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Deriving a GPS Monitoring Time Recommendation for Physical Activity Studies of Adults

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ABSTRACT

HOLLIDAY, K. M., A. G. HOWARD, M. EMCH, D. A. RODRÍGUEZ, W. D. ROSAMOND, and K. R. EVENSON. Deriving a GPS Monitoring Time Recommendation for Physical Activity Studies of Adults. *Med. Sci. Sports Exerc.*, Vol. 49, No. 5, pp. 939–947, 2017. **Introduction**: Determining locations of physical activity (PA) is important for surveillance and intervention development, yet recommendations for using location recording tools like global positioning system (GPS) units are lacking. Specifically, no recommendation exists for the number of days study participants should wear a GPS to reliably estimate PA time spent in locations. **Methods**: This study used data from participants (N = 224, age = 18–85 yr) in five states who concurrently wore an ActiGraph GT1M accelerometer and a Qstarz BT-Q1000X GPS for three consecutive weeks to construct monitoring day recommendations through variance partitioning methods. PA bouts ≥10 min were constructed from accelerometer counts, and the location of GPS points was determined using a hand-coding protocol. **Results**: Monitoring day recommendations varied by the type of location (e.g., participant homes vs parks) and the intensity of PA bouts considered (low and medium cut point moderate to vigorous PA [MVPA] bouts or high cut point vigorous PA [VPA] bouts). In general, minutes of all PA intensities spent in a given location could be measured with ≥80% reliability using 1–3 d of GPS monitoring for fitness facilities, schools, and footpaths. MVPA bout minutes in parks and roads required longer monitoring periods of 5–12 d. PA in homes and commercial areas required >19 d of monitoring. **Conclusions**: Twelve days of monitoring was found to reliably estimate minutes in both low and medium threshold MVPA as well as VPA bouts for many important built environment locations that can be targeted to increase PA at the population level. Minutes of PA in the home environment and commercial locations may be best assessed through other means given the lengthy estimated monitoring time required. **Key Words:** ACCELEROMETRY, GLOBAL POSITIONING SYSTEM, GIS, ENVIRONMENT, WEAR TIME

Lack of physical activity (PA) is an important contemporary public health concern. It both contributes to the global obesity epidemic and has weight-independent adverse health effects. Although the risks associated with lack of PA are well known, the majority of Americans fail to meet national PA guidelines (27). This pattern is also present in many areas worldwide. Public health researchers have therefore endeavored to identify built environment factors associated with active and inactive lifestyles. One important component of this built environment–PA research may include understanding the types of locations typically used for PA by some populations and potentially underused by others. Improving understanding of these location use patterns through surveillance may ultimately facilitate identification of locations for targeted PA interventions. Further, understanding locational context is important for accurately measuring other contextual exposures in the built environment that may influence PA.

Although the use of global positioning system (GPS) units in PA research has become a more common means of identifying PA locations, it is still a recent technological advancement. As such, few best practice recommendations have been created for researchers (12). Specifically, there is no current recommendation for the number of monitoring days needed to reliably estimate a participant's bout-based PA minutes spent in various locations. This is evidenced by a review of GPS-incorporated PA studies that found monitoring time varied drastically, from 40 min to 12 d (mean 4 d), and that inclusion of weekdays versus weekend days was inconsistent (13). In measuring PA, monitoring time recommendations for the number of days participants need to wear an accelerometer to reliably estimate their minutes of PA do exist (30).

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Researchers typically rely on those recommendations when designing protocols for PA studies that combine accelerometer and GPS units because of the lack of an independent standard for GPS (12,13). However, some have suggested that monitoring time may need to be longer to study locations of PA (12) and have called for the development of an independent recommendation (12,13,16).

Therefore, the aim of this project was to provide evidence toward establishing a recommendation for GPS monitoring length in PA studies of adults using data from participants who concurrently wore a GPS and an accelerometer for up to 3 wk. This will provide important study planning information for minimizing monetary cost as well as participant burden in surveillance studies of adult participants.

METHODS

Study population. This study used data collected as part of the System for Observing Play and Recreation in Communities (SOPARC) GPS substudy (8). The initial data collection involved recruitment of participants from five communities: Los Angeles, California; Albuquerque, New Mexico; Chapel Hill and Durham, North Carolina; Columbus, Ohio; and Philadelphia, Pennsylvania. Participants (N = 248) were recruited from six key parks in each of the communities (80%) (seven in the case of Los Angeles) as well as from residences located within one mile of these parks. Participants were ineligible for enrollment if they were <18 yr old, non-English speaking, or nonambulatory. Enrollment occurred in the spring, summer, and fall from May 2009 to April 2011, with most participants enrolled in 2009 and 2010 and only four enrolled in 2011.

Participants completed a survey to provide sociodemographic data, including age, sex, race/ethnicity, and highest level of education achieved. Study staff used a Tanita Bc551 scale and a Seca Portable Stadiometer to measure weight and height, respectively, of participants at enrollment, allowing classification of body mass index (BMI, $kg \cdot m^{-2}$) into categories of normal weight (<25 $kg \cdot m^{-2}$), overweight (≥25 to <30 $kg \cdot m^{-2}$), or obese (≥30 $kg \cdot m^{-2}$). Further participant recruitment and study details are available elsewhere (3,5,8).

PA and location assessment. Participants were asked to concurrently wear an accelerometer and a GPS on the same belt for three consecutive weeks, with participants exchanging units each week with local study staff. Participants wore an ActiGraph (model GT1M; ActiGraph LLC, Pensacola, FL) accelerometer on the right hip, an accelerometer with demonstrated high validity (29). The ActiGraph GT1M was used to measure acceleration in the vertical plane (11) and recorded in 1-min epochs. Accelerometer non–wear time was identified as 90 min of consecutive zero counts, allowing for up to two consecutive minutes of nonzero counts if the 30 min before and after those nonzero counts contained no positive counts, and counts for these minutes were set to missing (2). We chose to focus solely on PA in bouts to conform with the 2008 Physical Activity Guidelines for Americans (28) and the World Health Organization guidelines (31), which specify that PA should be of at least 10 min in duration to count toward meeting the weekly goal. Although appropriateness of the 10-min threshold is under studied in the literature, the use of PA bouts additionally facilitated the intensive visual coding protocol described below and may be more practical for intervention development as opposed to studying PA obtained in smaller durations. PA bouts were defined as ten or more minutes of accelerometer counts occurring above a given cut point, allowing for 20% of the minutes to fall below the cut point as long as the first and last minute of a bout were above the cut point, and there were no more than four consecutive minutes below the cut point. Because the choice of accelerometer count cut point can substantially influence results (6,15,17), two common sets of cut points were used to examine the sensitivity of the results to this choice. The chosen sets had comparable validity (4) and included Troiano cut points (moderate to vigorous PA [MVPA]: ≥2020 counts per minute, vigorous PA [VPA]: ≥5999 counts per minute) (24) and the Matthews cut point (MVPA: ≥760 counts per minute) (17), notably lower than Troiano MVPA and VPA cut points. Per published recommendations (30), 4 d of at least 10 h of wear time was used to define compliant accelerometer wear. This ensured inclusion of participants who had reliably estimated minutes of PA, which was important for accurately estimating the within- and between-person variation described in the statistical analyses. Monitoring for less than the recommendations could miss regular PA and therefore regular locations of PA. In addition, the sensitivity of results to inclusion of participants with varying numbers of compliant accelerometer wear days (4 or 7) as well as various definitions of a compliant wear day (7–12 h) was examined.

The geographic location of participants was tracked using a Qstarz BT-Q1000X portable GPS unit (weight = 65 g; dimensions = 72 × 46 × 20 mm) with wide area augmentation system enabled to improve accuracy (5,8). The GPS collected data in 1-min epochs and points with less than a 1-min epoch were removed. This GPS unit has been shown to have excellent static and dynamic validity in a variety of settings (20). Using a GPS with high performance in terms of validity was key to accurately converting the latitude and longitude points to PA location types using a coding protocol that is available from the authors. This protocol was developed to classify PA locations at a high resolution and to do so consistently across a multi-site study, both of which are not currently possible using available GIS data. Briefly, Google Fusion Tables (Google Inc., Mountain View, CA), which incorporates Google Maps (Google Inc.) features such as satellite and street view, was used to plot PA bouts. A standardized protocol was used to categorize more than 190,000 GPS points into PA location types based on visual interpretation of each point within a bout on Google imagery. Categories were commercial (including large and small stand-alone retail locations, strip malls, dense commercial districts, restaurants, and gas stations) fitness locations, including pay gyms and miscellaneous fitness areas (e.g., private tennis/soccer facilities, swim clubs), footpaths, participant homes, parks, residential locations (excluding the participant's home), roads, and schools (from pre-K through university). The protocol calls for consideration of the overall pattern of points within a PA bout when making coding decisions but allows for points within the same PA bout to be coded differently. For example, if a participant walked along a road to spend time in a park, he or she could have minutes coded as road and park for the same bout. In addition, the historical street view option was used to more accurately match the period during which the PA bout occurred. The protocol includes directions for using the GPS speed and GPS points to identify and reclassify motorized travel as inactive minutes if necessary. Participant home addresses were geocoded, and unmatched addresses were imputed with GPS data. Because GPS accuracy is often limited indoors, particularly in large buildings, missing GPS points were imputed if possible after the procedure outlined in the coding protocol. This procedure involved examining the recorded point(s) before and after the missing point(s) to impute the location of the missing point(s), as has been done in other studies of PA involving GPS (16). Study protocols for both the initial data collection and the subsequent data analyses were approved by appropriate study site affiliated institutional review boards, and participants provided written informed consent.

Statistical analyses. The concept of reliability has been used previously to determine the recommended number of monitoring days in PA accelerometry (9,10,14,18,19,23,26). Researchers typically use the intraclass correlation coefficient (ICC) and the generalized Spearman–Brown prophecy formula to estimate the number of days needed to reach a specified degree of reliability (25). This method is based on the assumption of parallel tests, which allows calculation of the increase in test length needed (days of monitoring in our case) given the reliability of a part test (single day in our case) to reach a desired level of reliability (22). As such, the number of needed monitoring days can be found by first calculating the ICC for each location category as ICC = $\sigma_b^2/(\sigma_b^2 + \sigma_w^2)$, where σ_b^2 represents the between (inter)individual variance and σ_w^2 represents the within (intra)individual variance, or day-to-day variance (25). This value represents the reliability of a single day of monitoring (25). Using this information, the Spearman–Brown prophecy formula estimates N, the number of needed monitoring days, as $N = [R_d/(1 - R_d)][(1 - CC)/ICC]$, where R_d is the desired level of reliability, and ICC is calculated from the model as shown earlier. This calculation therefore allows estimation of the required number of days even if the recommendation exceeds the 21 d for which participant data were available in this study as described by Traub (22). This extension differs from traditional extrapolation in that the assumption is only based on the stability of the within- and between-person variation, which we assumed is not expected to change noticeably after 21 d of monitoring. The two equations can be generalized, with the reliability for a given number of monitoring days calculated as $R_N = \sigma_b^2/(\sigma_b^2 + (\sigma_w^2/N))$. Under this framework, if the within-person variability is very high (relative to the between-person variability), the required number of monitoring days to achieve a highly reliable estimate of an individual's usual level of activity will increase; alternatively, if the between-person variability is very high (relative to the within-person variability), the number of monitoring days will be lower. Although we calculated reliability values for a range of monitoring days, we focused on a desired reliability of at least 80% to provide guidelines for monitoring days, as has been common practice (25).

In this framework, minute-by-minute repeated estimates of PA location types (commercial, fitness, footpath, home, park, residential, road, and school) for each participant were reduced to total daily minutes of PA within bouts occurring in each location, the value we were interested in estimating with a degree of reliability. Participants were considered to have 0 min in a PA location if no PA bout minutes were observed in the location type and the participant was compliant in their accelerometer wear for that day. In turn, participants were considered to have missing minutes in a PA location if they had no PA bout minutes in the location, but their accelerometer wear time did not meet the definition of a compliant day for that day (meaning they may have had minutes in the location if they had worn the accelerometer longer).

All analyses were completed within the full sample of included individuals ($N = 224$). Sensitivity analyses were also completed, including only those subsets of individuals who engaged in Troiano MVPA bouts ($n = 192$) or VPA bouts ($n = 47$). This was done to provide monitoring day guidelines for the entire study population as well as among the subset of those who actually participated in higher-intensity PA bouts.

We constructed negative binomial, random-intercept regression models using SAS PROC GLIMMIX (SAS software version 9.3) with a random intercept for participant and a fixed effect for state of residence to control for the between state variation. The negative binomial model was chosen to account for the skewed nature of the variables representing minutes of PA within bouts occurring in a given location type. These generalized linear mixed models are accepted methods of estimating the between- and within-person variances (1) used in the generalized Spearman–Brown formula and are one of the few methods that can computationally handle data of this complexity, specifically the large number of observations and the skewed nature of the data. When variance components are estimated using the Laplace method, as in this analysis, these models have been shown to provide estimates with reduced bias and better asymptotic behavior than the commonly used pseudo-likelihood methods (21). Confidence intervals for the number of monitoring days were estimated via bootstrapping by resampling, with replacement, 500 times.

RESULTS

Initially, 248 participants were enrolled. Thirteen were excluded because of missing data (2 who contributed no accelerometer data and 11 who had all missing data for PA GPS points), leaving 235 participants for analysis. Of these 235, 224 had at least four 10-h days of compliant accelerometer wear, contributing a median (interquartile range) of 17 (13–20) days of compliant wear. Only 1 of those 224 did not complete at least one bout of Matthews MVPA, 192 had at least one bout of Troiano MVPA, and 47 had at least one bout of Troiano VPA during the 3 wk of monitoring.

Sociodemographic characteristics of participants are displayed in Table 1, including description of those included in the full sample (N = 224 who had at least four 10-h days of compliant accelerometer wear) and the subsets of those who engaged in Troiano MVPA bouts and VPA bouts. Those included in the full sample ranged from 18 to 85 yr of age (mean ± SD = 41.1 ± 15.8), and 44% were male. Minority groups were represented in the full sample (24% non-Hispanic Black, 16% Hispanic, and 9% Other) as were individuals from varied educational backgrounds (21% ≤ high school education, 22% some college or vocational school, and 58% college or postgraduate degree). BMI was evenly distributed, with 34% under or normal weight, 32% overweight, and 33% obese (mean ± SD BMI = 28.3 ± 6.6 $kg \cdot m^{-2}$). Most included non-Hispanic Blacks were recruited in Ohio and Pennsylvania (64%) and most Hispanics were from New Mexico and California (75%). In addition, a large proportion of included individuals who had postgraduate education were recruited from the North Carolina site (45%), and 67% of those with a high school education or less were recruited from Pennsylvania and Ohio. In general, there were no differences in sociodemographic characteristics between the full sample and those originally enrolled in the study, nor were there differences between the full sample and the subset of those who engaged in higher-intensity Troiano MVPA bouts. However, those with Troiano VPA bouts were more educated (P = 0.01), had a lower BMI category (P = 0.05), and were more likely to be recruited from North Carolina (P = 0.02) as compared with the full sample.

In general, most states had physically active participants at all location types; however, there were some exceptions (e.g., fitness facilities and footpaths were only used for VPA bouts in three of the five states; Table 2). Therefore, results in these locations only included data from a subset of states. In addition, both participants and minutes of PA were not evenly distributed across the location types (Table 2). For Matthews MVPA, fitness facilities, schools, and footpaths required the fewest monitoring days (1–4); roads and parks an intermediate number of days (9–11); and participant home, commercial, and residential (excluding the participant's home) location types required the most monitoring days (19–55) to estimate PA bout minutes in a location type with at least 80% reliability.

For the higher-intensity Troiano MVPA bout GPS monitoring recommendation, we examined both the full sample

TABLE 1. Participant sociodemographic characteristics, SOPARC GPS substudy 2009–2011.

	Full Sample[a]		Troiano MVPA Subset[b]		Troiano VPA Subset[c]	
	N	Pct.	*N*	Pct.	*N*	Pct.
Overall number	224	—	192	—	47	—
Sex						
Male	98	43.8	88	45.8	20	42.6
Female	126	56.3	104	54.2	27	57.4
Age (yr)						
18–35	103	46.0	91	47.4	27	57.5
36–59	81	36.2	69	35.9	17	36.2
60–85	40	17.9	32	16.7	3	6.4
Race/ethnicity						
Non-Hispanic White	113	50.7	104	54.2	31	66.0
Non-Hispanic Black	53	23.8	37	19.3	7	14.9
Hispanic	36	16.1	31	16.2	4	8.5
Other	21	9.4	19	9.9	5	10.6
Missing	1	0.4	1	0.5	0	—
Education						
High school/GED or less	48	21.4	35	18.2	3	6.4
Some college or vocational	50	22.3	39	20.3	7	14.9
College	126	56.3	118	61.5	37	78.7
BMI ($kg \cdot m^{-2}$)						
Underweight or normal weight	77	34.4	74	38.5	21	44.7
Overweight	72	32.1	64	33.3	19	40.4
Obese	75	33.5	54	28.1	7	14.9
Recruitment city						
Los Angeles, CA	47	21.0	45	23.4	10	21.3
Albuquerque, NM	47	21.0	39	20.3	5	10.6
Chapel Hill and Durham, NC	49	21.9	48	25.0	21	44.7
Columbus, OH	41	18.3	28	14.6	5	10.6
Philadelphia, PA	40	17.9	32	16.7	6	12.8
Recruitment location						
Household	46	20.7	44	22.9	8	17.0
Park	176	79.3	146	76.0	39	83.0
Missing	2	0.9	2	1.0	0	—

CA, California; NM, New Mexico; NC, North Carolina; OH, Ohio; PA, Pennsylvania.
[a]Those who were included in the full sample; 223 of whom engaged in Matthews MVPA bouts (Matthews definition, ≥760 counts per minute).
[b]Subset engaged in Troiano MVPA bouts (Troiano definition, ≥2020 counts per minute).
[c]Subset who engaged in Troiano VPA bouts (Troiano definition, ≥5999 counts per minute).

EPIDEMIOLOGY

TABLE 2. GPS monitoring recommendations[a] for estimating minutes of PA in bouts for various location types with ≥80% reliability given compliant accelerometer wear of at least four 10-h days from the SOPARC GPS substudy 2009–2011.

		States (*n*)	Participants (*n*)	Minutes (*n*)	Full Sample Monitoring Days[b] (95% CI[c])	Active Subset Monitoring Days[d] (95% CI[c])
Matthews MVPA[e]	Fitness	5	40	6092	1 (1–2)	
	School	5	97	11,064	3 (2–4)	
	Footpath	5	64	2016	4 (1–4)	
	Road	5	165	21,885	9 (5–10)	
	Park	5	126	19,465	11 (4–10)	
	Home	5	205	42,735	19 (8–20)	
	Residential	5	83	5053	48 (2–5)	
	Commercial	5	147	12,375	55 (8–31)	
Troiano MVPA[f]	Fitness	5	31	3565	1 (1–2)	1 (1–2)
	School	5	53	4242	1 (1–2)	2 (1–2)
	Footpath	4	40	1352	1 (1–3)	2 (1–3)
	Road	5	127	12,820	12 (5–11)	16 (6–15)
	Park	5	82	5808	5 (2–6)	31 (2–11)
	Home	5	133	9447	16 (5–12)	25 (7–18)
	Residential	5	36	1009	2 (2–3)	2 (2–3)
	Commercial	5	65	1573	105 (2–3)	119 (2–10)
Troiano VPA[g]	Fitness	3	13	1023	1 (1–2)	2 (1–9)
	School	5	11	634	1 (1–2)	2 (1–3)
	Footpath	3	10	478	1 (1–1)	2 (1–4)
	Road	5	21	1250	1 (1–2)	9 (1–14)
	Park	5	6	227	1 (1–2)	2 (1–5)
	Home	5	19	944	1 (1–2)	10 (3–22)
	Residential	1	2	112	1 (1–2)	1 (1–3)
	Commercial	4	9	206	1 (1–4)	119 (1–432)

CI, confidence interval.
[a]Rounded up to a whole day for standard presentation of monitoring recommendations in whole days.
[b]Those who were included in the full sample; represents those who had compliant accelerometer wear (four 10-h days), of whom all but 1 had a Matthews MVPA bout.
[c]95% confidence intervals were calculated using bootstrapping (specifically resampling with replacement); therefore point estimates may lie outside of the 95% CI. See discussion for more detailed explanation.
[d]Subset engaged in Troiano MVPA bouts or VPA bouts.
[e]MVPA bouts defined by Matthews definition, ≥760 counts per minute.
[f]VPA bouts defined by Troiano definition, ≥2020 counts per minute.
[g]VPA bouts defined by Troiano definition, ≥5999 counts per minute.

of participants (N = 224) and the restricted subset of those who participated in Troiano MVPA bouts (N = 192). Results were similar for both groups, with slightly more monitoring days needed when restricting to the Troiano MVPA bout subset (Table 2). Fitness facilities, schools, footpaths, and residential (non–participant home) locations required the fewest number of days (1–2 d for both samples). Roads, parks, and homes required an intermediate number of days (5–16 d for the full sample and 16–25 d for the Troiano MVPA bout subset). Commercial areas required the most (105 for the full sample and 119 for the Troiano MVPA bout subset).

For the Troiano VPA bout GPS monitoring recommendation, we again examined the full sample of participants (N = 224) and the restricted subset of those who participated in Troiano VPA bouts (n = 47) (Table 2). All location types (fitness facilities, schools, footpaths, roads, homes, and parks) required only 1 d when considering the full sample of participants. When restricting to the subset with VPA bouts, sample sizes for the number of states, participants, and minutes of PA in each location decreased drastically. Roads and homes required monitoring for 9 and 10 d, respectively; commercial locations required 119 d; and all other location types remained low at 2 d.

The recommended number of GPS monitoring days needed to reach 80% reliability was generally similar in sensitivity analyses based on definitions of compliant accelerometer wear other than the minimum four 10-h days used for the main results (combinations of 4 or 7 d and 7–12 h of wear examined; see Table S1, Supplemental Digital Content 1, Table of recommendations by accelerometer wear day definitions for full sample, http://links.lww.com/MSS/A836, and Table S2, Supplemental Digital Content 2, Table of recommendations by accelerometer wear day definitions for active subset, http://links.lww.com/MSS/A837). Three exceptions were the residential (non–participant home) location for Matthews MVPA bouts, for which some analyses suggested fewer needed GPS monitoring days; commercial locations for Troiano MVPA bouts, for which a small number of analyses suggested fewer needed GPS monitoring days; and roads for Troiano VPA bouts, for which some analyses suggested more needed monitoring days.

In general, reliability improved more rapidly with increasing numbers of monitoring days for the higher-intensity Troiano MVPA and VPA bouts than for Matthews MVPA bouts, regardless of whether the full or subset samples were used for Troiano MVPA bout and VPA bout calculations (Figs. 1–3). Reliability for many location types had not yet crossed the desired 80% reliability threshold after 4 to 7 d of monitoring, which is the recommended range for accelerometer monitoring (30).

DISCUSSION

A GPS monitoring period longer than that recommended for accelerometers is necessary to reliably estimate the PA bout minutes spent in important PA locations where built

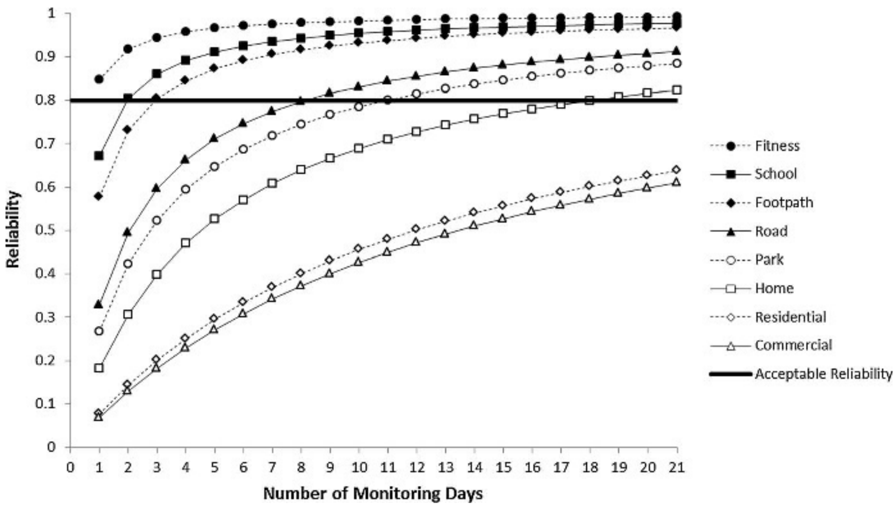

FIGURE 1—Number of GPS monitoring days needed to measure locations of Matthews MVPA for varying levels of reliability given at least four 10-h days of accelerometer wear.

environment interventions could be implemented. This study suggests that 12 d of surveillance would capture Matthews MVPA, Troiano MVPA, and Troiano VPA in roads and parks in a sample containing a mix of active and inactive individuals. Surveillance focused on PA at home, one of the most commonly used PA locations in this sample, would need nearly 20 d of GPS monitoring to reliably estimate at home MVPA time.

The number of days participants need to wear a GPS to reach 80% reliability for estimating the number of PA bout minutes in various locations depended on the specific location type, intensity, and distribution of minutes across all participants. For example, fitness locations consistently needed limited numbers of monitoring days (1,2), whereas commercial locations often required extremely long monitoring periods (55–119 d). Time in fitness locations was contributed by a small number of participants (*n* = 40 for Matthews MVPA bouts) as compared with those in commercial locations (*n* = 147 for Matthews MVPA bouts). In addition, PA bout minutes at fitness locations were less variable from day-to-day than PA bout minutes at commercial locations. A large proportion of PA bout minutes in commercial locations were completed by just a few individuals, who would be expected to drive the monitoring time estimates downward because of their large between-person variation when compared with their relatively smaller within-person variation. However, the effect of these few individuals was overshadowed by the large number of participants who had an intermediate amount of PA bout minutes in commercial locations on only a few days of their monitoring. These individuals collectively increased the within-person variation, thereby increasing the monitoring day recommendation overall.

For lower-intensity Matthews MVPA bouts, which was defined by a cut point that included activities of daily living, only minutes spent in fitness facilities, schools, and footpaths could consistently be assessed using the typical 4 or 7 d of monitoring based on accelerometer monitoring recommendations. To reliably estimate bout minutes of Matthews MVPA spent in other important built environment locations, like roads and parks, monitoring days would need to be increased to 12 d. Although the home is an important location for PA bouts, the number of needed monitoring days was quite long.

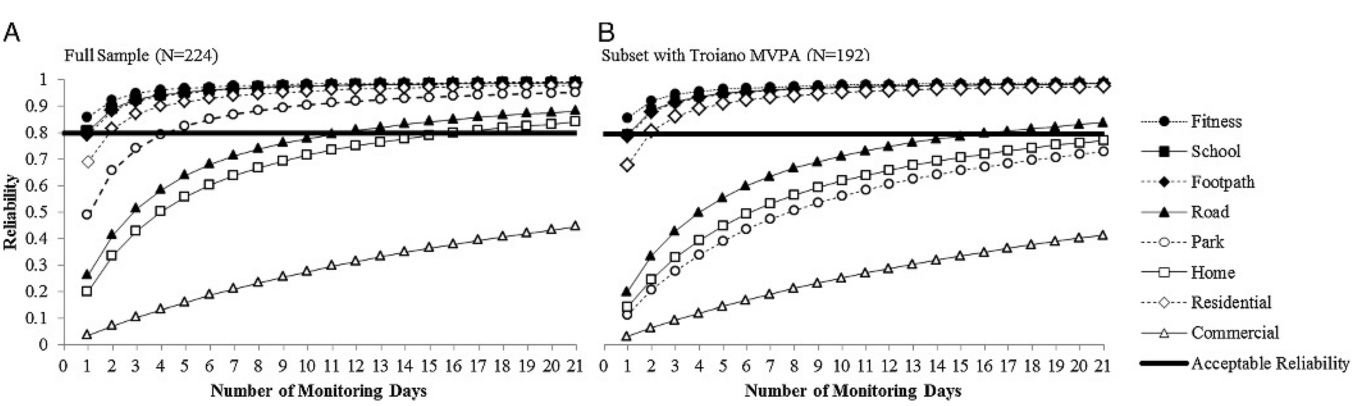

FIGURE 2—Number of GPS monitoring days needed to measure locations of Troiano MVPA for varying levels of reliability given at least four 10-h days of accelerometer wear among (A) all participants with Matthews MVPA and (B) participants with Troiano MVPA only.

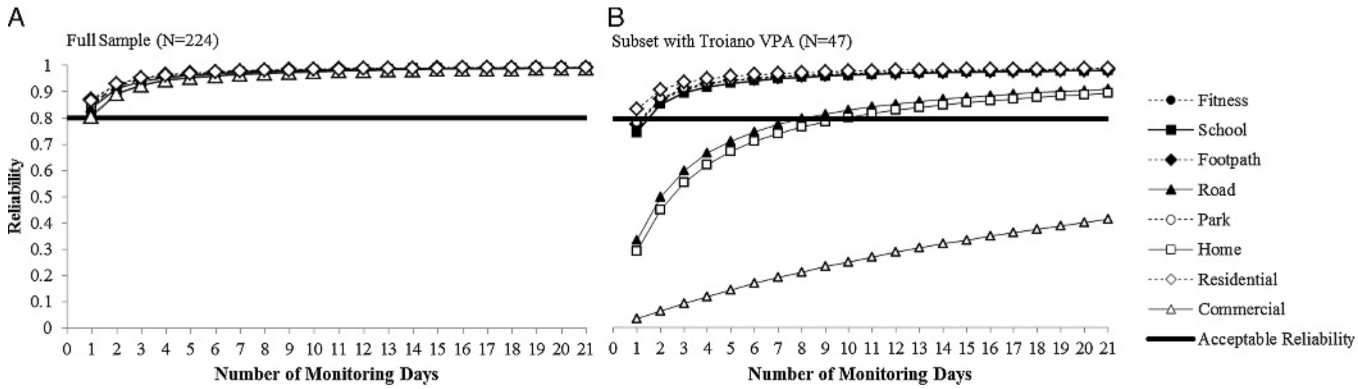

FIGURE 3—Number of GPS monitoring days needed to measure locations of Troiano VPA for varying levels of reliability given at least four 10-h days of accelerometer wear among (A) all participants with Matthews MVPA and (B) participants with Troiano VPA only.

This is likely due to the large variety of Matthews MVPA that can occur at home, including intentional and unintentional MVPA, which could result in large day to day variability in MVPA bout minutes. Similarly, minutes of Matthews MVPA in bouts at commercial and residential (non–participant home) locations is likely best captured through means other than GPS given the extremely long monitoring time requirements suggested by this sample. At the same time, the proportion of MVPA or VPA bout minutes occurring in many of the nonhome locations that required long monitoring periods was fairly small for this sample, except commercial locations in some subgroups (e.g., 23% of Matthews MVPA bout minutes for Hispanics).

In addition, sensitivity analyses demonstrated that monitoring recommendations may vary with the proportion of individuals in the sample who engaged in PA bouts of a given intensity. For example, VPA bouts were uncommon in this sample, with only 21% of participants completing a VPA bout. The main analysis included the full sample of participants and, therefore, estimates how many monitoring days are required in a population with a large proportion of participants who consistently have zero bouts of VPA. These individuals with no VPA bouts have small between-day variation, which decreases the estimates of needed monitoring days for the full sample. The sensitivity analysis restricted to only those individuals who completed at least one bout of VPA estimates how many monitoring days are required to estimate the number of VPA bout minutes in a population in which everyone participates in VPA bouts. This analysis eliminated many of the individuals with no between-day variation (those who consistently do no VPA) and subsequently increased recommendations to 10 d for road and home locations, although recommendations for the other location types remained low. Therefore, it is important to consider the proportion of individuals who complete PA bouts of a given intensity in a population and to decide whether focus is on estimating the bout minutes of PA within the population overall or only among the subset of those who engage in bouts of PA of a given intensity when deciding on length of GPS monitoring.

In some cases, the observed number of required monitoring days calculated from the original sample fell outside the 95% confidence interval as estimated through bootstrapping. Because of the nature of bootstrapping, this phenomenon is possible under certain circumstances. For example, PA bout minutes in the commercial location were in part contributed by a few individuals who had extremely high minutes of commercial activity at moderate consistency during the 3 wk (likely employees of the commercial locations). These individuals contributed considerably to increasing the ICC for commercial locations (and thus lowering the number of monitoring days) given the large influence they have on between-person variance because of the large difference between their individual mean commercial minutes and the overall mean commercial minutes. Bootstrapping allowed for resampling with replacement of these individuals with high minutes of PA, resulting in a higher proportion of individuals in the sample with this PA bout pattern. When this occurs, the monitoring time recommendations for many bootstrapped samples will be lower than the original sample that contained each individual only once.

Much PA research focuses on PA occurring within home neighborhoods. Although the methods used in this study could be extended to examine how many days of monitoring are required to reliably estimate PA minutes spent in the home neighborhood, participants in this study spent a large proportion of their PA bout minutes outside of the home neighborhood as measured by various residential buffers. Therefore, this study focused on estimating PA bout minutes occurring in specific location types regardless of whether they were within or outside of the home neighborhood. More participants in this study completed Matthews and Troiano MVPA bouts than has been reported in national surveys such as the National Health and Nutrition Examination Survey; however participants in this study had two additional weeks of monitoring during which to accrue MVPA bouts, suggesting that these participants are not more likely to engage in bouts of PA than the greater population despite the recruitment strategy used in this study.

Although active transportation researchers seek to study similar questions as those informed by this GPS wear time recommendation, these results may not directly apply to the assessment period used for travel diaries. In the present study, time spent on roads was not separated by use for active transport versus leisure time PA. Further, no attempt was made to establish whether a specific PA location (e.g., commercial and park) was reached by active transportation. Given the large difference between the monitoring day recommendations suggested by this study for reliably estimating an individual's minutes of PA in various locations and the commonly used 2-d travel diary, active transportation research may benefit from studies examining how many days of assessment are necessary to reliably estimate questions of interest in this field.

One limitation of this study is that the sampling strategy, in which many participants were recruited from parks, hinders generalizability. Individuals who spend time in parks may be more likely to be physically active or more likely to be active in parks. However, a large proportion of the sample did not participate in VPA bouts, and park use was not exceptional (79% of those with Matthews MVPA bouts were recruited from parks but only 57% of them had MVPA bout minutes in a park; 76% of those with Troiano MVPA bouts were recruited from a park but only 43% of them had MVPA bout minutes in a park; and 83% of those with VPA bouts were recruited from a park yet only 13% of them had VPA bout minutes in a park). A second limitation is that these monitoring recommendations cannot be directly applied to studies of participants less than 18 yr of age and restricting data collection to the spring, summer, and fall limited examination of seasonal patterns because of inclement winter weather. Third, the same cut points were used for all participants to define intensity of PA bouts for consistency; however, these cut points may not be valid across the age span of 18–85 yr (7), and potential differences in wear-day recommendations by sociodemographic characteristics could not be examined because of sample size limitations. Fourth, some coding and analytic decisions may affect the results. For example, the protocol allowed for imputation of missing GPS points. Imputation was completed for 34% of missing GPS points for Matthews MVPA bout minutes (6% of the total Matthew's MVPA bout minutes). Sensitivity analyses showed that had this imputation not been completed, the estimated wear day recommendation would have changed slightly only for those locations with very high recommended wear days (e.g., >20 d). Also, the coding protocol allowed for more detailed categorization of locations than could be used in this analysis because of sample size. For example, commercial areas were further coded as large and small stand-alone retail locations, strip malls, dense commercial districts, restaurants, and gas stations. Grouping of these locations may hide patterns of variability for each specific location. Five percent of Matthews MVPA bout minutes (and less for Troiano MVPA and VPA bout minutes) were coded into an "other" category and therefore could not be assessed using this method. Finally, an implicit assumption of all GPS–accelerometer studies is that the location data recorded while the participant wears the accelerometer originate from concurrently worn accelerometer and GPS units; however, in this study, there was no need for participants to separate the GPS and accelerometer from the belt as participants were to charge the GPS unit overnight and were not required to wear the accelerometer at this time.

Despite these limitations, the data used for this analysis have several strengths. First, the included participants were from diverse geographic locations and sociodemographic backgrounds. Second, they wore a GPS that has been ranked highly for accuracy across a variety of settings (20), and the data coding protocol allowed for precise location classification. In addition, participants wore the accelerometer and GPS for up to 3 wk, providing a longer sampling time than many PA studies. Combined, these strengths suggest this sample is suitable to contribute evidence toward a GPS monitoring time recommendation for PA studies.

CONCLUSIONS

In conclusion, the often-used 4 or 7 d of monitoring for GPS (12,13) may not be accurate for estimating bout minutes of PA while conducting surveillance in certain location types. Indeed, using GPS to estimate bout minutes of PA in some locations may be impractical because of the lengthy monitoring time recommendations. Fortunately, many of the locations in which individuals undertake intentional PA may be reasonable to monitor with GPS (fitness facilities, roads, parks, schools). These results may vary by sociodemographic characteristics of the sample considered and should therefore be investigated in other populations before finalized recommendations for GPS monitoring time are developed. At present, this study suggests that 12 d of surveillance may reliably estimate both MVPA and VPA bout minutes in fitness facilities, footpaths, parks, roads, and schools for populations in need of interventions. Importantly, this recommendation includes adequate surveillance for several key built environment locations that may ultimately be useful for increasing PA at the population level.

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