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Procedures Used to Standardize Data Collected by RT3 Triaxial Accelerometers in a Large-Scale Weight-Loss Trial

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Abstract

Background.—Accelerometers measure intensity, frequency, and duration of physical activity. However, the scarcity of reports on data reduction makes comparing accelerometer results across studies difficult.

Methods.—Participants were asked to wear a triaxial accelerometer (RT3) for ≥10 hours for at least 4 days, including one weekend day. We summarize our data-cleaning procedures and assess the impact of defining a usable day of measurements as at least 6, 8, or 10 hours of wear time, and of standardizing data to a 12-hour day.

Results.—Eighty-two percent of participants met wear time requirements; 93% met requirements when we defined a day as 8-or-more hours of wear time. Normalization of data to a 12-hour day had little impact on estimates of daily moderate-to-vigorous physical activity (MVPA) (16.9 vs. 17.1 minutes); restricting MVPA to activities occurring in bouts of 10 minutes or longer had greater impact (16.9 vs. 6.3 minutes per day).

Summary.—Our account of accelerometry quality-control and data-cleaning procedures documents the small impact of variations in daily wear time requirements on MVPA estimates, and the larger impact of evaluating total MVPA vs. MVPA occurring in extended bouts. This paper should allow other researchers to duplicate or revise our methods as needed.

Keywords

accelerometry; methodology; data processing; physical activity; measurement

Introduction

Modification of physical activity is a proven behavioral approach for reducing cardiovascular risk factors and improving overall fitness and health.[1] For lifestyle intervention trials in which physical activity is a targeted intervention, simple-yet-accurate

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devices are needed to monitor participants' physical activity. Among the devices most commonly used for this purpose are pedometers and accelerometers, both of which provide researchers with objective data not subject to the biases of self-report instruments.[2]

Unlike pedometers, which simply count steps, accelerometers can capture intensity, frequency, and duration of movement. Thus, they are able to distinguish moderate-to-vigorous physical activity (MVPA) from less-intense activity, and can, in theory, distinguish sporadic MVPA from the more-sustained MVPA that is usually defined as formal exercise. Accelerometers are divided into uniaxial devices, which measure vertical displacement,[3] and triaxial devices, which simultaneously measure movement in three planes and hence offer the potential to capture physical activity more sensitively. Because of this potential benefit, triaxial accelerometers were adopted for use in two large, multi-site, NIH-funded trials: Look AHEAD[4] and Weight Loss Maintenance (WLM).[5]

To accurately assess physical activity, participants generally are asked to wear the devices for a period of several days. Despite protocol requirements for obtaining accurate data from the devices, in reality individuals may wear them for varying numbers of days and for varying hours per day. Unfortunately, no standards yet exist for how best to summarize the resulting data, even though differences in data-reduction procedures can presumably influence estimates of physical activity. Further complicating matters, data-processing procedures have not been well-described in the literature,[6] and the details that have been published are limited and vary across studies.[7] Ward and colleagues outlined the need for describing data-reduction procedures in order to allow more valid comparisons of physical activity to be made across study populations.[8]

This paper summarizes our methods for collecting and processing data from triaxial accelerometers in the WLM trial, which represents one of the largest known trials collecting objective measures of physical activity in overweight and obese adults. The intent of this paper is to disseminate our methods in the public domain for the benefit of other researchers and to share our findings regarding the impact of various means of processing these data on summary measures of physical activity.

Methods

Study Design

WLM was a four-center randomized clinical trial designed to compare the effects of two strategies to help individuals achieve successful long-term maintenance of initial weight loss. The study protocol was approved by the Institutional Review Boards of each clinical site and the coordinating center, and all participants provided written informed consent. To enter the study, participants had to be 25 years or older, have a body mass index of 25–45 kg/m^2, and be taking blood pressure- and/or cholesterol-lowering medications. Following an initial six-month intensive intervention involving 1,685 participants, those achieving weight loss of at least 4 kg were invited to be randomized into the maintenance phase of the study.[5] Physical activity was an integral part of both the initial intervention and the subsequent weight loss maintenance strategies.

Accelerometry Protocol

All study participants were asked to wear a triaxial accelerometer (RT3, Stayhealthy, Inc, Monrovia, California) four separate times: prior to participation in the initial weight loss intervention (the “screening” measurement), at the end of the initial intervention and prior to randomization (the “baseline” measurement), and again at 12 months and 30 months post-randomization. Only screening data are reported in this paper. The accelerometers were set to record movement in each of three directions in one-minute intervals. The analyses presented here use only an integrated measure of overall activity, although quality control testing conducted during the study examined separate indicators of movement to assure proper operation of the devices.

Participants were instructed to wear the accelerometers on a continuous basis from when they dressed in the morning until bedtime at night, and to take them off only when bathing or engaging in swimming or other water-related activities. Participants were asked to wear the accelerometers for a minimum of 10 hours per day for at least four days, including at least one weekend day.

Once a participant returned an accelerometer, staff downloaded the data and assessed wear time using a graphical display of the data. If, after examining the graph, staff could not be certain that the wear time criteria were met, they reviewed the files using a spreadsheet designed to evaluate wear time more precisely. Participants who did not meet the wear-time requirements were asked to wear the accelerometers again and, if more complete measurements were obtained, data were retained for analysis.

Most accelerometers were initialized and activated at face-to-face clinic visits immediately prior to being given to participants. However, in some cases they were initialized at the clinic and then mailed to participants, who were then instructed on how to activate them. Participants were asked to keep a usage log that was used to assess the end of wear time in cases where participants were not able to return for a clinic visit at the scheduled end of their wear time. The accelerometers were set to record continuously following activation until their storage capacity (just over 7 days) was reached.

Staff Training

Clinical center staff were trained and certified to program, download data from, and assess the calibration of the accelerometers. Training included completing a written test and a practicum. The written test assessed the staff’s ability to recognize adequate wear time and the function of each axis of the RT3 from the display produced during the data download. The practicum included demonstrating proper RT3 initialization, activation, and downloading; use of the participant script; properly completing the RT3 data form; and reviewing the supplemental physical activity questionnaire. Staff also demonstrated proper use of an Excel spreadsheet designed to assist them in assessing wear time.

Accelerometer Quality Control

Accelerometer performance for each device was assessed at least semi-annually using a device developed locally (the Swing Test device) to create a reproducible accelerometer signal. RT3 units whose measurement variability exceeded preset thresholds were flagged for repeat testing and, if the pattern persisted, were either not used or sent to the Stay Healthy reference lab for servicing. (Details of the Swing Test device construction and operation are available upon request.)

File Processing and Data Reduction Conducted at Coordinating Center

Once received at the coordinating center, a series of SAS programs were used to clean and process the data. Initially, incoming files were checked to ensure there were no duplicates and that the dates on the files corresponded with start/stop dates on the accompanying paper logs, which had been entered separately. Duplicate files resulted from interrupted data transfers from the RT3 unit to the PC, and were identifiable by the size of the resulting data file, which was usually double that of a typical file. Battery failure was one of the more-frequent causes of date mismatches; in several cases the initialization date was recorded as 1/1/2000 and the time was recorded as 00:00 am.

Next, we stripped off the first and last five minutes of data on each file to eliminate movement associated with the placement and removal of the units. Following this, we identified all (one-minute) non-zero readings that were immediately preceded and followed by zero-activity counts. We assumed these counts represented spurious activity and reset them to zero. Thirty-seven percent of all apparent usage periods (i.e., consecutive minutes of nonzero activity) lasted only one minute and thus were reset to zero by this procedure. While this process undoubtedly set some real activity records to zero, the focus of the WLM physical activity intervention was on MVPA, and we deemed it highly unlikely that a true one-minute period of MVPA would be preceded and followed by one or more minutes of zero activity. Thus, we are confident that we dropped few real periods of MVPA by this procedure.

As the final step in data-cleaning, we defined periods of zero activity that lasted at least 15 minutes to be periods when the accelerometer was not being worn. In order to validate this rule, which is generally consistent with the practice used in another published report,[6] we conducted a substudy in which 16 volunteers were asked to wear the accelerometers during periods of sedentary activity, including napping, watching television, and reading a book. The volunteers were asked to engage in each activity for at least 30 minutes, and to keep a log of when they were engaged in such activities. These volunteers ultimately contributed 94 periods of sedentary activity of the required duration. The results suggest that the vast majority (80%) of intervals of zero readings during true sedentary activity last for just 1–4 minutes, and that only 3% of such intervals last for 15 minutes or longer.

Measures of Moderate to Vigorous Physical Activity (MVPA)

We used a cutoff point of 1316.6 for the integrated acceleration as the threshold of MVPA.[9] For purposes of analysis, we calculated both total minutes of MVPA, regardless of duration, and total minutes of MVPA that occurred in “bouts” lasting at least 10 minutes. To define a bout of MVPA, we allowed for, on average, one minute of less-than-MVPA activity for every nine minutes of MVPA activity.[6, 7, 10] The algorithm begins by finding the first 10-minute interval starting with an MVPA minute and containing at least nine MVPA minutes.

Next, the algorithm drops the first minute and checks the next additional minute. If the resulting new 10-minute window also contained at least nine MVPA minutes, the additional minute was considered part of the same bout of exercise and the next minute was considered in the same manner. Otherwise the MVPA bout was considered to have ended. Our subsequent use of the term “bout MVPA minutes” refers to MVPA that occurred as part of one of these concentrated bouts of activity.

Minutes of MVPA were computed on a daily basis, and then used to compute estimated weekly activity, by taking a weighted average of daily weekday and weekend activity (weekly MVPA = (5 * average daily weekday MVPA) + (2 * average daily weekend MVPA)). The daily minutes of MVPA reported in table 3 reflect this weighted weekly estimate divided by seven. Twenty four individuals who did not have both usable weekday and weekend data were excluded from this table.

Self-Reported Assessment of Physical Activity

Immediately after returning accelerometers, participants completed a self-administered activity log indicating the number of minutes spent in various types of physical activity during the previous week. The activities captured on this form include swimming and water skiing, during which the participant would not be wearing the accelerometer, and bicycling, during which the accelerometer might be expected to substantially underestimate activity.[11]

Statistical Methods

Although participants were asked to wear accelerometers for the entire day, in practice, estimated wear time varied widely. For purposes of this analysis, we defined a usable day of RT3 measurements as any day with at least 6, 8, or 10 hours of estimated wear time, and compared the impact of each definition on our results.

Recognizing that for any of these definitions of a “usable day,” a wide variation in wear times still existed, we also computed “normalized” estimates of daily (and hence weekly) MVPA minutes by standardizing any given day’s measurements to that of a 12-hour day. This was done by dividing the total minutes of observed MVPA in a day by the estimated wear time in hours, and then multiplying by 12. We present both normalized and non-normalized data to show the impact of this procedure.

Results

Ninety-eight percent of the 1,685 participants who began the initial weight-loss intervention provided screening accelerometry data. Using our post-processing definition of wear time, 82% of them provided data satisfying the minimum wear time criterion of four or more 10-hour days, including at least one weekend day (Table 1). This figure increased to 93% when we reduced the minimum daily wear-time threshold to 8 hours, and further increased to 97% when the minimum daily wear-time threshold was set to 6 hours. Though not shown in the table, 93% of participants who wore accelerometers achieved at least four days with 10 or more hours of wear time, but not all of these individuals had at least one weekend day with 10 or more hours of wear time.

Mean wear time was less for the first and last days of wear time (when the accelerometer was either placed or removed) than for the intervening (middle) days (Table 2). For the latter, mean wear time was 12.6 hours, with 84% of days exceeding 10 hours and 50% exceeding 13 hours. Because most clinic visits occurred early in the morning, the mean wear time for the initial day of use tended to be longer (mean 10.2 hours) than that for the last day of use (mean 4.6 hours). Efforts to place/remove accelerometers either early or late in the day should minimize data wastage. Including the first and last days of wear time, 71% of observation days consisted of 10 or more hours of wear time. This increased to 79% with 8 or more hours of wear time and to 84% with 6 or more hours of wear time (data not shown). If we exclude the last day of use, these figures increased to 80%, 88%, and 93%, and if we include data from only the middle days (when participants could wear the accelerometers all day), these numbers increased to 84%, 91%, and 94%. The minimum and maximum wear times ranged from 0 to 23 hours, with the latter suggesting that some participants may have worn their accelerometers while sleeping.

At entry to the study, the most frequently reported physical activities in the past week (excluding household chores, gardening, and yard work categories) were walking for exercise, stretching exercises, and weight training, as reported by 54%, 32%, and 15% of participants. Bicycling (including use of an exercise bike) was reported by 12% of participants, averaging 65 minutes per week. Water-related activities were reported by just over 5% of participants, with an average duration among this subgroup of 75 minutes per week.

Counting all MVPA minutes, and using the 6-hour threshold to define a usable day’s data, the mean number of MVPA minutes per day was 16.9 minutes for the non-normalized data and 17.1 minutes using normalized days (Table 3). When restricted to “bout MVPA minutes” these figures reduced to 6.3 minutes for both non-normalized and normalized days. Over 75% of all measurement days had zero bout MVPA minutes (data not shown).

Discussion

These findings demonstrate a high level of compliance with a multi-day measurement protocol among a large, ethnically diverse sample of overweight and obese adults. Eighty-two percent of participants wore their accelerometers for four or more 10-hour days, and 93% wore their accelerometers for four or more 8-hour days, including a weekend day. We attribute our success in this data collection effort to the combination of a clearly laid-out protocol for data collection, and to quality control, staff training at study sites, and ongoing monitoring of data completeness by the coordinating center. The detailed discussion of quality control and data-reduction procedures used in WLM should aid other investigators using accelerometers to assess physical activity, and should lead to greater standardization of measurement in this field.

Loss of data from the RT3 units was a major concern, however. The WLM trial protocol included guidelines for regular calibration and maintenance of the accelerometers, including regular replacement of batteries. Such basic steps have been identified as recommended best practice for accelerometer measurement.[8] Nevertheless, we still received anecdotal reports of data loss or devices being reset at some point during the wear period. It is unclear how best to address these concerns in future studies, as most such events are beyond the researcher's control.

Equipment failure was also an ongoing problem. We performed calibration testing, as described in the Methods, after which defective units were refurbished or replaced as needed. Staff became expert at troubleshooting minor technical glitches (such as failure of the monitor to properly initialize or transmit data), although on occasion RT3 units needed to be sent to the manufacturer for cleaning. The coordinating center also established a rigorous inventory process for tracking the timely return of RT3 data by participants and for data transfer back to the coordinating center.

Analytically, it is important to be able to distinguish true wear time from periods of nonuse. Although this distinction is unlikely to impact assessment of MVPA, it is critical to determining if wear time criteria were met and could have a substantial impact on measurement of total activity. Our criterion of 15-or-more-minutes of consecutive zero readings to define nonuse is consistent with a previous literature report[6]and also was supported by our pilot study assessing accelerometer counts with recorded sedentary activities. We acknowledge that our decision to set isolated one-minute periods of activity to zero early in the data cleaning process may have resulted in an underestimation of true wear time, especially since this included 37% of all wear time intervals. From a practical perspective, however, this means that actual wear time is likely even higher than reported here.

After data cleaning, a decision must be made as to what constitutes a usable day's measurement. Our results suggest that, using a 6-hour minimum threshold for wear time, normalization to some fixed number of hours of daily wear time has little impact on the estimate of mean MVPA minutes. This conclusion reflects in large part the fact that our mean daily wear time was close to the normalized wear time of 12 hours. Had noncompliance with our protocol been greater, with correspondingly lower mean wear times, normalizing to a 12-hour day likely would have had a much greater impact than we observed. Others have suggested alternative methods of imputation of missing accelerometer data.[12]

Of much greater impact, at least for this study, was the decision whether to use MVPA minutes occurring in bouts of at least 10 minutes rather than total MVPA minutes. Physical activity is defined as activity resulting in movement, whereas exercise is defined as planned physical activity with a purpose or ultimate intent, such as improved fitness.[13] While total MVPA minutes may represent a better estimate of moderate to vigorous activity, and hence of activity-related energy expenditure, we believe that bout MVPA minutes provide a better measure of moderate-to-vigorous exercise. Ultimately, the decision of which measure to use should be based on known or hypothesized relationships to the health index being measured. For instance, the latest recommendation from the American College of Sports Medicine (ACSM) and the American Heart Association (AHA) suggests that MVPA needs to occur in intervals of at least 10 minutes' duration to provide clinically meaningful health benefits.[14] Following these criteria, bout minutes of MVPA seem preferable to total MVPA minutes as a measure. However, if weight loss is the primary consideration in a study, total energy consumption may be the more important metric, in which case total MVPA minutes may be the more relevant measure.

It is also important to realize that both measures of MVPA minutes, but particularly bout MVPA minutes, will be highly skewed in a general population and even more so in a sedentary, overweight and obese population such as the WLM cohort at entry into the study. In this high-risk cohort, prior to initial implementation of a formal weight-loss program, fewer than 25% of measured days included a period of 10 minutes or more of sustained MVPA. Even among the subset of the population engaging in MVPA, MVPA minutes are likely to be skewed, though much less so than for the population as a whole. While this skewness likely would not affect the choice of which measure to use, it does have important implications for data analysis.

We used the cut points established by Rowlands et al.,[9] some of the few validated RT3 cut points for MVPA among adults. The RT3 is a relatively new instrument, and sufficient validity studies have not yet been conducted to identify appropriate accelerometer counts that correspond to metabolic equivalent (MET) levels. In addition, to the extent that accelerometer cut points for intensity vary by body mass index, MVPA estimates may be systematically biased in overweight and obese adults. Ultimately, researchers wishing to measure physical activity may need to conduct population-specific validity studies to identify appropriate cut points of MVPA.

Critical to obtaining reliable accelerometry data is the need for compliance in wearing the monitor. We believe our high compliance rates resulted in representative estimates of moderate-to-vigorous-intensity activity. Accelerometer-measured MVPA estimates reported here compare favorably to national self-report surveys of physical activity levels among overweight and obese adults.[15]

In summary, this is one of the few methods papers that describe in detail the quality-control procedures used for the collection and processing of accelerometry data in a large, multi-center trial. Multi-center trials are complex for many reasons, including geographic dispersal of study staff. Thus, rigorous measurement training protocols and quality control assurances are imperative to ensure consistent data collection across sites. Too often, these procedures have received insufficient attention, making replication of results difficult and preventing the scientific community from understanding the assumptions involved in data cleaning. Detailed protocols, diligent equipment maintenance and diagnostics testing, and careful monitoring by the coordinating center, played a major role in our high compliance rates. Other researchers can duplicate our methods or revise as needed to meet their specific study needs.

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Table 1.

Compliance with accelerometry protocol[1] by minimum wear time

Minimum acceptable wear time	Compliance[1] (%)
	(n=1648)[2]
10 hours	82.0%
8 hours	92.5%
6 hours	96.6%

[1]Four days of accelerometry data including at least one weekend day

[2]Total number of study participants at screening

Table 2.

Distribution of cumulative daily wear time (hours) by day of data collection

Day	N	Mean	Median	Hours of wear time			
				< 6	6 – 7.94	8 – 9.94	≥ 10
				(%)	(%)	(%)	(%)
First	1648	10.2	11.0	15.9	10.9	11.8	61.5
Middle	8940	12.6	13.0	5.7	3.5	7.2	83.6
Last	1684	4.6	3.0	68.4	8.3	8.0	15.3

Table 3.

Minutes per day of moderate and vigorous physical activity (MVPA), N=1615

	Accelerometer[1]				Self Report		
	MVPA (Mins/Day)		MVPA (Mins/Day) from bouts[2]		MVPA (Mins/Day)		
	unadjusted	normalized to a 12-hr day	unadjusted	normalized to a 12-hr day	All Activities	Excluding household chores, gardening & yard work	
						With water related activities*	Without water related activities*
Mean (SD)	16.9(17.0)	17.1(17.2)	6.3(11.7)	6.3(12.5)	50.5(67.2)	20.8(26.8)	20.2(26.4)
Percentile							
25th	5.8	6.0	0.0	0.0	12.9	0.0	0.0
50th	12.0	12.4	0.0	0.0	31.4	12.1	11.4
75th	21.9	21.9	7.7	7.4	62.9	30.0	29.3
85th	30.4	30.4	14.0	13.9	90.0	42.9	41.1
95th	48.4	50.1	30.3	28.9	154.9	70.7	70.7

[1] computed as 1/7 of weighted weekly estimate based on 6-hour wearing threshold

[2] bouts are defined as periods of 10 or more consecutive minutes of MVPA

* e.g., swimming, water skiing