)	122.7	(119.5–125.9)	122.4	(119.3–125.4)	123.1	(121.3–124.9)	0.0366
DBP, mm Hg	67.2	(65.3–69.1)	70.7	(69.0–72.4)	70.3	(68.2–72.4)	70.2	(68.8–71.6)	70.6	(68.7–72.4)	0.0164
Glucose, mg·dL^{-1}	107.9	(102.0–114.0)	105.4	(100.0–111.1)	103.1	(98.0–108.4)	100.2	(97.6–102.8)	102.2	(97.8–106.8)	0.0230
Insulin, μU·mL^{-1}	13.9	(11.7–16.6)	10.0	(9.0–11.2)	8.6	(7.3–10.3)	7.9	(7.0–8.9)	6.0	(5.3–6.9)	<0.0001
HOMA-IR^d	3.7	(3.1–4.5)	2.6	(2.3–2.9)	2.2	(1.8–2.7)	2.0	(1.7–2.2)	1.5	(1.3–1.8)	<0.0001
HDL cholesterol, mg·dL^{-1}	53.4	(51.1–55.9)	54.5	(51.9–57.2)	57.7	(56.1–59.2)	58.4	(56.1–60.7)	60.7	(58.4–63.0)	0.0005
Triglyceride, mg·dL^{-1}	131.1	(114.4–150.4)	110.5	(100.8–121.1)	109.0	(99.6–119.4)	98.5	(90.9–106.7)	92.6	(81.4–105.3)	0.0006
C-reactive protein, mg·dL^{-1}	0.34	(0.28–0.40)	0.25	(0.22–0.28)	0.22	(0.17–0.28)	0.21	(0.16–0.26)	0.16	(0.13–0.20)	0.0002
Glycohemoglobin, %	5.66	(5.56–5.77)	5.59	(5.50–5.69)	5.55	(5.45–5.64)	5.55	(5.50–5.61)	5.49	(5.41–5.57)	0.0216

[a]Median steps per day for male was 2247, 4745, 6762, 9001, and 12,334 for the first, second, third, fourth, and fifth quintiles, respectively. Median steps per day for females was 1755, 3682, 5284, 6766, and 9824 for the first, second, third, fourth, and fifth quintiles, respectively.
[b]Mean: geometric mean values for all the variables except SBP and DBP were covariate adjusted for age (yr) and race.
[c]n: sample size range.
[d]HOMA-IR: calculated as fasting insulin {[(μU·mL^{-1}) × [fasting glucose (mmol·L^{-1})] / 22.5}.

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TABLE 3. Mean (95% CI) for selected variables with peak 30-min cadence (steps per minute) quintiles for male and female 20+ yr old from NHANES 2005–2006.

	First Quintile		Second Quintile		Third Quintile		Fourth Quintile		Fifth Quintile		Linear
					Mean[b] (95% CI)						
Men											
n^c	164–345		149–345		160–345		169–345		156–345		
Waist circumference, cm	104.2	(101.6–106.9)	101.5	(99.0–104.1)	99.8	(96.9–102.7)	97.6	(95.0–100.3)	96.2	(94.0–98.5)	<0.0001
Weight, kg	88.6	(85.1–92.3)	87.1	(84.1–90.2)	84.7	(81.1–88.6)	81.9	(78.7–85.2)	81.0	(78.3–83.8)	<0.0001
BMI, kg·m^{-2}	29.5	(28.3–30.6)	28.9	(27.9–29.9)	28.1	(27.0–29.2)	27.3	(26.4–28.2)	27.2	(26.5–27.9)	<0.0001
SBP, mm Hg	124.5	(122.4–126.6)	126.7	(124.6–128.9)	126.1	(124.7–127.4)	124.7	(122.9–126.6)	124.7	(122.7–126.8)	0.5549
DBP, mm Hg	67.8	(65.6–70.1)	72.8	(70.5–75.0)	74.0	(71.5–76.4)	72.3	(70.3–74.3)	71.3	(69.6–73.0)	0.0622
Glucose, mg·dL^{-1}	109.0	(104.4–113.8)	104.5	(101.1–108.1)	103.9	(100.9–107.0)	104.5	(100.8–108.4)	104.4	(100.4–108.6)	0.2098
Insulin, μU·mL^{-1}	13.0	(10.3–16.4)	10.0	(8.8–11.4)	10.1	(7.8–12.6)	8.6	(7.4–10.0)	8.7	(7.8–9.8)	0.0005
HOMA-IR[d]	3.5	(2.7–4.4)	2.6	(2.2–3.0)	2.6	(2.0–3.3)	2.2	(1.9–2.6)	2.2	(1.9–2.5)	0.0003
HDL cholesterol, mg·dL^{-1}	44.9	(43.1–46.7)	45.2	(43.1–47.5)	47.1	(45.3–48.8)	48.6	(45.8–51.5)	49.4	(47.4–51.4)	0.0001
Triglyceride, mg·dL^{-1}	145.0	(120.3–174.7)	141.0	(124.3–160.0)	132.9	(118.6–149.1)	123.7	(109.6–139.6)	131.2	(114.7–150.2)	0.0321
C-reactive protein, mg·dL^{-1}	0.27	(0.22–0.33)	0.24	(0.20–0.27)	0.17	(0.15–0.20)	0.15	(0.13–0.19)	0.12	(0.10–0.14)	<0.0001
Glycohemoglobin, %	5.77	(5.59–5.96)	5.62	(5.53–5.70)	5.59	(5.48–5.71)	5.59	(5.46–5.72)	5.51	(5.44–5.59)	0.0184
Women											
n^c	148–333		147–333		139–332		143–333		143–332		
Waist circumference, cm	101.8	(99.4–104.1)	96.9	(94.1–99.8)	94.7	(92.6–96.8)	90.6	(89.0–92.2)	87.5	(85.1–90.0)	<0.0001
Weight, kg	79.1	(75.9–82.5)	75.3	(72.0–78.8)	73.7	(71.1–76.5)	69.6	(68.1–71.2)	66.2	(63.6–68.8)	<0.0001
BMI, kg·m^{-2}	31.2	(30.0–32.4)	29.5	(28.3–30.8)	28.9	(28.1–29.8)	27.0	(26.3–27.6)	25.9	(24.8–27.0)	<0.0001
SBP, mm Hg	126.5	(122.8–130.3)	125.0	(123.4–126.7)	123.1	(120.3–126.0)	122.5	(120.4–124.5)	120.8	(118.9–122.6)	0.0005
DBP, mm Hg	69.1	(67.1–71.0)	70.1	(68.8–71.4)	70.2	(68.6–71.9)	70.7	(69.1–72.3)	68.9	(67.1–70.7)	0.9023
Glucose, mg·dL^{-1}	106.9	(101.8–112.2)	105.9	(101.6–110.5)	104.6	(99.8–109.7)	99.4	(96.9–101.9)	100.8	(96.3–105.5)	0.0224
Insulin, μU·mL^{-1}	14.3	(11.8–17.5)	9.7	(8.6–10.9)	9.1	(7.6–10.8)	6.5	(5.6–7.6)	6.7	(5.8–7.6)	<0.0001
HOMA-IR[d]	3.8	(3.1–4.7)	2.5	(2.2–2.9)	2.4	(2.0–2.8)	1.6	(1.4–1.9)	1.7	(1.4–1.9)	<0.0001
HDL cholesterol, mg·dL^{-1}	52.8	(50.8–54.9)	56.0	(53.9–58.2)	56.2	(54.2–58.2)	58.5	(56.7–60.3)	61.8	(59.3–64.4)	<0.0001
Triglyceride, mg·dL^{-1}	128.4	(110.1–149.7)	111.3	(100.9–122.8)	118.1	(106.1–131.5)	90.3	(82.8–98.5)	91.3	(81.0–103.0)	0.0013
C-reactive protein, mg·dL^{-1}	0.32	(0.26–0.39)	0.26	(0.22–0.30)	0.26	(0.20–0.34)	0.17	(0.14–0.21)	0.15	(0.12–0.18)	<0.0001
Glycohemoglobin, %	5.66	(5.58–5.74)	5.60	(5.51–5.68)	5.61	(5.53–5.70)	5.50	(5.44–5.56)	5.47	(5.39–5.55)	0.0016

[a]Median peak 30-min cadence for males was 48.1, 62.6, 72.4, 82.3, and 96.0 for the first, second, third, fourth, and fifth quintiles, respectively. Median peak 30-min cadence for females was 40.8, 57.0, 67.8, 78.3, and 96.2 for the first, second, third, fourth, and fifth quintiles, respectively.
[b]Mean: geometric mean values for all the variables except SBP and DBP were covariate adjusted for age (yr) and race.
[c]n: sample size range.
[d]HOMA-IR: calculated as fasting insulin {[(μU·mL^{-1}) × [fasting glucose (mmol·L^{-1})]/22.5}.

compilation considering a wide array of cardiometabolic risk factors and also include relationships with %TZC, an indicator of sedentary time shaped by behaviors where no stepping occurs. Strong and consistent significant linear relationships and correlations were observed for both men and women between each movement/nonmovement dimension and several of the cardiometabolic risk factors, including waist circumference, weight, insulin, HOMA-IR, and C-reactive protein.

As previously mentioned, steps per day has been criticized for not capturing the quality or pattern of physical activity (7), with intensity-based physical activity and sedentary behavior measures seemingly preferred. However, in the current analyses, significant linear relationships were observed between steps per day quintile and cardiometabolic outcomes, highlighting the relevance and usefulness of steps per day (Table 2; Figure, Supplemental Digital Content 1, scatterplot displaying linear trends for insulin, http://links.lww.com/MSS/A764). Indeed, linear trends for steps per day were statistically significant for all cardiometabolic risk factors except systolic blood pressure for men. Further, for several of the outcomes (e.g., weight, waist circumference, insulin, and HOMA-IR), similar or even stronger linear relationships and Spearman correlations were observed for steps per day when compared with relationships with peak 30-min cadence and %TZC. Thus, these analyses provide justification for the use of steps per day recommendations in national physical activity guidelines.

Consistent with our step-based approach, we included peak 30-min cadence in these analyses as a proxy measure describing physical activity intensity. This metric resonates with physical activity guidelines that recommend adults participate in a minimum of 30 min·d^{-1} of at least *moderate* intensity activity (accumulated in minimum bouts of 10 min) on most or preferably all days per week (7,22). In parallel to this, a series of controlled laboratory studies have consistently demonstrated that ~100 steps per minute seems to be a reasonable heuristic indicator of at least *moderate* intensity (i.e., 3 METs) physical activity (1,3,18,24,38). Taken together then, previous guidelines have recommended that adults engage in 30 min·d^{-1} of physical activity at ~100 steps per minute to meet physical activity guidelines (7). Interestingly, in the current analysis, the natural distribution of peak 30-min cadences across quintiles indicated that only the highest quintile of participants (fifth quintile: median peak 30-min cadence, ~96 steps per minute for men and women) achieved a peak 30-min cadence similar to what has been considered a direct translation of enacted moderate intensity physical activity. Despite this finding, statistical testing across quintiles revealed highly statistically significant linear relationships but, perhaps more importantly, clinically meaningful associations in expected directions, for the majority of the cardiometabolic risk factors. Furthermore, it is interesting to note that the third (~70 steps per minute) and fourth quintiles (~80 steps per minute), despite achieving median peak 30-min cadences well below what would be considered moderate intensity, displayed clinically favorable values for many of the cardiometabolic outcomes. The same was also true for

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TABLE 4. Mean (95% CI) for selected variables with percent time at zero cadence quintiles for male and female 20+ yr old from NHANES 2005–2006.

	%TZC Quintiles[a]										Linear
	First Quintile		Second Quintile		Third Quintile		Fourth Quintile		Fifth Quintile		
					Mean[b] (95% CI)						
Men											
n^c	164–345		149–345		160–345		169–345		156–345		
Waist circumference, cm	99.0	(96.9–101.2)	99.6	(96.6–102.6)	98.0	(95.6–100.6)	99.7	(97.1–102.4)	102.2	(100.3–104.2)	0.0307
Weight, kg	83.1	(80.1–86.2)	84.4	(80.6–88.3)	83.1	(80.2–86.1)	85.0	(81.7–88.3)	87.1	(84.2–90.2)	0.0094
BMI, kg·m^{-2}	27.8	(27.3–28.4)	28.3	(27.2–29.5)	27.6	(26.8–28.5)	28.2	(27.1–29.3)	28.6	(27.8–29.4)	0.1373
SBP, mm Hg	125.1	(123.2–127.0)	126.4	(124.7–128.1)	125.2	(122.8–127.7)	124.9	(123.2–126.6)	125.1	(122.8–127.3)	0.6656
DBP, mm Hg	71.2	(69.5–72.9)	73.5	(71.2–75.9)	71.9	(70.1–73.6)	71.6	(69.4–73.7)	70.4	(68.6–72.2)	0.1312
Glucose, mg·dL^{-1}	103.8	(100.0–107.8)	104.7	(101.5–108.0)	104.0	(100.8–107.3)	108.6	(105.0–112.3)	105.2	(101.6–109.0)	0.2013
Insulin, μU·mL^{-1}	8.2	(7.2–9.3)	9.8	(8.4–11.5)	9.2	(7.8–10.9)	10.8	(8.8–13.3)	12.0	(10.1–14.1)	0.0015
HOMA-IR^d	2.1	(1.8–2.4)	2.5	(2.1–3.0)	2.4	(2.0–2.8)	2.9	(2.3–3.6)	3.1	(2.6–3.7)	0.0010
HDL cholesterol, mg·dL^{-1}	49.4	(47.1–51.7)	47.3	(45.7–48.9)	47.8	(45.7–49.9)	45.3	(43.7–47.0)	45.3	(43.5–47.2)	0.0070
Triglyceride, mg·dL^{-1}	120.7	(106.1–137.3)	126.0	(111.2–142.6)	144.3	(123.5–168.6)	136.9	(118.2–158.5)	146.4	(129.2–165.8)	0.0183
C-reactive protein, mg·dL^{-1}	0.17	(0.13–0.23)	0.18	(0.15–0.21)	0.17	(0.14–0.20)	0.17	(0.15–0.19)	0.21	(0.17–0.25)	0.3222
Glycohemoglobin, %	5.62	(5.53–5.71)	5.62	(5.50–5.74)	5.56	(5.48–5.65)	5.60	(5.51–5.69)	5.66	(5.54–5.77)	0.5733
Women											
n^c	148–333		147–333		139–332		143–333		143–332		
Waist circumference, cm	94.8	(92.6–97.1)	94.8	(92.6–97.1)	93.6	(91.4–95.8)	94.8	(92.1–97.6)	95.8	(93.5–98.1)	0.1486
Weight, kg	73.9	(71.3–76.6)	70.6	(69.0–72.2)	72.7	(70.4–75.1)	73.5	(70.5–76.7)	72.9	(70.0–75.9)	0.8251
BMI, kg·m^{-2}	29.0	(28.1–30.0)	27.7	(27.2–28.3)	28.2	(27.5–29.0)	28.7	(27.5–29.9)	28.7	(27.8–29.6)	0.8028
SBP, mm Hg	125.7	(123.5–127.9)	122.4	(119.9–125.0)	121.0	(119.1–123.0)	124.9	(122.4–127.3)	123.6	(121.0–126.3)	0.6253
DBP, mm Hg	70.9	(68.9–72.9)	70.0	(68.5–71.5)	69.3	(67.6–70.9)	69.8	(67.9–71.7)	69.1	(67.5–70.7)	0.1356
Glucose, mg·dL^{-1}	105.1	(100.1–110.3)	104.1	(99.9–108.4)	101.0	(96.5–105.8)	102.7	(99.9–105.7)	105.1	(101.4–109.1)	0.8045
Insulin, μU·mL^{-1}	7.6	(6.6–8.7)	8.6	(7.1–10.4)	8.9	(7.5–10.4)	9.2	(8.0–10.7)	11.7	(9.9–13.9)	0.0028
HOMA-IR^d	2.0	(1.7–2.3)	2.2	(1.8–2.7)	2.2	(1.9–2.6)	2.3	(2.0–2.7)	3.0	(2.5–3.6)	0.0034
HDL cholesterol, mg·dL^{-1}	58.5	(55.7–61.4)	57.5	(55.3–59.7)	56.7	(55.1–58.4)	56.6	(54.5–58.8)	54.9	(53.0–56.9)	0.0438
Triglyceride, mg·dL^{-1}	99.4	(89.8–110.0)	108.2	(97.4–120.2)	104.3	(94.9–114.6)	104.7	(94.5–116.0)	128.3	(112.9–145.9)	0.0315
C-reactive protein, mg·dL^{-1}	0.22	(0.17–0.29)	0.21	(0.16–0.27)	0.20	(0.17–0.23)	0.23	(0.20–0.27)	0.28	(0.25–0.32)	0.1201
Glycohemoglobin, %	5.60	(5.49–5.72)	5.55	(5.48–5.63)	5.56	(5.50–5.62)	5.55	(5.52–5.58)	5.57	(5.46.5.68)	0.5328

[a]Median % time at zero cadence for male was 17.6, 26.8, 34.1, 40.6, and 51.0 for the first, second, third, fourth, and fifth quintiles, respectively. Median % time at zero cadence for females was 19.9, 27.1, 32.9, 39.0, and 47.6 for the first, second, third, fourth, and fifth quintiles, respectively.
[b]Mean: geometric mean values for all the variables except SBP and DBP were covariate adjusted for age (yr) and race.
[c]n: sample size range.
[d]HOMA-IR: calculated as fasting insulin $\{[(\mu$U·mL$^{-1}) \times$ [fasting glucose (mmol·L$^{-1})]/22.5\}$.

participants in the third and fourth quintiles for steps per day (Table 2; Figure, Supplemental Digital Content 1, scatterplot displaying linear trends for insulin, http://links.lww.com/MSS/A764), who achieved less than the popularized 10,000 steps per day but still displayed favorable values for several of the cardiometabolic risk factors. A fundamentally similar pattern was also observed in %TZC (Table 4; Figure, Supplemental Digital Content 1, scatterplot displaying linear trends for insulin, http://links.lww.com/MSS/A764); however, due the nature of variable, quintiles 1–3 were associated with clinical favorable values, as these correspond to a lower percentage of the day spent in sedentary behavior. These findings have important implications for public health and provide additional evidence-based support for the recommendation that "some physical activity is better than none," as stated in the 2008 physical activity guidelines for Americans (40). Simply put, small increases in the volume (steps per day) and intensity (peak 30-min cadence expressed in steps per minute) of physical activity across the day and decreased amount of sedentary time (%TZC) are associated with clinically favorable values for a wide range of cardiometabolic risk factors.

Within the extant literature, sedentary time has been defined by a variety of objectively measured metrics, including time spent at <100 (20) or <150 (16) activity counts per minute and time spent at zero cadence (41). It is important to note that all of the aforementioned metrics are related to accelerometer-determined wear time, which can be empirically demonstrated via the strong correlations apparent between each metric and accelerometer wear time in this investigation (e.g., $r = 0.577$ between time at zero cadence and wear time and $r = 0.401$ between time <100 activity counts per minute and wear time). Not surprisingly, several studies have demonstrated that varying the minimum wear time requirement while defining a "valid" day of accelerometer data can substantially affect estimates of sedentary time (11,12). As an illustrative example using data from the 2005 to 2006 NHANES, Herrmann et al. (12) previously reported that decreasing the minimum accelerometer-determined wear time requirement from 14 to 10 h·d^{-1} reduced estimates of sedentary time (defined in this case by <100 activity counts per minute) by 30%. In light of these results, time-based comparisons of sedentary time with varying definitions of a valid day (e.g., 10 vs 14 h·d^{-1}), or with different mean values of accelerometer-determined wear time, may lead to spurious observations of significant differences in sedentary time which are largely attributable to discrepant wear time estimates. To address this issue, previous analyses have sought to incorporate statistical adjustments for accelerometer-determined wear time, or to present sedentary time metrics in relative terms as a proportion of accelerometer wear time (10). These analytic strategies inherently assume that sedentary time during wear and nonwear times are similar (15). It remains unknown whether this is a tenable assumption; however, Herrmann et al. (12) reported that the mean proportion of daily sedentary time (relative to wear time) remained relatively stable across

TABLE 5. Spearman's correlations between physical activity volume (steps per day), intensity (peak 30-min cadence; steps per minute), and sedentary behavior (%TZC) and cardiometabolic risk factors.

	n^a	Steps per Day	Peak 30-min Cadence	%TZC (%)^b
Men				
Waist circumference, cm	1685	−0.25	−0.24	0.14
Weight, kg	1725	−0.16	−0.15	0.10
BMI, kg·m^{-2}	1725	−0.17	−0.18	0.06
SBP, mm of Hg	1670	−0.15	−0.12	0.08
DBP, mm of Hg	1662	0.03	0.02	−0.04
Glucose, mg·dL^{-1}	806	−0.20	−0.17	0.16
Insulin, μU·mL^{-1}	799	−0.22	−0.15	0.12
HOMA-IR^b	799	−0.25	−0.18	0.14
HDL cholesterol, mg·dL^{-1}	1667	0.13	0.11	−0.07
Triglyceride, mg·dL^{-1}	801	−0.13	−0.08	0.11
C-reactive protein, mg·dL^{-1}	1668	−0.24	−0.28	0.10
Glycohemoglobin, %	1662	−0.22	−0.22	0.10
Women				
Waist circumference, cm	1630	−0.28	−0.35	0.08
Weight, kg	1663	−0.16	−0.24	0.02
BMI, kg·m^{-2}	1663	−0.21	−0.29	0.02
SBP, mm of Hg	1598	−0.21	−0.26	0.07
DBP, mm of Hg	1588	0.03	−0.02	−0.03
Glucose, mg·dL^{-1}	741	−0.21	−0.26	0.04
Insulin, μU·mL^{-1}	721	−0.32	−0.34	0.17
HOMA-IR^c	720	−0.34	−0.36	0.16
HDL cholesterol, mg·dL^{-1}	1583	0.11	0.14	−0.03
Triglyceride, mg·dL^{-1}	728	−0.29	−0.32	0.17
C-reactive protein, mg·dL^{-1}	1591	−0.19	−0.22	0.08
Glycohemoglobin, %	1599	−0.23	−0.26	0.07

^{a}n: sample size.
^{b}%TZC, percent time at zero cadence.
^{c}HOMA-IR: calculated as fasting insulin {[(μU·mL^{-1}) × [fasting glucose (mmol·L^{-1})]/22.5}.

varying definitions of a valid day (proportion of sedentary time at 14 h—54.9%, 13 h—54.5%, 12 h—54.3%, 11 h—54.2%, and 10 h—54.0%). To be clear, absolute wear time did little to affect variability of computed proportion of sedentary time when it was considered relative to wear time. Therefore, because our volume and intensity metrics herein were step based, and zero cadence is consistent with sedentary time (41), we selected a consistent step-based metric to capture sedentary time relative to wear time.

Although steps per day and peak 30-min cadence were highly correlated (Spearman correlation > 0.80), results herein indicated that each measure seemed to provide unique contributions when predicting cardiometabolic outcomes. Interestingly, cardiometabolic associations were strongest with steps per day among men, whereas peak 30-min cadence was more strongly associated with cardiometabolic outcomes in women. Previous longitudinal analyses have indicated that self-reported walking speed (a marker of physical activity intensity) was more important than walking volume in reducing risks for heart failure and metabolic syndrome (17,26). However, comparisons of these findings with results presented here are problematic because of the discrepant physical activity assessment measures used (self-report questionnaire vs accelerometer). %TZC seemed to be less strongly associated with cardiometabolic measures than steps per day and peak 30-min cadence when considered collectively in multivariable regression models; however, %TZC remained a significant predictor of BMI, triglycerides, and glycohemoglobin in women. Analyses among adults using metrics similar to peak 30-min cadence and %TZC have indicated that sedentary time is independently associated with fasting insulin, 2-h plasma glucose, HOMA-IR, HDL cholesterol, and triglycerides after adjustment for time spent in moderate-to-vigorous physical activity (5). However, we are unaware of any other published studies that collectively examined the associations of various cardiometabolic outcomes with volume (steps per day) and intensity (peak 30-min cadence) step-based physical activity, as well as time spent in nonmovement (%TZC). Further research elucidating the independent and collective relationships of these measures with longitudinal outcomes remain needed.

This study has several strengths, including the use of a large nationally representative sample (NHANES) and use of objectively measured PAM (waist-worn accelerometer) data. This study also has some limitations to acknowledge.

TABLE 6. Multiple regression analyses for censored steps per day, peak 30-min cadence, and percent of time at zero cadence (%TZC) with each cardiometabolic outcome.

	Intercept	Censored Steps per Day^a		Peak 30-min Cadence		%TZC		
	B_0 (SE)	B_1 (SE)	VIF	B_2 (SE)	VIF	B_3 (SE)	VIF	P^b
Men								
BMI, kg·m^{-2}	3.48 (0.03)	−0.0080 (0.0021)*	3.29	−0.0008 (0.0004)*	2.12	−0.0009 (0.0005)	1.84	<0.001
SBP, mm Hg	131.05 (2.31)	−0.6012 (0.1742)*	3.27	−0.0225 (0.0307)	2.10	−0.0310 (0.0412)	1.84	<0.001
Glucose, mg·dL^{-1}	4.72 (0.04)	−0.0085 (0.0028)*	3.12	−0.0002 (0.0005)	2.06	−0.0002 (0.0007)	1.77	<0.001
Insulin, μU·mL^{-1}	2.60 (0.16)	−0.0490 (0.0114)*	3.10	0.0004 (0.0021)	2.03	−0.0017 (0.0028)	1.79	<0.001
HDL cholesterol, mg·dL^{-1}	3.75 (0.04)	0.0074 (0.0030)*	3.27	0.0005 (0.0005)	2.09	0.0002 (0.0007)	1.85	<0.001
Triglyceride, mg·dL^{-1}	4.90 (0.13)	−0.0283 (0.0092)*	3.10	0.0023 (0.0017)	2.03	0.0007 (0.0022)	1.78	<0.001
Glycohemoglobin, %	1.79 (0.02)	−0.0032 (0.0015)*	3.27	−0.0010 (0.0003)*	2.11	−0.0001 (0.0004)	1.84	<0.001
Women								
BMI, kg·m^{-2}	3.69 (0.03)	−0.0039 (0.0034)	3.60	−0.0034 (0.0004)*	2.74	−0.0028 (0.0007)*	1.57	<0.001
SBP, mm Hg	136.10 (2.93)	0.4720 (0.2907)	3.59	−0.2749 (0.0379)*	2.72	0.0604 (0.0569)	1.59	<0.001
Glucose, mg·dL^{-1}	4.78 (0.04)	−0.0066 (0.0048)	3.72	−0.0014 (0.0006)*	2.87	−0.0010 (0.0009)	1.55	<0.001
Insulin, μU·mL^{-1}	2.68 (0.15)	−0.0498 (0.0164)*	3.64	−0.0053 (0.0021)*	2.82	0.0022 (0.0030)	1.53	<0.001
HDL cholesterol, mg·dL^{-1}	3.87 (0.04)	0.0066 (0.0040)	3.57	0.0014 (0.0005)*	2.74	0.0012 (0.0008)	1.55	<0.001
Triglyceride, mg·dL^{-1}	4.97 (0.11)	−0.0097 (0.0117)	3.62	−0.0054 (0.0015)*	2.79	0.0044 (0.0022)*	1.54	<0.001
Glycohemoglobin, %	1.80 (0.02)	−0.0033 (0.0018)	3.58	−0.0010 (0.0002)*	2.75	−0.0007 (0.0003)*	1.56	<0.001

VIF, variance inflation factor. Dependent variables in all regression models were transformed using the natural logarithm (ln) except SBP.
^{a}Censored steps per day were divided by 1000.
^{b}Significance of F test associated with overall regression model.
*Significant at $P < 0.05$.

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These are cross-sectional data, and as such, the ability to make causal conclusions is limited. An obvious potential confounder in the apparent relationships between the different step-based metrics and the evaluated cardiometabolic outcomes is body mass/composition, itself a cardiometabolic risk factor. Because there are few people with high body mass/composition with also relatively high steps per day, high peak 30-min cadence, or low %TZC, it is difficult to attribute the seeming effects cataloged in Tables 2 through 5 exclusively (or at all) to these movement/nonmovement dimensions.

CONCLUSIONS

Collectively, this assemblage of data adds to the body of evidence supporting the important role of physical activity for reducing cardiometabolic risk by providing a useful classification of associations organized across organic distribution parameters natural to each of the selected movement/nonmovement dimensions. As such, these data also offer a set of quantified access points for researchers/clinicians studying the potential dose–response effects of each of these dimensions separately or collectively in longitudinal observational or intervention study designs. At face value, it is quite apparent that these distinct yet overlapping dimensions of movement/nonmovement are related in multifarious ways to an array of cardiometabolic risk factors. In addition, it is important to consider, even without an acceptable method of statistical proof, the complex and interactive effects of these small-to-moderate improvements in cardiometabolic outcomes

on overall health; we should not dismiss these effects simply by a judgment of their seemingly small magnitude or nonsignificant P values. Rather, it is important to consider the multiplicity of effects, which may compound on one another and act in concert to achieve minimal clinically important differences in these cardiometabolic risk factors, ultimately leading to improved health outcomes.

These findings are also pertinent to the general population, particularly users of commercial PAM. Moving forward, PAM devices and their software developers might consider presenting these step-related movement/nonmovement dimensions in an integrated way, e.g., a total movement score that encompasses the whole spectrum and pattern of movement/nonmovement for 24 h. Providing the end user with feedback on these movement/nonmovement dimensions and their association with cardiometabolic risk factors, e.g., waist circumference, insulin, and C-reactive protein, may also provide additional motivation to improve/maintain physical activity accordingly.

REFERENCES

1. Abel M, Hannon J, Mullineaux D, Beighle A. Determination of step rate thresholds corresponding to physical activity intensity classifications in adults. *J Phys Act Health*. 2011;8(1):45–51.

2. Ayabe M, Aoki J, Kumahara H, et al. Minute-by-minute stepping rate of daily physical activity in normal and overweight/obese adults. *Obes Res Clin Pract*. 2011;5(2):e79–156.

3. Beets MW, Agiovlasitis S, Fahs CA, Ranadive SM, Fernhall B. Adjusting step count recommendations for anthropometric variations in leg length. *J Sci Med Sport*. 2010;13(5):509–12.

4. Bravata DM, Smith-Spangler C, Sundaram V, et al. Using pedometers to increase physical activity and improve health: a systematic review. *JAMA*. 2007;298(19):2296–304.

5. Brocklebank LA, Falconer CL, Page AS, Perry R, Cooper AR. Accelerometer-measured sedentary time and cardiometabolic biomarkers: a systematic review. *Prev Med*. 2015;76:92–102.

6. Chan CB, Spangler E, Valcour J, Tudor-Locke C. Cross-sectional relationship of pedometer-determined ambulatory activity to indicators of health. *Obes Res*. 2003;11(12):1563–70.

7. Garber CE, Blissmer B, Deschenes MR, et al. American College of Sports Medicine Position Stand: quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. *Med Sci Sports Exerc*. 2011;43(7):1334–59.

8. Grundy SM, Cleeman JI, Daniels SR, et al. Diagnosis and management of the metabolic syndrome: an American Heart Association/National Heart, Lung, and Blood Institute scientific statement: executive Summary. *Crit Pathw Cardiol*. 2005;4(4):198–203.

9. Hair JF, Black WC, Babin BJ, Anderson RE. *Multivariate Data Analysis*. 7th ed. Upper Saddle River (NJ): Prentice-Hall; 2010.

10. Healy GN, Clark BK, Winkler EA, Gardiner PA, Brown WJ, Matthews CE. Measurement of adults' sedentary time in population-based studies. *Am J Prev Med*. 2011;41(2):216–27.

11. Herrmann SD, Barreira TV, Kang M, Ainsworth BE. How many hours are enough? Accelerometer wear time may provide bias in daily activity estimates. *J Phys Act Health*. 2013;10(5):742–9.

12. Herrmann SD, Barreira TV, Kang M, Ainsworth BE. Impact of accelerometer wear time on physical activity data: a NHANES semisimulation data approach. *Br J Sports Med*. 2014;48(3):278–82.

13. Inoue S, Yumiko O, Odagiri Y, et al. Sociodemographic determinants of pedometer-determined physical activity among Japanese adults. *Am J Prev Med*. 2011;40(5):566–71.

14. Kang M, Marshall SJ, Barreira TV, Lee JO. Effect of pedometer-based physical activity interventions: a meta-analysis. *Res Q Exerc Sport*. 2009;80(3):648–55.

15. Kang M, Rowe DA. Issues and challenges in sedentary behavior measurement. *Meas Phys Educ Exerc Sci*. 2015;19(3):105–15.

16. Kozey-Keadle S, Libertine A, Lyden K, Staudenmayer J, Freedson PS. Validation of wearable monitors for assessing sedentary behavior. *Med Sci Sports Exerc*. 2011;43(8):1561–7.

17. Laursen AH, Kristiansen OP, Marott JL, Schnohr P, Prescott E. Intensity versus duration of physical activity: implications for the metabolic syndrome. A prospective cohort study. *BMJ Open*. 2012;2(5).

18. Marshall SJ, Levy SS, Tudor-Locke CE, et al. Translating physical activity recommendations into a pedometer-based step goal: 3000 steps in 30 minutes. *Am J Prev Med*. 2009;36(5):410–5.

19. Matthews CE. Calibration of accelerometer output for adults. *Med Sci Sports Exerc*. 2005;37(11 Suppl):S512–22.

EPIDEMIOLOGY

20. Matthews CE, Chen KY, Freedson PS, et al. Amount of time spent in sedentary behaviors in the United States, 2003–2004. *Am J Epidemiol*. 2008;167(7):875–81.

21. Mudge S, Taylor D, Chang O, Wong R. Test–retest reliability of the StepWatch Activity Monitor outputs in healthy adults. *J Phys Act Health*. 2010;7(5):671–6.

22. Pate RR, Pratt M, Blair SN, et al. Physical activity and public health. A recommendation from the Centers for Disease Control and Prevention and the American College of Sports Medicine. *JAMA*. 1995;273(5):402–7.

23. Richardson CR, Newton TL, Abraham JJ, Sen A, Jimbo M, Swartz AM. A meta-analysis of pedometer-based walking interventions and weight loss. *Ann Fam Med*. 2008;6(1):69–77.

24. Rowe DA, Welk GJ, Heil DP, et al. Stride rate recommendations for moderate-intensity walking. *Med Sci Sports Exerc*. 2011; 43(2):312–8.

25. Ryan D, Stebbings GK, Onambele GL. The emergence of sedentary behaviour physiology and its effects on the cardiometabolic profile in young and older adults. *Age (Dordr)*. 2015;37(5):89.

26. Saevereid HA, Schnohr P, Prescott E. Speed and duration of walking and other leisure time physical activity and the risk of heart failure: a prospective cohort study from the Copenhagen City Heart Study. *PLoS One*. 2014;9(3):e89909.

27. Sisson SB, Camhi SM, Church TS, Tudor-Locke C, Johnson WD, Katzmarzyk PT. Accelerometer-determined steps/day and metabolic syndrome. *Am J Prev Med*. 2010;38(6):575–82.

28. Swartz AM, Strath SJ, Miller NE, Cashin SE, Cieslik LJ. Glucose control and walking in a multiethnic sample of older adults. *Gerontology*. 2007;53(6):454–61.

29. Thorp AA, Healy GN, Owen N, et al. Deleterious associations of sitting time and television viewing time with cardiometabolic risk biomarkers: Australian Diabetes, Obesity and Lifestyle (AusDiab) study 2004–2005. *Diabetes Care*. 2010;33(2):327–34.

30. Troiano RP, Berrigan D, Dodd KW, Masse LC, Tilert T, McDowell M. Physical activity in the United States measured by accelerometer. *Med Sci Sports Exerc*. 2008;40(1):181–8.

31. Tudor-Locke C, Brashear MM, Katzmarzyk PT, Johnson WD. Peak stepping cadence in free-living adults: 2005–2006 NHANES. *J Phys Act Health*. 2012;9:1125–9.

32. Tudor-Locke C, Camhi SM, Leonardi C, et al. Patterns of adult stepping cadence in the 2005–2006 NHANES. *Prev Med*. 2011; 53(3):178–81.

33. Tudor-Locke C, Craig CL, Brown WJ, et al. How many steps/day are enough? For adults. *Int J Behav Nutr Phys Act*. 2011;8:79.

34. Tudor-Locke C, Johnson WD, Katzmarzyk PT. Accelerometer-determined steps per day in US adults. *Med Sci Sports Exerc*. 2009;41(7):1384–91.

35. Tudor-Locke C, Johnson WD, Katzmarzyk PT. Relationship between accelerometer-determined steps/day and other accelerometer outputs in US adults. *J Phys Act Health*. 2011;8:410–9.

36. Tudor-Locke C, Johnson WD, Katzmarzyk PT. U.S. population profile of time-stamped accelerometer outputs: impact of wear time. *J Phys Act Health*. 2011;8(5):693–8.

37. Tudor-Locke C, Schuna JM Jr. Steps to preventing type 2 diabetes: exercise, walk more, or sit less? *Front Endocrinol (Lausanne)*. 2012;3:142.

38. Tudor-Locke C, Sisson SB, Collova T, Lee SM, Swan PD. Pedometer-determined step count guidelines for classifying walking intensity in a young ostensibly healthy population. *Can J Appl Physiol*. 2005;30(6):666–76.

39. Tully MA, McBride C, Heron L, Hunter RF. The validation of Fibit Zip™ physical activity monitor as a measure of free-living physical activity. *BMC Res Notes*. 2014;7:952.

40. U.S. Department of Health and Human Services. *2008 Physical Activity Guidelines for Americans: Be Active, Healthy, and Happy!* Washington (DC); 2008.

41. Wong SL, Colley R, Connor Gorber S, Tremblay M. Actical accelerometer sedentary activity thresholds for adults. *J Phys Act Health*. 2011;8(4):587–91.

42. Yamanouchi K, Shinozaki T, Chikada K, et al. Daily walking combined with diet therapy is a useful mean values for obese NIDDM patients not only to reduce body weight but also to improve insulin sensitivity. *Diabetes Care*. 1995;18(6):775–8.

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