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ORIGINAL RESEARCH

Accelerometer and GPS Analysis of Trail Use and Associations With Physical Activity

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Background: Concurrent use of accelerometers and global positioning system (GPS) data can be used to quantify physical activity (PA) occurring on trails. This study examined associations of trail use with PA and sedentary behavior (SB) and quantified on trail PA using a combination of accelerometer and GPS data. **Methods**: Adults (N = 142) wore accelerometer and GPS units for 1–4 days. Trail use was defined as a minimum of 2 consecutive minutes occurring on a trail, based on GPS data. We examined associations between trail use and PA and SB. On trail minutes of light-intensity, moderate-intensity, and vigorous-intensity PA, and SB were quantified in 2 ways, using accelerometer counts only and with a combination of GPS speed and accelerometer data. **Results**: Trail use was positively associated with total PA, moderate-intensity PA, and light-intensity PA ($P < .05$). On trail vigorous-intensity PA minutes were 346% higher when classified with the combination versus accelerometer only. Light-intensity PA, moderate-intensity PA, and SB minutes were 15%, 91%, and 85% lower with the combination, respectively. **Conclusions**: Adult trail users accumulated more PA on trail use days than on nontrail use days, indicating the importance of these facilities for supporting regular PA. The combination of GPS and accelerometer data for quantifying on trail activity may be more accurate than accelerometer data alone and is useful for classifying intensity of activities such as bicycling.

Keywords: exercise, sedentary time, geographic information system, environment, recreation

Recent US guidelines for physical activity (PA) indicate that adults should engage in a minimum of 150 minutes per week of moderate-intensity PA (MPA), or 75 minutes per week of vigorous-intensity PA (VPA) or some combination of both.[1] Well-demonstrated health benefits of moderate- to vigorous-intensity PA (MVPA) include reduced risks for heart disease, certain cancers, stroke, type 2 diabetes, hypertension, and psychological issues.[1] Beyond the focus on MVPA, there has been increasing interest in examining the protective effects of light-intensity PA (LPA) on health outcomes.[2] Recent studies have shown that independent of MVPA, LPA is inversely associated with risk factors for cardiovascular disease, such as triglycerides,[2] blood glucose,[3] metabolic syndrome,[4] and diabetes,[4] as well as the risk for chronic kidney disease.[5]

Over the past 2 decades, social ecological frameworks that emphasize the use of environmental and policy approaches to increase PA have been embraced by researchers and practitioners.[6,7] Numerous studies have shown beneficial relationships between the neighborhood built environment, including a greater mix of residential and commercial land uses, street connectivity, access to parks and open spaces, and PA.[8–10] One specific component of the built environment, community trails, has received growing attention as an important resource for supporting PA among adults.[11,12] For instance, studies have shown that new community trails were positively associated with PA.[13,14] Another study demonstrated that parks with a trail were more likely to be used for PA than parks without trails.[15] Finally, a study examining PA levels among adults in the US national level indicated that individuals who used trails at least once a week were twice as likely to meet PA guidelines, compared with those who rarely or who never utilized trails.[16] Despite evidence for the PA benefits of trail use, there are 2 key limitations in this research area. First, the majority of trail studies have relied on self-report surveys to assess trail use and PA.[17] These measures are limited by recall[18] and social desirability bias.[19] Although some studies have utilized infrared counters to objectively measure trail use,[20,21] these methods are not designed to quantify activity at an individual level; instead, they provide aggregate measures of trail traffic at different locations and times. Another limitation of the research on trails is that self-report measures have focused on assessing MVPA.[22] Given the growing evidence that LPA may have positive health effects, examining how trails may also support LPA is important to explore.

Simultaneous use of accelerometers and global positioning system (GPS) units can be used to quantify PA occurring on trails and thereby provide a better understanding of how community trails can support regular PA.[23,24] To date, researchers have concurrently used these devices to objectively assess how much PA occurs at home and school,[25,26] in parks and recreational facilities,[25,27] and in open spaces.[25–27] One study used accelerometer and GPS monitoring with adults to demonstrate that bouts of daily MVPA were greater on days when participants visited a park.[23] Although this is a rapidly developing research area, to our knowledge, no studies have examined the association between trail use and LPA, MPA, VPA, and sedentary behavior (SB) measured through simultaneous accelerometer and GPS assessments. In addition, using accelerometer and GPS data together may allow a more complete assessment of PA that takes place on trails, such as bicycling. Therefore, the aims of this study were 2-fold: (1) to

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examine associations between trail use and LPA, MPA, VPA, total PA (TPA), and SB among a sample of adult trail users and (2) to objectively quantify PA and SB occurring on trail, using 2 approaches: the first using accelerometer counts only and the second using both accelerometer counts and GPS speed data.

Methods

Participants and Trail Characteristics

The sample for this study was recruited among 1194 adults who completed brief intercept surveys at 5 trails in Massachusetts during the fall of 2004 and the spring/summer of 2005. The trails were: (1) Cutler Park Reservation (suburban conservation land with a 2-mile circular dirt path, highly wooded, and with water views); (2) Franklin Park (500-acre urban park with a 3-mile path around a golf course); (3) Minuteman Bikeway (11 mile, suburban, and asphalt-paved rail trail); (4) Nashua River Rail Trail (12 mile, rural, and mostly asphalt-paved rail trail); and (5) Southwest Corridor (5 mile, urban, and asphalt-paved linear park). Survey respondents who reported having used a trail at least 4 times in the past 4 weeks were asked to participate in a second study that involved wearing an accelerometer (model 7164; ActiGraph™, Pensacola, FL) and GPS unit (GeoStats Wearable GeoLogger™, Rockville, MD) for a 4-day period (2 weekdays and 2 weekend days). Among 294 individuals who initially provided contact information, 178 wore the 2 devices. Recruitment procedures were described in detail in a prior study.[28] All procedures were approved by the Human Subjects Committee at the Harvard T.H. Chan School of Public Health and the institutional review board at Purdue University. Participants provided written informed consent and were told that the main purpose of the study was to assess how much of their PA occurred while they were on a trail or at other locations.

Data Collection

Research staff met participants at public places (eg, libraries, town halls) to deploy and pick up equipment. Staff instructed participants on how to wear the 2 devices and provided daily log sheets to record time-on and time-off for both devices. Participants were instructed to wear the accelerometer at all times for 4 days, except while sleeping, bathing, or swimming. The accelerometer was initialized to collect data using 1-minute epochs. Participants were also instructed to wear the GPS device when they were outside, irrespective of whether they were physically active or engaged in sedentary forms of travel, such as driving a car or taking a bus. GPS data were collected at 5-second intervals.

Data Processing

The data processing procedures were described previously.[28] GeoStats software was used to download raw data from the GPS receivers. For each participant, a research analyst evaluated the GPS data for the 4-day period to identify outlying points that were likely because of poor GPS signals and multiple points occurring at the same location. These points were subsequently removed from the database. GPS points were then aggregated to 1-minute intervals, which had latitude and longitude for both the starting and ending points of each minute.

We used Actisoft software (Pensacola, FL) to initialize and download the accelerometer data. GPS and accelerometer data were merged using their respective date and time stamps. A valid monitoring day was defined as having a minimum of 40 minutes with GPS readings[28] and ≥600 minutes of valid accelerometer wear time.[29,30] Among 178 participants, 148 met both GPS and accelerometer criteria for at least 1 valid monitoring day. Four participants who did not reside in Massachusetts and 2 without demographic data were excluded from the study, leaving a final sample of 142 individuals. These participants had 431 person-days of observations; a mean number of valid monitoring days = 3.0 (1.1) days per person. To examine associations between trail use and PA, 2 datasets were used: one dataset using only monitoring minutes where accelerometer counts were linked to actual GPS readings (N = 60,335), and the other dataset including all accelerometer monitoring minutes (N = 472,175), both with and without GPS coordinates. For statistical analyses, minutes in each dataset were aggregated to the person-day level.

Determination of Monitoring Minutes on Trails

A variable indicating whether participants were on or off in one of the 5 study trails (1 = on trail; 0 = off trail) was initially created by an outside GPS vendor (Westat, Rockville, MD; https://www.westat.com/). The vendor used automated procedures (.NET Framework v1.1; Microsoft, Redmond, WA) to define trips as sets of GPS points grouped in time and space. To verify the on/off trail classification created by the vendor, a variable indicating whether participants were on or off in one of the 5 study trails (1 = on trail; 0 = off trail) was created based on visual assessment of all monitoring minutes with GPS recordings. Visual checks of monitoring minutes were performed by the lead author to determine the location as on or off trail. We first plotted all the GPS monitoring minutes (ie, visually represented the last point recorded during that minute) and then manually inspected all the GPS monitoring minutes by overlaying the data on publicly available high-resolution aerial photography and other geographic information system (GIS) data sources (ie, OpenStreetMap: https://www.openstreetmap.org) using ArcGIS 10.2 (ESRI, Redlands, CA). To be categorized as on trail activity, a minimum of 2 consecutive minutes needed to occur on the trail. This criterion excluded isolated GPS minutes when a participant may have briefly crossed a trail, for example, when traveling along a road that intersected a linear trail. Each monitoring minute was carefully examined concurrently with the preceding and following minutes to assess whether any location or time discontinuity of on trail activity occurred. These procedures involved examination of the average speed for each minute, distance covered during a given minute, accelerometer counts, and the spatial context surrounding GPS points as interpreted from aerial photography. The time spent visually inspecting the data ranged from 5 to 30 minutes for each participant-monitoring day.

The following 4 scenarios were most commonly observed where there was disagreement between the vendor's classification and ours. First, some monitoring minutes that occurred in parking lots adjacent to trails were initially classified by the vendor as on trail. Based on our visual inspection, these minutes were reclassified as off-trail. Second, we reclassified some minutes as on trail that the vendor initially classified as off-trail because of an average speed of 0 miles per hour (mph) for the minute despite geographic proximity to a trail. These points likely represented when users stopped for some reason while using the trails. In the third case, some monitoring minutes were misclassified by the vendor as on trail as the GPS points occurred in close proximity, but not directly on a trail. For example, if the participant was using a sidewalk or road that closely paralleled a trail segment. After our visual checks, these minutes were reclassified as off-trail. Fourth, some minutes classified by the vendor as on trail had sustained high average speeds (>25 mph), low accelerometer counts, and covered long distances. We reevaluated these minutes and determined that they could not feasibly be considered on trail activity. They appeared to occur while the participant was driving a car on roads either parallel to the trails or on roads that crossed a trail.

Classification of Intensity of Activity On Trail Using GPS and Accelerometer

We utilized 2 approaches to classify intensity of activity on trails: (1) using accelerometer counts only (applying Matthew's cut points) and (2) using a combination of accelerometer counts and GPS speed. For the second approach, intensity of activity was classified based on average speed from the GPS device for a given minute, the metabolic equivalent (MET) value for bicycling at that speed,[31] and activity counts from accelerometer data. If the GPS speed was <2.5 mph, we exclusively utilized accelerometer counts to define PA intensity (ie, individuals could not be bicycling at <2.5 mph, assuming that someone would be walking[31]). If GPS speed for a given minute was ≥2.5 mph, intensity was classified based on average speed from the GPS device, the MET value for bicycling at that speed,[31] and activity counts from accelerometer data. If the average speed for the minute was ≥2.5 and <9.52 mph (ie, MET = 3.0–5.9) and the activity count was <5725, then the activity for a given minute was classified as moderate. If the average speed was ≥9.52 mph (ie, MET = 6.0 for bicycling[31]), then activity was classified as vigorous. LPA and SB were classified based on activity counts using the Matthew's cut points described previously.[32,33]

Trail Use Days

A binary variable was created to indicate whether or not a participant used any of the 5 study trails on a given day (1 = yes; 0 = no). To be defined as a trail use day, at least 2 consecutive minutes had to occur on trail. This operational definition is comparable to one used in a recent study of parks in which researchers defined a park visit day as one where the user was in the park for ≥3 consecutive minutes.[23] As several trails in our study are commonly used for bicycling and a relatively long distance can be covered quickly, we decided to use a 2-minute threshold for defining trail use.

PA and SB Outcomes

Using cut points developed by Matthew,[32] each monitoring minute was classified as SB (ie, 0–99 counts), LPA (100–759 counts), MPA (760–5724 counts), or VPA (≥5725 counts).[32,33] LPA, MPA, VPA, and SB were expressed as mean minutes per day. In addition, a TPA outcome was created based on daily mean activity counts per minute.

Covariates

Age, gender, race (white or nonwhite), and education (≤ undergraduate degree, ≥ some graduate school) were controlled as covariates in multivariable models. In addition, several other variables were included as covariates as they could potentially confound relationships between trail use and PA and SB. These covariates included length of time using a study trail (<3 y or ≥3 y), weekday versus weekend trail use,[34] origin when using trails (home vs other), usual reason for using trails (exercise/recreation, transportation, or both), and trail sites (Cutler Park Reservation, Franklin Park, Minuteman Bikeway, Nashua River Rail Trail, Southwest Corridor).

Statistical Analysis

Descriptive statistics were used to summarize all study variables. Linear mixed models (PROC MIXED in SAS, Cary, NC) were used to estimate relationships between trail use and TPA and mean daily minutes of LPA, MPA, VPA, and SB. Two datasets were used to analyze these relationships: one with accelerometer data linked to GPS coordinates (N = 60,335) and the other with all accelerometer data (N = 472,175). For both datasets in the analyses, we only used accelerometer counts to define intensity of activity. Specifically, for accelerometer/GPS data, we only utilized the data where location information (ie, GPS data) was available. For both datasets, daily minutes of activity were aggregated to the person-day level, and the unit of analysis was the person-day. The data structure was hierarchical with person-day observations (level 1) nested within the individual (level 2). For all outcomes, an intraclass correlation coefficient with an intercepts-only model was used to assess the extent to which the total proportion of variance in each outcome was from the variability between participants, compared with the variability within participants. Using accelerometer data linked to GPS coordinates, the intraclass correlation coefficient ranged from 0.23 to 0.47 indicating that 23%–47% of the total variance in each outcome was due to the variability between participants. In turn, using the accelerometer data only, the intraclass correlation coefficient ranged from 0.31 to 0.46. Models were fully adjusted for age, gender, race, education, trail site, and time of week. The model for SB adjusted for LPA, MPA, and VPA outcomes, while minutes of PA was adjusted for in models for SB. Based on the Akaike's information criterion for model selection (ie, model is better when the Akaike's information criterion value is smaller), covariates such as length of time using trail, origin when using the trail, and usual reason for using trail were not included in the fully adjusted models. All analyses were performed with SAS version 9.3 (Cary, NC).

Results

Participants' Characteristics

The average age of participants was 44.0 (13.0) years (Table 1). Slightly over half (52.8%) were women; the majority (72.5%) were white, 20.4% were African American or black, and 7.1% were Asian, Native Hawaiian, or other Pacific Islander. Over 90% had at least some college education.

Approximately 48% of the participants (n = 68) had 4 valid monitoring days with accelerometer data linked to GPS coordinates; 21% (n = 30) had 3 days; 18% (n = 25) had 2 days; and 13% (n = 19) had 1 day. There were 232 participant-monitoring days with trail use and 199 days without trail use. Mean valid wear time (based on the smaller accelerometer/GPS dataset) was 155.0 (87.2) minutes per day on days with trail use and 141.1 (91.4) minutes per day on days without trail use ($P = .11$). Daily mean counts per minutes per day were higher on days with trail use [541.7 (237.7)], compared with days without trail use [465.1 (266.7), $P < .01$]. MPA was higher on days with trail use [65.3 (44.0) min/d], compared with days without trail use [35.0 (35.8) min/d, $P < .01$]. SB minutes per day was lower on days with trail use [34.9 (37.7)], compared with nonuse days [47.2 (37.7), $P = .01$]. No statistically significant

Table 1 Participants' Demographics, Patterns of Trail Use, and PA, Overall and by Site (N = 142)

	Overall (N = 142)	Cutler Park Reservation (n = 20)	Franklin Park (n = 35)	Minuteman Bikeway (n = 33)	Nashua River Rail Trail (n = 20)	Southwest Corridor (n = 34)
Age, mean (SD), y	44.0 (13.0)	42.0 (9.2)	46.5 (12.9)	42.2 (12.6)	49.1 (16.2)	41.4 (12.9)
Gender, n (%)						
Female	75 (52.8)	10 (50.0)	12 (34.3)	16 (48.5)	12 (60.0)	17 (50.0)
Male	67 (47.2)	10 (50.0)	23 (65.7)	17 (51.5)	8 (40.0)	17 (50.0)
Race, n (%)						
White	103 (72.5)	17 (85.0)	3 (8.6)	31 (93.9)	20 (100)	32 (94.1)
African American or black	29 (20.4)	0 (0)	28 (80.0)	0 (0)	0 (0)	1 (2.9)
Other[a]	10 (7.0)	3 (15.0)	4 (11.4)	2 (6.1)	0 (0)	1 (2.9)
Education, n (%)						
Some college or undergraduate degree	80 (56.3)	9 (45.0)	25 (78.1)	11 (33.3)	12 (60.0)	20 (58.8)
Some graduate or graduate degree	62 (43.7)	11 (55.0)	7 (20.0)	22 (66.7)	8 (40.0)	14 (41.2)
Length of time using trail, n (%)						
<12 mo	13 (9.2)	2 (10.0)	2 (5.7)	2 (6.1)	3 (15.0)	4 (11.8)
1–3 y	40 (28.2)	10 (50.0)	5 (14.3)	6 (18.2)	8 (40.0)	11 (32.4)
>3 y	89 (62.7)	8 (40.0)	28 (80.0)	25 (75.8)	9 (45.0)	19 (55.9)
Reason for using trail, n (%)						
Recreation	99 (69.7)	20 (100)	33 (94.3)	18 (54.5)	20 (100)	8 (23.5)
Transportation	21 (14.8)	0 (0)	0 (0)	3 (9.1)	0 (0)	18 (52.9)
Both recreation and transportation	22 (15.5)	0 (0)	2 (11.4)	12 (36.4)	0 (0)	8 (23.5)
Trail use, mean number of days (SD)						
Weekdays	0.9 (0.8)	0.4 (0.6)	0.9 (0.8)	1.0 (0.8)	0.7 (0.7)	1.1 (1.0)
Weekend days	0.8 (0.7)	0.6 (0.8)	0.8 (0.7)	0.9 (0.8)	0.8 (0.6)	0.7 (0.8)
PA outcomes						
TPA, mean counts per minutes per day	506.4 (254.1)	504.9 (257.5)	513.8 (252.1)	524.8 (295.7)	454.1 (229.5)	515.6 (215.6)
VPA, mean minutes per day	4.89 (14.3)	3.1 (8.0)	6.1 (14.4)	8.1 (21.3)	2.7 (8.8)	2.5 (8.8)
MPA, mean minutes per day	51.3 (43.1)	44.2 (36.9)	50.8 (40.0)	51.3 (42.8)	45.0 (42.4)	60.7 (49.1)
LPA, mean minutes per day	43.2 (48.8)	32.1 (23.4)	41.3 (34.9)	42.5 (42.6)	77.5 (75.5)	28.7 (30.9)
SB, mean minutes per day	40.6 (38.2)	55.0 (47.0)	42.6 (32.1)	38.1 (36.1)	55.5 (36.8)	21.7 (32.5)

Abbreviations: LPA, light-intensity PA; MPA, moderate-intensity PA; PA, physical activity; TPA, total PA; SB, sedentary behavior; VPA, vigorous-intensity PA.
[a]Other = American Indian, Asian, Native Hawaiian, or other Pacific Islander.
[b]Based on daily mean activity counts per minute.

differences were found for VPA minutes per day on trail use [5.4 (13.8)] and nontrail use days [4.3 (15.0), $P = .40$], and LPA minutes per day on trail use [45.6 (48.8)] and nonuse days [40.6 (40.5), $P = .25$]. Trail use patterns are shown in Table 1.

Classification of Trail Activity Using Accelerometer Only Versus Accelerometer and GPS

The distribution of LPA, MPA, VPA, and SB minutes on the 5 trails differed substantially depending on whether it was based on accelerometer counts only or on the combination of accelerometer and GPS data (Table 2). Minutes of VPA across all trails were 346% higher using a combination of accelerometer and GPS information, whereas minutes of MPA, LPA, and SB were 15%, 91%, and 85% lower, respectively. The higher amount of VPA minutes using the 2 data sources ranged from 2% at Cutler Park Reservation to 1015% at the Nashua River Rail Trail. The largest percentage differences in VPA were found at the 3 linear paved trails (ie, Minuteman Bikeway, Nashua River Rail Trail, and Southwest Corridor), likely due to frequent bicycling on these trails. MPA minutes were 2% higher at Franklin Park and 6% higher at Cutler Park Reservation, whereas they were 24%–43% lower on the other 3 trails. Minutes of LPA were 62%–95% lower on the 5 trails using accelerometer and GPS data to determine intensity, and minutes of SB were 48%–92% lower.

Associations Between Trail Use and PA and SB

Based on accelerometer data linked to GPS coordinates (N = 60,335), there were statistically significant positive associations between trail use and PA and an inverse association with SB (Table 3). Trail use was positively associated with TPA, though attenuated from $\beta = 582.3$ counts per minute in an age-adjusted model to $\beta = 520.6$ counts per minute in the fully adjusted model. Trail use was also positively associated with MPA and LPA (27.9 mean min/d and 10.7 mean min/d more, respectively) compared with no trail use in fully adjusted models. Trail use was only significantly associated with VPA in the age-adjusted model ($\beta = 2.5$ mean min/d). Trail use was inversely associated with SB in both age and fully adjusted models.

Table 2 Distribution of PA and Sedentary Minutes on Trails Based on A[a] and A/G[b] (N = 10,531[c])

	Overall minutes on trail			Cutler Park Reservation			Franklin Park			Minuteman Bikeway			Nashua River Rail Trail			Southwest Corridor		
	A	A/G	&Dgr;%[d]	A	A/G	&Dgr;%	A	A/G	&Dgr;%	A	A/G	&Dgr;%	A	A/G	&Dgr;%	A	A/G	&Dgr;%
VPA[e]	999	4456	346	94	96	2.1	546	595	9	195	2061	956.9	109	1215	1014.7	55	489	789.1
MPA[f]	6839	5800	−15.2	670	709	5.8	2976	3029	1.8	1618	921	−43.1	742	511	−31.1	833	630	−24.4
LPA	2189	199	−90.9	29	11	−62.1	118	36	−69.5	1109	59	−94.7	679	58	−91.5	254	35	−86.2
SB	506	78	−84.6	27	4	−85.2	42	22	−47.6	130	11	−91.5	284	30	−89.4	23	11	−52.2

Abbreviations: A, accelerometer data only; A/G, accelerometer and GPS data; LPA, light-intensity PA; MPA, moderate-intensity PA; mph, miles per hour; PA, physical activity; SB, sedentary behavior; VPA, vigorous-intensity PA.

[a]Used to define intensity of activity, using the cut points: sedentary = 0–99, light = 100–759, moderate = 760–5724, and vigorous ≥5725).

[b]Used to define intensity of activity.

[c]Based on monitoring minutes occurring on trail across all participants during the study period (1–4 d).

[d]&Dgr;% = {[(A/G) − A]/A} × 100.

[e]If average speed ≥9.52 mph, then intensity is vigorous.

[f]If average speed = 2.5–9.51 mph and counts ≤5725, then intensity is moderate. If the GPS speed was <2.5 mph, then exclusively used activity counts to define the intensity based on the cut points.

Table 3 Associations Between Trail Use and Objective Measures of PA and Sedentary Time (N = 431 Person-Days)

	Accelerometer/GPS data[a]				Accelerometer data[b]			
	Age-adjusted model		Fully-adjusted model[c]		Age-adjusted model		Fully-adjusted model[c]	
	β	95% CI	β	95% CI	β	95% CI	β	95% CI
TPA	582.32*	338.14 to 826.50	520.64*	271.84 to 769.43	88.69*	43.91 to 133.48	95.0*	49.87 to 140.14
VPA	2.54	0.02 to 5.07	2.44	−0.12 to 5.00	1.51	−1.38 to 4.41	1.58	−1.36 to 4.52
MPA	28.44*	20.57 to 36.32	27.92*	19.72 to 36.11	24.97*	13.62 to 36.32	21.11*	10.49 to 31.72
LPA	5.28	−2.27 to 12.83	10.69*	3.99 to 17.38	4.97*	−9.09 to 19.03	3.49*	−9.93 to 16.90
SB	−10.18	−17.67 to −2.68	−12.25	−19.99 to −4.51	−20.57	−45.99 to 4.85	−5.25	−28.39 to 17.90

Abbreviations: CI, confidence interval; GPS, global positioning system; LPA, light-intensity PA; MPA, moderate-intensity PA; PA, physical activity; SB, sedentary behavior; TPA, total PA; VPA, vigorous-intensity PA.

[a]N = 60,335: accelerometer counts are linked with GPS recordings. In the analyses, GPS speed was not used to classify intensity of activity.

[b]N = 472,175; including GPS recordings, imputed GPS recordings, and missing GPS recordings.

[c]Adjusted for age, gender, race, education, trail site, weekday versus weekends, and sedentary time (for PA outcomes, except TPA), and LPA, MPA, and VPA minutes (for sedentary outcome).

*$P < .05$.

When using the accelerometer dataset only (ie, without corresponding GPS readings; N = 472,175), there were statistically significant positive associations between trail use and TPA (β = 95.0 mean counts per minute) and MPA (β = 21.1 min/d in fully adjusted models). However, trail use was not associated with VPA, LPA, or SB.

Discussion

Simultaneous assessment of PA with accelerometers and GPS units with 142 trail users in Massachusetts indicated that trail use was positively associated with daily minutes of LPA, MPA, and TPA, and inversely associated with SB in fully adjusted models. However, trail use was not associated with VPA. Using a larger database of accelerometer data with and without GPS location data, statistically significant positive associations between trail use and TPA and MPA were also found. However, the magnitude of these effects was lower compared with the results from the smaller GPS/accelerometer data. No associations were found between trail use and VPA, LPA, and SB using the accelerometer database without locational information.

The amount of VPA on trails was substantially higher when it was classified with a combination of accelerometer counts and GPS speed, compared with classification with counts only. Overall, on trail VPA was 4- to 5-fold higher when both accelerometer and GPS speed data were used. In contrast, minutes of on trail LPA, MPA, and SB were substantially lower when both accelerometer and GPS data were used to classify intensity of activity. Notably, minutes of VPA on trails was markedly higher on 3 linear trails (using this combined approach) where bicycling is a more common activity.

The statistically significant positive associations between trail use and TPA, MPA, and LPA were comparable to the results from a recent study by Evenson et al[23] on parks and PA in 5 US states. However, in contrast to this prior study,[23] trail use was inversely associated with SB in the present study. Using accelerometer and GPS data collected from 218 adult men and women, significantly higher levels of TPA, MPA, and LPA were observed on days with a park visit compared with days without a visit.[23] However, there were no significant differences in VPA on days when parks were used and days when they were not used. Similarly, in our study, trail use was associated with more TPA, MPA, and LPA. These associations were expected because these trails are settings that support MPA and LPA, particularly walking, which is the most common on trail activity identified by participants. The findings that trail use was not associated with VPA may in part be due to the overall low levels of VPA among participants. The low level of VPA is consistent with national surveillance data from accelerometers, which showed that adults accumulate about 4 minutes per day of VPA or less.[30] In the present study, trail use was negatively associated with SB, which is inconsistent with the findings from Evenson et al.[23] However, this is expected because trails may encourage more MPA and LPA, which could reduce overall SB when participants utilized trails.

Our findings from the analysis of an accelerometer dataset both with and without GPS-based locations are generally consistent with the findings for TPA and MPA based on the accelerometer data linked to locations. Evenson et al[23] found almost the same amount of LPA on days with and without a park visit. On days with a park visit, Evenson's participants accumulated more SB compared with days without a visit. In the present study, trail use was not associated with SB when we used the larger accelerometer dataset that did not have all minutes linked to locations. Parks are often designed with a wide range of amenities that not only support different types of PA, but also support SB such as sitting and reading on a bench or having a picnic. Alternatively, trails by their very design are intended to support moving about and participating in PAs such as walking, jogging, and bicycling.[15]

A growing number of studies have applied both accelerometer and GPS data to examine relationships between the built environment and PA, whereas others focused on classifying modes of activity using either accelerometer or GPS data.[35–37] For example, a recent study examined modes of transportation such as walking, bicycling, driving a car, and taking a bus or train, based on GPS speed only.[35] Another study utilized both GPS speed and accelerometer counts to identify mode of activity.[36] A third study examined whether routes of activity for transportation-related PA (ie, commutes to/from workplace) can be determined by intensity and speed of activity using GPS, accelerometer, and survey data.[37] These studies have demonstrated that GPS data can be utilized to identify types of activities such as walking, running, bicycling, or driving a car. In contrast, we attempted to classify intensity of activity occurring on trail by using 2 approaches: accelerometer counts only and the combination of accelerometer counts and GPS speed.

In our study, on trail VPA minutes were substantially higher on 3 linear trails, the Minuteman Bikeway, Nashua River Rail Trail, and Southwest Corridor, when using accelerometer and GPS data to classify intensity, whereas MPA, LPA, and SB minutes were much lower. In contrast, on trail VPA minutes were only slightly higher at Cutler Park Reservation and Franklin Park when a combination of accelerometer and GPS data were used to classify intensity. A plausible explanation for these differences is that Cutler Park Reservation and Franklin Park are circular trails generally used for walking, jogging, and running. Conversely, the Minuteman Bikeway, Nashua River Rail Trail, and Southwest Corridor are relatively long, paved rail trails, and linear parks that experience a high volume of bicycling, in addition to walking and jogging/running.

Intercept survey data indicated that more than half of the participants recruited on the Minuteman Bikeway (18 of 33 participants) and the Nashua River Rail Trail (17 of 20) reported that their usual activity on the trails was bicycling. In contrast, few participants recruited from Cutler Park Reservation and Franklin Park reported that bicycling was their typical activity. The results of our study suggest that the use of combined GPS and accelerometer data to classify intensity of PA may be better suited to specific outdoor settings such as trails, where researchers can be more certain that faster speeds are indicative of bicycling or in-line skating, versus driving a car.

On average, participants in our study engaged in 45.4 minutes per day (SD = ±36.0 min), specifically on a trail (n = 232 trail use days). Furthermore, they engaged on average in 33.8 minutes (SD = ±32.9 min) of MVPA while they visited a trail. Findings from our study support the previous study that showed adults using trails at least once a week are twice as likely to meet PA guidelines than nontrail users.[16] As shown in this study, if individuals could be encouraged to use trails more, they might engage in more PA when they use trails, which could, in turn, lead to meeting the current PA recommendations. From a public health policy perspective, our study indicated that one additional trail use day by an adult trail user contributes approximately 34 minutes to overall minutes to achieve the PA recommendations of 150 minutes of MVPA per week.

This study makes several contributions to the evidence base on trails and PA. The use of accelerometer data linked to GPS coordinates allowed us to objectively determine trail use days; a distinct advantage over previous studies that have relied almost exclusively on self-reports to identify trail use. Furthermore, as the majority of previous trail studies using survey data focused on MVPA, this study added to limited literature on associations between trail use and objectively measured LPA and SB. This has public health relevance given the growing evidence that LPA may have health benefits and that SB has health risks independent of PA. A final strength is that we explored a new approach for classifying intensity of activity on trails using a combination of GPS and accelerometer data. Using GPS speed data in addition to accelerometer counts may help to improve the classification of PA intensity in certain outdoor contexts, particularly those where bicycling is a common activity.

This study has several limitations. Participants were generally well educated, outdoor oriented, frequently used trails, and their levels of PA were greater than those of the representative US population. Therefore, the findings from this study are not necessarily generalizable to adult trail users using other trails in Massachusetts or elsewhere in the United States. As only 5 study trails were used to define trail use, associations between trail use and PA and SB may be biased. In addition, our participants were limited to regular trail users. This restricts the generalizability of our findings. Despite this limitation, the findings from this study underscore the importance of community trails for promoting higher levels of PA. Several variables including intrapersonal (eg, attitudes, enablers, and barriers toward PA[14]), interpersonal (eg, social support[38]), and environmental factors (eg, weather conditions[17]) in ecological frameworks were not included in this study. Some of these variables may confound or moderate the associations between trail use and PA and SB. For example, attitude toward being physically active is known to be positively associated with PA.[39] Social support from families and friends is also related to higher PA levels.[40] Furthermore, weather conditions such as temperature and daylight hours are positively associated with PA.[34] Thus, the findings from our study could potentially be confounded by individual, interpersonal, and environmental variables. Last, our determination of monitoring minutes on trials with visual inspection may be biased as the lead author only checked to see whether monitoring minutes occurred on trails. Alternatively, researchers can use machine learning algorithms that may accurately determine activities such as bicycling and vehicle travel.[41]

Simultaneous use of accelerometer and GPS data allowed us to examine associations between an objective measure of trail use and objective measures of LPA, MPA, VPA, TPA, and SB. Trail use was positively associated with LPA, MPA, and TPA. These findings are consistent with prior research on the benefits of trails in terms of supporting regular PA and further support the Community Preventive Services Task Force recommended strategy of creating and enhancing accessibility to places for PA.[11] In addition, this study provides preliminary evidence that trails may contribute to higher levels of LPA, which, in turn, might contribute to reducing risk of adverse health outcomes such as cardiometabolic disease.[4] Finally, this study's findings indicate that combined accelerometer and GPS monitoring may provide an improved method to measure PA on trails, particularly where bicycling is a common activity.

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