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How Many Days Are Enough? A Study of 365 Days of Pedometer Monitoring

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This study was designed to determine the number of days of pedometer monitoring necessary to achieve reliable and valid estimates of a 1-year average of step counts in adults based on either consecutive days (CD) or random days (RD) of data collection. Twenty-three participants (16 women; M age = 38 years, SD = 9.9) wore a Yamax SW 200 pedometer and recorded their step counts for 365 consecutive days. Nine measurement periods of various lengths were selected (2, 3, 4, 5, 6, 7, 14, 21, and 30 days). Each measurement period was randomly selected 10 times each for CD and RD from the larger database. For reliability and validity, two-way intraclass correlation coefficients and mean absolute percentage error (MAPE) were calculated, respectively. The year-round average was considered the criterion measure of the "true" habitual physical activity. Data were analyzed separately by CD and RD. At least 5 CD or 6 RD were necessary to achieve an ICC of .80. A minimum of 30 CD or 14 RD were necessary to achieve an MAPE lower than 10%. These findings provide researchers and practitioners with useful information to determine appropriate measurement length and the method of data selection based on a desired level of reliability and validity.

Key words: measurement, reliability, step counts, validity

Pedometers are simple and inexpensive body-worn motion sensors for measurement of physical activity (Tudor-Locke & Bassett, 2004). During the past decade, pedometers have been widely used to measure physical activity levels for intervention (Chan, Ryan, & Tudor-Locke, 2004; Swartz et al., 2003), correlational (Bjorgaas et al., 2005; Duncan, Schofield, & Duncan, 2006), and diagnostic studies (Eisenmann, Laurson, Wickel, Gentile, & Walsh, 2007; Loucaides, Chedzoy, & Bennett, 2004). Pedometers have also been used to promote healthy lifestyles (Bravata et al., 2007; Kang, Marshall, Barreira, & Lee, 2009; Tudor-Locke, Hatano, Pangrazi, & Kang, 2008). Measuring physical activity using pedometers in an accurate and reliable way is thus important in order to evaluate effective interventions, characterize the relationship between physical activity and health outcomes, and promote a healthy lifestyle.

To accurately assess physical activity behavior is, however, a challenging task due to known high inter- and intraindividual variability (Baranowski & de Moor, 2000). Studies have provided information on factors that can contribute to variability: weather, season, weekday versus weekend day, and work versus nonwork day (Chan, Ryan, & Tudor-Locke, 2006; Matthews, Ainsworth, Thompson, & Bassett, 2002; Tudor-Locke, Bassett et al., 2004). Efforts have been made to determine the minimum number of days needed to obtain reliable step-count measurements for adult populations. Gretebeck and Montoye (1992) determined that 5–6 days of adult pedometer-data collection were necessary to achieve reliable estimates.

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Tudor-Locke et al. (2005) reported that for adults a minimum of 3 days was necessary to achieve an intraclass correlation coefficient (ICC) of .80. While those studies provide enough evidence to determine an appropriate measurement period to achieve a stable estimate (i.e., reliability) of pedometer data, information is lacking on the level of accuracy (i.e., validity) that can be achieved with those measurement periods.

Valid assessment of physical activity is necessary to fully understand the important health-related behavior for research, surveillance, intervention, and evaluation purposes (Tudor-Locke, Williams, Reis, & Pluto, 2004). The validity issue, however, has been overlooked in the pedometer research, and to our knowledge, only one study has examined the validity of step-count measurement for weekly physical activity. Tudor-Locke and colleagues (2005) made an initial attempt to examine the number and type of days of monitoring required to predict one week of pedometer monitoring. They used a stepwise regression model and considered step-count average during a week as a criterion measure. The study demonstrated that 1 day accounted for 79% of the variability in weekly physical activity and 3 days accounted for 94% of the variability. The results from the stepwise regression in combination with the ICC results suggested that 3 days of data collection could be enough to achieve a reliable and valid estimate of weekly physical activity for adults.

Physical activity behavior can be described as unstable in nature, because it fluctuates from day to day with a coefficient of variation of about 32%, as determined by objective movement measures, such as a pedometer (Tudor-Locke, Bassett et al., 2004). It follows that, depending on what type of research is being conducted, data collection procedures might need to vary accordingly. For example, if typical physical activity is viewed as weekly physical activity, 3 days of data collection, suggested by Tudor-Locke and colleagues (2005), may be sufficient in terms of reliability and validity of step-count measurement. However, if habitual physical activity is considered as yearly physical activity, there are new reliability and validity issues, which have not been addressed yet. In other words, 3 days of data collection does not necessarily guarantee a stable and accurate reflection of the year-round physical activity. Baranowski, Mâsse, Ragan, and Welk (2008) also pointed to the fact that the measurement of physical activity over an extended period of time (e.g., months or years) has not received sufficient attention to date and that point estimates (i.e., 1 week) of physical activity often do not generalize to typical physical activity behavior over longer periods.

Another important point raised by Baranowski et al. (2008) was that physical activity studies have not addressed the issue of measurement being made in consecutive versus random days. They indicated that data collection over consecutive days may violate the independence assumption of statistical analysis. That is, if a person overdoes physical activity on one day, he or she may do less the next day to compensate. Therefore, the present study was designed to identify sampling strategies that researchers could use in order to obtain a reliable and valid estimate of an adult's year-round average step counts based on consecutive and random days of data collection.

Method

Participants

This was part of a larger study examining the impact of various factors on pedometer-determined physical activity over a one-year period. The participants resided in Tennessee or South Carolina, and they were predominantly Caucasian and college-educated. All participants signed a written, informed consent form approved by the IRBs of University of Tennessee and University of South Carolina. More information about the participants and data collection can be found elsewhere (Tudor-Locke, Bassett et al., 2004). Briefly, 23 participants (7 men, 16 women; *M* age = 38 years, *SD* = 9.9; *M* body mass index = 27.7 kg/m^2, *SD* = 6.2) wore a Yamax SW 200 pedometer (Yamax Corporation, Tokyo, Japan), and recorded their step counts for 365 consecutive days. The daily average of these step counts was 10,090 ± 3,388 steps with a coefficient of variation of 32%.

Before data analysis, data screening was performed. The total missing values accounted for 2% of the data. The average number of missing days per participant was 8 days, with 5 participants having no missing days; the participant with the greatest amount of missing data had 25 missing days. Missing values were replaced using an individual-information-centered approach proposed by Kang, Zhu, Tudor-Locke, and Ainsworth (2005) and cross-validated by Kang, Rowe, Barreira, Robinson, and Mahar (2009). Specifically, missing values from each participant were replaced by the average of the remaining values of that same participant.

Study Design and Data Analysis

First, 9 step-count measurement periods of various lengths (2, 3, 4, 5, 6, 7, 14, 21 and 30 days) were selected for consecutive and random days. The 10 samples for each measurement period were randomly selected from the larger database. This sampling plan was designed to account for systematic variation in physical activity behaviors attributable to seasonal and day-of-the-week (weekday vs. weekend) effects. For consecutive days, the starting day for each measurement period was randomly selected using the SPSS subcommand "select cases," and the appropriate number of consecutive days was selected thereafter. For random days, all the values were selected using the SPSS subcommand "select cases." Ten data sets of consecutive days and 10 data sets of random days were created for each measurement period, for a total of 180 data sets. The sampling plan used in this study was designed to account for systematic variation in physical activity behaviors attributable to seasonal and day-of-the-week effects.

To determine the reliability of step counts recorded over various measurement periods, two-way ICCs were calculated for the 10 samples of both consecutive days and random days for each measurement period. Two-way ICC was used because differences in steps counts from day to day are expected, not only because of measurement error but because of the nature of the measurement. The 10 samples' ICCs were then averaged, resulting in the ICC for each measurement period. The ICCs in consecutive days and random days were inspected separately to determine the number of days necessary to obtain a reliability of ICC ≥ .70, ≥ .80, and ≥ .90. Evaluation of the ICC provides an estimate of the number of days necessary to differentiate between individuals in the population (i.e., low vs. high step counts).

To determine validity, the same data sets created for the reliability calculations were used to compute the mean absolute percentage error (MAPE) for 10 samples of both consecutive and random days for each measurement period. The year-round average was considered a criterion measure of the "true" habitual physical activity. This is a similar approach to the one used in the nutrition literature, where multiple 24-hr diet recalls are used as the "gold standard" against shorter measurement periods (Kelemen, 2007). First, the absolute percentage error (APE) was calculated as the absolute difference between a person's step-count average over the selected measurement period (e.g., 2 days) and their 365-day average, which was divided by the 365-day average and then multiplied by 100. The APE was computed for each person, and 23 participants' APEs were averaged, resulting in the MAPE for the specific sample. The formula for MAPE is as follows:

$$\text{MAPE} = \frac{1}{n}\sum_{t=1}^{n}\frac{[\text{Selected MP step-ct. avg.} - \text{365 day step-ct. avg.}]}{\text{365 day step-count avg.}} \times 100$$

where *MP* refers to measurement period. The mean of the 10 samples was then computed both for consecutive and random days. A smaller MAPE represents a better estimate of the "true" habitual physical activity. The MAPEs in consecutive days and random days were inspected separately to determine the number of days to obtain valid estimates of MAPE ≤ 10%, ≤ 15%, and ≤ 20%. The MAPE provides information on the number of days required to obtain a mean value within a defined level of precision around the true mean for an individual in the population.

Results

A summary of the ICC results can be found in Table 1, and the complete ICC results can be seen in Table 2 and Figures 1 and 2. As the length of the measurement periods increased, there was an increase in the ICC value and a decrease in standard deviation. The ICC averages were larger with consecutive days, compared to random days. The ICC averages for consecutive days ranged from .71 for 2 days to .96 for 30 days, with an average ICC greater than .80 at 5 days (ICC = .83 ± .04). The ICC averages for random days ranged from .65 for 2 days to .96 for 30 days, with an average ICC greater than .80 at 6 days (ICC = .82 ± .04).

A summary of the results for MAPE can be found in Table 3, and the complete MAPE results can be seen in Table 3 and Figures 3 and 4. As the length of the measurement periods increased, the MAPE scores decreased. The MAPEs were smaller for random days than for consecutive days. The MAPE averages for consecutive days ranged from 20.47% for 2 days to 9.57% for 30 days, with an average less than 10% at 30 days (*M* MAPE = 9.57%, *SD* = 2.13%). The MAPE averages for random days ranged from 21.65% for 2 days to 5.40% for 30 days, with an average less than 10% at 14 days (*M* MAPE = 8.25%, *SD* = 1.14).

Discussion

This study examined how many days of pedometer monitoring were necessary to achieve reliable and valid estimates of a 1-year average of step counts in adults based on consecutive and random days of data collection. The results suggested that at least 5 consecutive days were necessary to achieve an average ICC ≥ .80. These results resemble those of Gretebeck and Montoye (1992), who concluded that of 5–6 days (including weekend days) of adult pedometer-data collection were necessary to

Table 1. Number of days necessary to achieve desired intraclass correlation coefficients and mean absolute percentage error

Data		ICC			MAPE	
selections	≥ .70	≥ .80	≥ .90	≤ 20%	≤ 15%	≤ 10%
Consecutive days	2	5	14	4	7	30
Random days	4	6	14	3	5	14

Note. ICC = intraclass correlation coefficient; MAPE = mean absolute percentage error.

achieve reliable estimates. There was a large variation in the ICC values at each measurement period. Within the 10 samples of 3 days an ICC ≥ .80 was achieved only twice and ICCs ranged from .60 to .88. Within the 10 samples of 4 days an ICC ≥ .80 was achieved five times. An ICC ≥ .80 for all the samples was achieved only in the samples of 7 days or more.

Reliability results for random days have not been reported on previous studies. The ICCs of the random days' samples were lower than the ICCs of the consecutive days' samples. A minimum measurement period of 6 days was necessary to achieve an ICC ≥ .80. The ICCs within the samples of 3 days was ≥ .80 only once. A sampling period of at least 5 days was necessary to achieve an ICC ≥ .80 at least half the time, and a sampling period of 14 days or more was necessary to achieve an ICC ≥ .80 for all the samples. Collecting data on consecutive days may violate the independence assumption of statistical analysis. That is, step counts from two (or more) consecutive days tend to be correlated. We can expect that collecting data on single days (i.e., *random days*) may overcome the correlated-days issue (Baranowski et al., 2008). However, it should be noted that the approach of collecting data over multiple single days may not be feasible in all research settings.

To determine valid estimates of step-count measurement, MAPEs were calculated. Because the year-round average of step counts for this study sample was 10,090 steps per day , a 10% MAPE represents a measurement error of around 1,000 steps for each participant. For the *consecutive days'* samples, an average of less than 10% was achieved at the measurement period of 30 days. The results show that even though 5 consecutive days can be enough to provide reliable estimates, a period of 5 days of data collection does not provide accurate measurements of yearly physical activity; for example, a person may record only 1,000 steps every day for 5 consecutive days because of illness or inclement weather. These results differ from those in the study by Tudor-Locke et al. (2005), who suggested that 3 days of consecutive data collection should be enough to achieve valid results. That study was based on a week's estimate of pedometer-determined physical activity behavior. Here, the MAPEs of random days were lower than consecutive days at almost all measurement periods. Within the sampling period of 14 days, all samples had an MAPE lower than 10%, averaging 8.25%. These results indicate that a data collection period longer than

Table 2. Intraclass correlation coefficients for consecutive versus random days selections

	Selected measurement periods for consecutive days								
	2	3	4	5	6	7	14	21	30
Sampling #1	.73	.62	.77	.84	.82	.87	.94	.92	.97
Sampling #2	.81	.79	.73	.84	.85	.88	.94	.96	.96
Sampling #3	.79	.86	.66	.87	.86	.89	.88	.97	.95
Sampling #4	.70	.67	.86	.83	.85	.91	.94	.94	.97
Sampling #5	.92	.75	.80	.73	.83	.87	.93	.95	.96
Sampling #6	.53	.88	.72	.82	.81	.86	.92	.95	.95
Sampling #7	.77	.77	.85	.79	.84	.84	.91	.93	.97
Sampling #8	.63	.60	.75	.86	.78	.93	.92	.95	.96
Sampling #9	.48	.66	.80	.88	.87	.89	.95	.94	.96
Sampling #10	.76	.74	.88	.81	.91	.91	.91	.95	.96
M	.71	.73	.78	.83	.84	.88	.92	.95	.96
SD	.13	.10	.07	.04	.03	.03	.02	.01	.01
	Selected measurement periods for random days								
Sampling #1	.51	.59	.85	.75	.87	.81	.87	.92	.96
Sampling #2	.71	.79	.84	.78	.81	.79	.92	.96	.96
Sampling #3	.76	.82	.80	.72	.76	.84	.91	.93	.96
Sampling #4	.59	.69	.65	.80	.82	.85	.90	.93	.96
Sampling #5	.86	.72	.61	.78	.86	.85	.92	.94	.95
Sampling #6	.44	.71	.82	.81	.83	.85	.91	.94	.95
Sampling #7	.76	.71	.64	.83	.80	.86	.93	.93	.96
Sampling #8	.50	.54	.74	.72	.84	.78	.90	.94	.95
Sampling #9	.64	.59	.77	.90	.75	.78	.94	.94	.95
Sampling #10	.76	.62	.84	.83	.82	.88	.91	.95	.96
M	.65	.68	.76	.79	.82	.83	.91	.94	.96
SD	.14	.09	.09	.05	.04	.04	.02	.01	.01

Note. M = mean; *SD* = standard deviation.

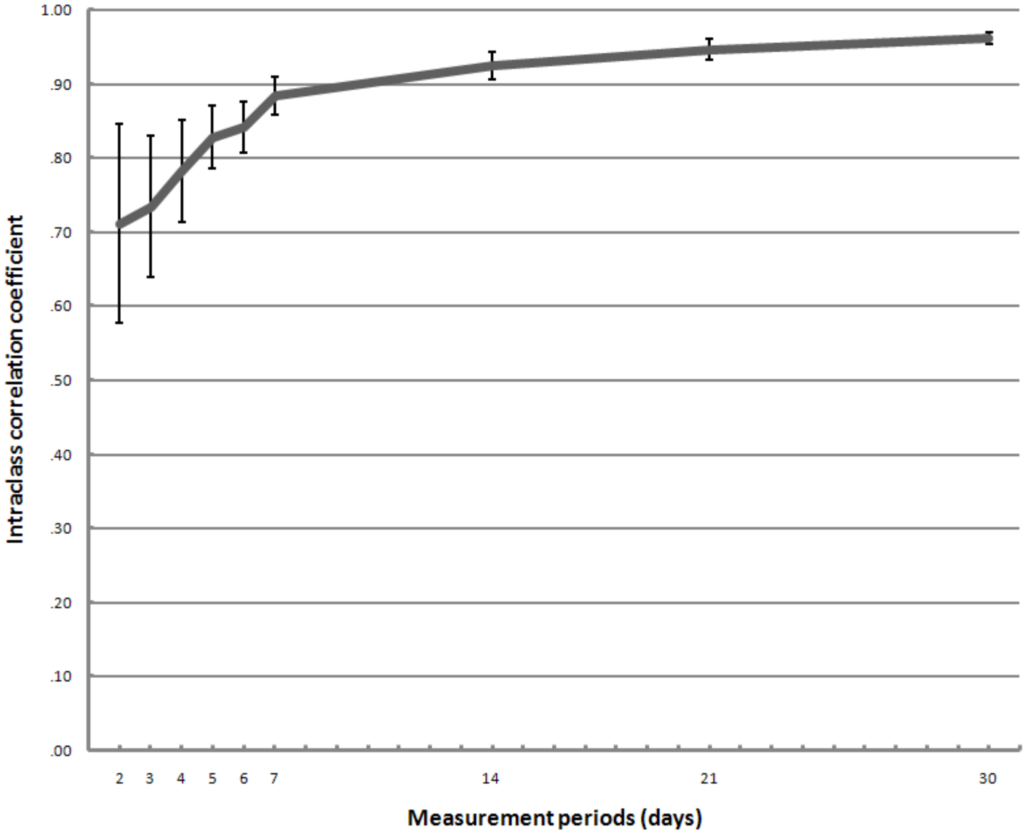

Figure 1. Intraclass correlation coefficients of step-count measurement periods for consecutive days.

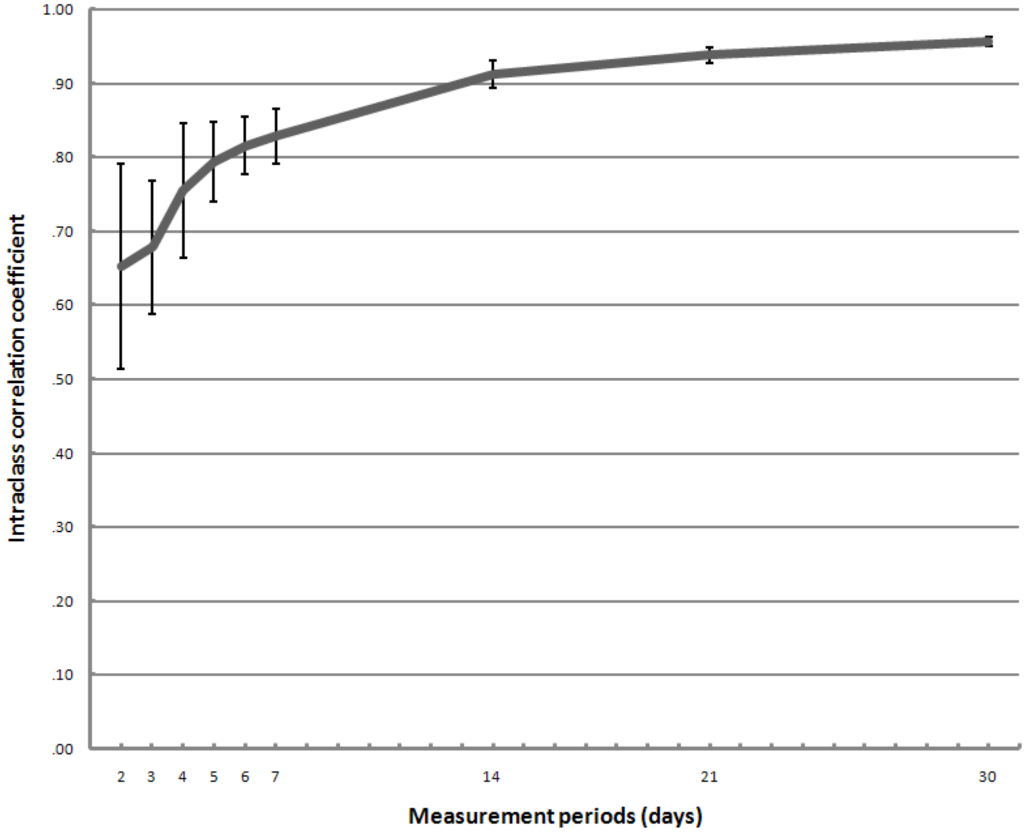

Figure 2. Intraclass correlation coefficients of step-count measurement periods for random days.

the commonly recommended periods of 3–7 days is necessary to achieve valid data, at least in terms of a year-long estimate of usual behavior.

Typical physical activity behavior is unstable in its pattern, and depending on what type of research is being conducted, this may affect the minimum number of days needed to obtain valid and reliable results. For intervention studies focused on capturing physical activity levels at a specific point in time before treatment, 3 days of data collection may be sufficient to provide reliable and accurate estimates of a week's physical activity levels for adults (Tudor-Locke et al., 2005). However, studies examining the correlation between step counts and other health outcomes would likely benefit from longer monitoring periods. Certainly studies investigating the chronic effects of physical activity should consider an even more extended period of time. Data representing periods of 28 days or more, like those collected by Clemes, Griffiths, and Hamilton (2006), are examples of this type of research.

The combination of the reliability and validity results in this study indicate that an individual's daily physical activity levels are fairly stable within a brief measurement period, but those measurement periods may not represent the habitual physical activity level over a year. This is evident from the high ICCs and the low MAPEs for consecutive days, and the low ICCs and the high MAPEs for random days. Researchers and practitioners should take the results of this analysis into consideration when preparing for data collection of habitual physical activity levels. Previous studies have determined the minimum number of days necessary to achieve reliable estimates of physical activity levels. However, because the validity aspect of the measurement has been neglected, the number of days previously recommended is associated with a large margin of error for an estimation of year-round habitual physical activity. Researchers and practitioners now can use the information provided in this study to determine the acceptable level of error for their own unique research questions, resources, and subject burden and protocol compliance concerns.

Previous research with children and older adults examined the measurement periods necessary to achieve reliable measurements. Vincent and Pangrazi (2002) reported that 5 days of pedometer monitoring are required of elementary school children to obtain an ICC of .80. Rowe, Mahar, Raedeke, and Lore (2004) found that

Table 3. Mean absolute percentage error (%) for consecutive versus random days selections

	Selected measurement periods for consecutive days								
	2	3	4	5	6	7	14	21	30
Sampling #1	13.50	16.72	10.15	13.44	11.99	9.16	11.14	10.68	10.39
Sampling #2	19.48	25.57	20.37	22.14	19.02	21.01	12.91	10.97	12.56
Sampling #3	19.42	22.54	9.47	21.68	17.53	13.42	10.82	15.12	8.49
Sampling #4	21.68	19.54	19.05	11.44	14.38	14.68	9.93	11.08	9.56
Sampling #5	20.70	23.56	19.89	18.69	12.24	13.12	7.65	10.87	11.43
Sampling #6	22.58	25.51	18.47	11.18	13.10	11.57	12.42	9.62	9.22
Sampling #7	27.00	18.56	9.42	19.67	21.30	12.20	18.08	10.21	11.65
Sampling #8	26.38	21.64	18.10	15.61	13.56	15.95	10.93	5.85	9.41
Sampling #9	15.89	24.39	17.11	18.08	14.26	17.41	12.48	9.05	5.21
Sampling #10	18.08	16.75	18.01	17.21	17.22	15.24	12.39	17.59	7.79
M	20.47	21.48	16.00	16.91	15.46	14.38	11.88	11.11	9.57
SD	4.23	3.41	4.47	3.93	3.13	3.31	2.68	3.22	2.13
	Selected measurement periods for random days								
Sampling #1	18.02	16.88	19.41	11.44	10.75	14.63	7.12	5.12	5.96
Sampling #2	21.11	25.20	18.62	12.39	12.49	12.51	6.90	6.52	7.48
Sampling #3	24.37	16.36	17.89	13.62	10.95	9.48	6.85	7.21	4.79
Sampling #4	21.32	12.72	13.88	14.80	10.99	13.47	7.03	6.85	5.50
Sampling #5	25.92	20.81	13.68	18.02	9.26	9.45	9.42	6.44	5.12
Sampling #6	31.37	18.28	16.88	10.89	12.12	15.56	9.01	9.78	4.64
Sampling #7	18.29	10.06	14.61	14.08	13.98	14.02	9.32	7.64	5.62
Sampling #8	16.37	22.00	16.23	17.03	16.52	8.73	8.87	6.35	4.90
Sampling #9	22.11	18.97	14.88	16.92	10.72	9.89	9.50	5.69	4.60
Sampling #10	17.56	16.06	19.48	13.40	11.24	12.96	8.52	7.30	5.41
M	21.65	17.74	16.56	14.26	11.90	12.07	8.25	6.89	5.40
SD	4.59	4.41	2.24	2.43	2.05	2.47	1.14	1.26	0.86

Note. M = mean; *SD* = standard deviation.

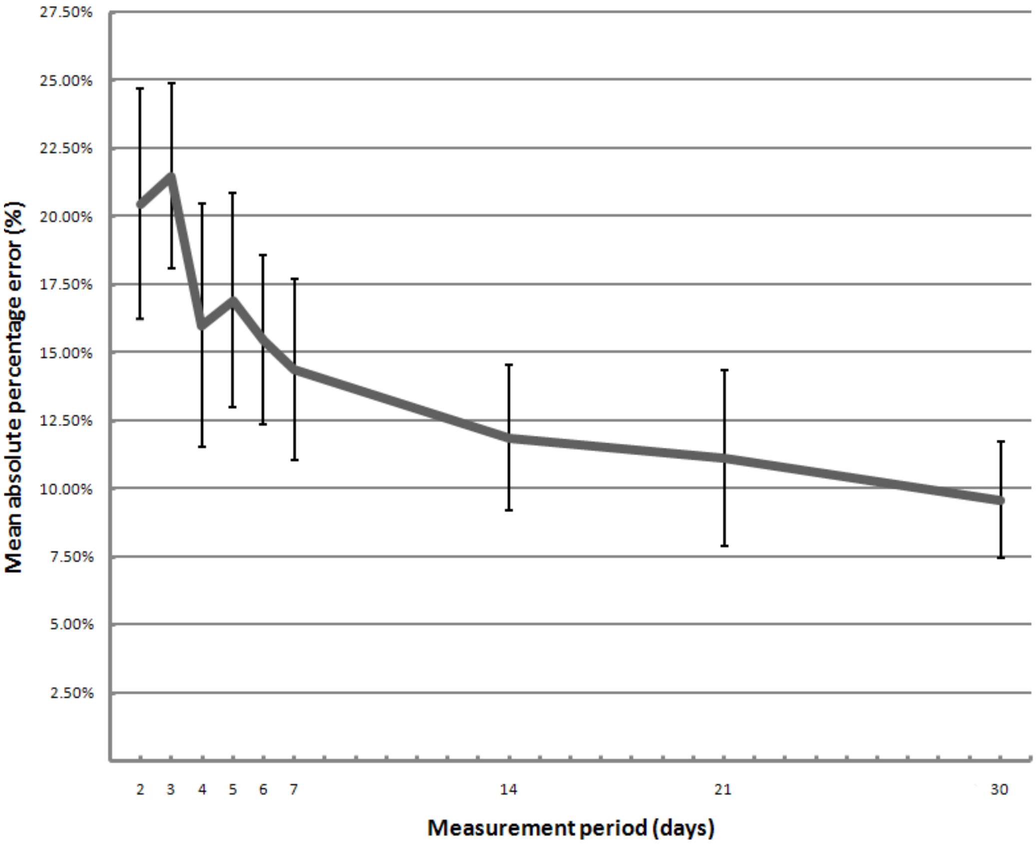

Figure 3. Mean absolute percentage error of step-count measurement periods for consecutive days.

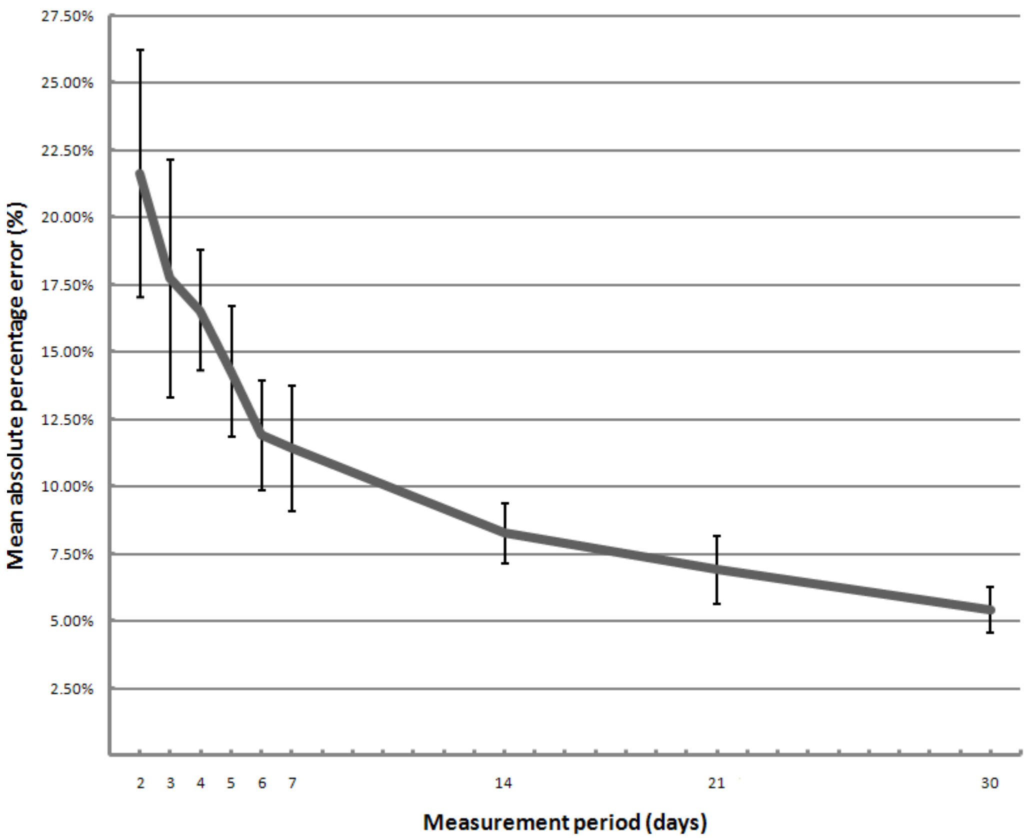

Figure 4. Mean absolute percentage error of step-count measurement periods for random days.

6 days of pedometer data were adequately reliable for researching the physical activity of children. Strycker and colleagues (2007) determined that reliability coefficients of .80 or greater were obtained with 5 or more days of data collection in a youth sample and 2 or more days in a sample of older women. Rowe, Kemble, Robinson, and Mahar (2007) reported that only 2 days of data collection were required for adults over 60 years of age to obtain a minimally acceptable reliability of ≥ .80. Validity and reliability are context specific and may vary across different subject populations. Therefore, research similar to the present study is necessary with other age groups.

This study presents some unique results, but it is not without some limitations. The analysis was made using a small, relatively homogeneous sample. The data were collected in two southeastern U.S. states, where the weather is relatively moderate during the summer and winter seasons. It is acknowledged that severe weather can affect physical activity levels (Chan et al., 2006), so the generalizability of these results could be different for different regions in the world. Future research should examine the possible violation of compound symmetry due to differences in the variances and covariances among the multiple days of step-count measurement. The violation of compound symmetry may lead to an overestimate of ICC, which would result in an underestimation of the number of days recommended. The effects of month and seasonal variation should be further explored in future research by restricting sampling to certain times of the year (i.e., by months and/or by seasons). The use of generalizability theory also holds promise for examining the sources of variation in step-count data (i.e., person, day of week, season), through analysis of variance (Baranowski et al., 2008; Ragan & Kang, 2005).

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