U.S. Population Profile of Time-Stamped Accelerometer Outputs: Impact of Wear Time

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Background: We examined the effects of wear time on a population profile of time-stamped accelerometer outputs using the 2005–2006 National Health and Nutrition Examination Survey (NHANES) data representing 3744 adults ≥ 20 years of age. Methods: Outputs included activity counts, steps, and time variables: nonwear (macro-determined), sedentary behavior (<100 activity counts/minute), and time in low (100–499 activity counts/minute), light (500–2019 activity counts/minute), and moderate-to-vigorous physical activity (MVPA; ≥2020 activity counts/minute) intensities. We describe mean values according to a 24-hour clock. Analysis was repeated in a reduced data set with only those who wore the accelerometer for 60 minutes within each considered hour of the day. Results: Between 12:00 and 17:00, U.S. adults spend approximately 31 minutes each hour in sedentary behaviors, and approximately 14 minutes, 10 minutes, and 2 minutes in low, light, and MVPA intensity activity, respectively. Removing the effect of nonwear time, sedentary behaviors are reduced in the morning hours and increase in the evening hours. Conclusion: At either end of the day, nonwear time appears to distort population estimates of all accelerometer time and physical activity volume indicators, but its effects are particularly clear on population estimates of time spent in sedentary behavior.

Keywords: walking, physical activity, pedometer, assessment, surveillance

Time is a limited resource and there are a finite number of minutes in a day. Accelerometers, like those adopted by the National Health and Nutrition Examination Survey (NHANES), have allowed us the opportunity to examine the day in defined time segments to classify time spent in various activity intensities. Using these objectively monitored data, Troiano et al.1 reported that less than 5% of monitored adults achieve public health guidelines (ie, at least 30 minutes/day of moderate-to-vigorous physical activity or MVPA). These data have also been used2 to describe time spent in sedentary behaviors.

Objective monitoring by accelerometry produces an abundance of time-stamped data that can be synthesized, transformed, and recoded to better understand the multifaceted and interrelated nature of time spent in a full range of human physical activity/inactivity behaviors. The notion of physical activity profiling (eg, examining a complete panel of physical activity/inactivity variables simultaneously) attempts to push past monopoint estimates of time spent only in MVPA or sedentary behaviors alone, for example.3 Conceptually, each individual contributes a unique profile that encompasses minute-by-minute daily records of activity counts, steps counts, and time in a spectrum of activity intensities including sedentary behaviors, MVPA, and nonwear time (which logically includes sleep in protocols focused on monitoring waking hours only). A population profile would then coalesce these independent individual values to produce a portrait of time-stamped accelerometer outputs, for example, mean values by each hour of a 24-hour day. The significance of this approach is that unique insights are likely to be garnered from concurrent examination of multiple outputs in the context of a time-segmented full day.

A challenge to interpreting accelerometer data has been variability in wear time. Matthews et al.2 have previously commented that accelerometer wearing time in the NHANES physical activity monitor (PAM) is equal to ~1.5 hours per day less than might be expected based on other national surveys. This implies that PAM participants are removing the accelerometer well before they go to bed, and/or putting it on well after they rise. On a population level, patterns of accelerometer outputs could be distorted by the number of individuals registering nonwear at any time point. For example, time in sedentary behavior (or any other output indicating time spent in activity intensity) during any hour of the day would be reduced when the majority of people are contributing data suggesting nonwear (eg, in the early morning hours); as more people put the device on, additional data would be collected producing an artifactual increase in sedentary behavior (or any other output indicating time spent in activity intensity). A way to test this is to consider data only from those individuals actually wearing the device on an hour-by-hour basis and determine if population

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patterns differ when compared with a full data set. Therefore, the purpose of this analysis is evaluate the effects of wear time on different accelerometer outputs by producing and exploring a population profile comprising a complete roster of time-stamped accelerometer outputs derived from the 2005–2006 NHANES PAM data, considering the full data set and one reduced to only those actually wearing the device within each hour of the day.

**Methods**

**NHANES 2005–2006**

NHANES is an on-going health and nutrition data surveillance program that is implemented under a complex, multistage probability design to be a nationally representative sample of the civilian, noninstitutionalized adults and children in the U.S. Data are collected year-round on approximately 5000 people and released in 2-year increments. NHANES collects data in an initial household interview and a follow-up visit to a mobile examination center (MEC) where medical, dental, physiological measurements, and laboratory tests are administered by highly trained personnel. The PAM component was added to NHANES in 2003, however, 2005–2006 is the first release of accelerometer-determined step data in addition to activity counts.

PAM participants ≥ 6 years of age were recruited during the MEC visit. Exclusion criteria included walking impairments or other limitations that prevented wearing an accelerometer according to protocol. Accelerometers (ActiGraph AM-7164; formerly distributed as CSA/MTI AM-7164; manufactured by ActiGraph, of Ft. Walton Beach, FL) were initialized to detect and record both activity counts and steps in 1 minute intervals (epochs). Participants were asked to wear the accelerometer (on the right hip using an elasticized fabric belt) for 7 days and only to remove them during any water activities (eg, swimming, showering, and bathing) and at bedtime. Participants were compensated $40 when accelerometers were returned by prepaid mail.

PAM data files are publically available and contain detailed activity count and step data, recorded minute-by-minute for each day worn by each participant. Before being posted on the NHANES website, the data are systematically screened by National Center for Health Statistics (NCHS) staff for outliers and unreasonable step or activity count values based on a combination of published literature and expert judgment. Unreliable data are flagged in the data set. The NCHS ethics review board approved the NHANES survey protocols, and informed consent was obtained for all participants. The Pennington Biomedical Research Center’s institutional review board approved of this analysis.

**Data Treatment**

This analysis is focused on NHANES adult participants ≥ 20 years of age with NCHS designated reliable accelerometer data. A SAS macro made available by the National Cancer Institute (NCI) (at http://riskfactor.cancer.gov/tools/nhanes_pam) was used to determine time worn in hours and minutes. A valid day was defined as ≥ 10 hours of wear (consistent with other analyses of NHANES PAM data) and only those participants with at least 1 valid day of monitoring were considered (n = 3744). We have previously demonstrated that mean accelerometer-determined steps/day in the NHANES PAM data set varies with valid days worn; the most active people tended to wear the accelerometer for more days than the least active people. Therefore, inclusion of everyone with at least 1 valid day ensures more conservative estimates. Other researchers have also included those with at least 1 valid day of monitoring in their analyses. Descriptive characteristics of this exact sample have been published previously and are not repeated here.

Each monitored day provided 1440 minutes of records for each individual. Each minute has data associated with it; thus there are no missing data. A data point might be 0, but this 0 could indicate no movement or time that the instrument was not worn. Minutes that were considered reflective of time when the instrument was not worn were identified by the SAS macro described above. Briefly, the macro was designed to interpret a minimal string of 60 consecutive zeros as a period of nonwear. Masse et al previously showed that the number of participants included in an analyses of accelerometer data were optimized when wear time was defined by 60 versus 20 minutes of continuous zeros. As stated previously, this nonwear time logically includes sleep time, since participants were specifically instructed to “remove the device at bedtime.” The remaining time (“wear time”) was classified on a minute-by-minute basis using activity count cut points previously used to analyze NHANES data: <100 activity counts/minute was used to define sedentary behaviors; 100–499 activity counts/minute indicated low intensity (previously called “inactive,” but renamed here for improved clarity); 500–2019 indicated light intensity; and 2020 activity counts/minute indicated MVPA. Minutes accumulated within each hour of the day were summed to produce hour-by-hour records and these were averaged across the study sample.

Concurrently recorded activity count and step data were available minute-by-minute. Activity counts and steps recorded each minute were independently summed over each hour of the day to produce an hour-by-hour record (averaged across the study sample). We examined both raw (uncensored) accelerometer-determined steps/day and censored steps/day, after censoring those steps taken at an intensity of <500 activity counts/minute. This censoring process has been previously rationalized and described and allows us to interpret these accelerometer-determined data on a scale that may be more congruent with the output of research quality pedometers.

**Analysis**

All analyses were performed employing procedures for sample survey data that are readily available in the SAS© System for Windows Version 9.1 (SAS Institute, Cary,
NC, 2004) to account for the complex sampling design of NHANES. All analyses also employed sample weights to account for oversampling and nonresponse to provide nationally representative results. We describe mean and SEM time spent in nonwear, sedentary behavior and each of the various physical activities throughout the time-stamped day, hour-by-hour, according to a 24-hour clock. Since, as stated above, on a population level, patterns displayed by each of the accelerometer outputs studied could be distorted by the number of individuals registering nonwear at any time point, we repeated these analyses in a reduced data set with only those individuals who actually wore the accelerometer for 60 minutes within each considered hour of the day. We also report the number of individuals in this reduced data set contributing data during each hour. Finally, we assembled activity counts, and uncensored and censored step data in a similar manner (using both the full and reduced data sets).

Results

Figure 1A displays population mean time (minutes in each hour of the 24-hour day) spent not wearing the accelerometer, being sedentary, and doing low, light, and MVPA intensity activities using the full data set. Nonwear time is high between 01:00 and 03:00 and drops quickly through the morning hours to stabilize around 12:00. At the same time, all other monitored behaviors (sedentary behaviors and time in the various activity intensities) are very low and increase during the morning hours. Between 12:00 and 17:00, U.S. adults spend approximately 31 minutes each hour in sedentary behaviors, and approximately 14 minutes, 10 minutes, and 2 minutes in low, light, and MVPA intensity activity, respectively. There is always some amount of detected nonwear throughout the day. Nonwear begins to increase after 17:00 to night time values. Time spent in the various activity intensities

![Figure 1](image_url)

**Figure 1** — A. Mean and SEM time (minutes in each hour of at 24-hour day) spent not wearing the ActiGraph (solid black), being sedentary (gray solid), and doing low intensity activity (dotted black), light intensity activity (dashed gray) and MVPA (dashed black) of 2005–2006 NHANES U.S. adults. B. Data from only those (hourly n noted by black squares) wearing the accelerometer for 60 minutes in each considered hour. Error bars represent SEM.
decreases at the same time, but a noticeable decrease in sedentary behaviors is delayed until approximately 19:00 hours.

Figure 1B displays the same data considering only those who wore the device for the full hour, hour-by-hour, as well as the count of PAM participants providing these data each hour. Although the overall pattern of time indicators is different from that displayed in Figure 1A (eg, sedentary behaviors are reduced in the morning hours and increase in the evening hours), between 12:00 and 17:00, U.S. adults spend similar amounts of time in sedentary behaviors, and low, light, and MVPA intensity activity (approximately 33, 15, 11, and 2 minutes, respectively). There is no time spent in nonwear at any point during the day since this was effectively removed by this specific data treatment. The number of PAM participants providing data each hour increases during the morning, reaches a plateau between 12:00 and 17:00 and decreases in the evening. There are always some individuals providing accelerometer data at all hours of the 24-hour day.

Figure 2A displays mean and SEM activity counts and uncensored and censored steps at each hour during the 24-hour day for the full data set. Similar patterns are observed throughout the day; however, there is a sharper decrease in the slope of the uncensored steps in the evening hours compared with the censored steps. Figure 2B shows activity counts, uncensored steps, and censored steps based on the reduced data set. Compared with the smoother pattern portrayed in Figure 2A, Figure 2B indicates relatively more activity counts/steps taken around 07:00 (which constitutes the zenith point) with decreasing hourly totals thereafter. Again, the patterns of all the volume indicators (activity counts, uncensored and censored steps/day) reflect each other throughout the day.

Figure 2 — A. Average and SEM activity counts (dotted, left axis), and uncensored (solid, right axis) and censored steps (dashed, right axis) at each hour of the 24-hour day of 2005–2006 NHANES U.S. adults. B. Only those wearing the accelerometer for 60 minutes in each considered hour. Error bars represent SEM.
day, but again a more precipitous slope is apparent for the uncensored steps into the evening hours.

**Discussion**

Acknowledging the potential influence of nonwear time, we produced a population profile comprising a full roster of time-stamped accelerometer outputs using the 2005–2006 NHANES PAM data. Even though we, like others, considered only valid days in our analysis (ie, defined as having ≥10 hours of wear\(^1\)), the influence of nonwear time is still apparent even within the confines of this data constraint. Specifically, at either end of the day (through the morning and evening hours), nonwear time appears to distort population estimates of all accelerometer time and physical activity volume indicators, but its effects are particularly clear on population estimates of time spent in sedentary behavior.

Although we cannot be absolutely sure about what types or intensities of activity are missed during this unmonitored time, it is more logical that these activities represent undetected sedentary behaviors. To be clear, it is more difficult to believe that individuals are removing this accelerometer (known to participants during protocol instruction to detect physical activity) before taking an evening run than they are removing it before settling into an evening of television watching. In support of this, sedentary behaviors increased over the evening in the reduced data set (compared with the full data set) and all of the other intensities of activity, including low intensity activity, decreased over the evening in both data sets. Matthews et al\(^2\) determined that 54.9% of the monitored day is spent in sedentary behavior, and used this value to predict additional time (0.8 hours) spent in sedentary behaviors that was missed as a result of unmonitored time. Even more sedentary behaviors may be lost to detection, however, as it appears that sedentary behaviors actually increase during the evening hours (at least in those who continue to monitor their behaviors; we can only speculate on those who removed it). The apparent decrease in sedentary behaviors in the full data set is an artifact of the increasing amount of nonwear time (discerned from Figure 1A) produced by increasingly more individuals removing the device (discerned from Figure 1B).

We must emphasize that nonwear was identified during postprocessing using an NCI-supplied SAS macro that makes inferences about nonwear based on accumulation patterns of 60 consecutive 0 data points. As we note above, Masse et al\(^3\) determined that defining nonwear based on minimally 60 minutes of consecutive zeros was less restrictive (in terms of optimizing sample size) than 20 minutes. However, they also showed that this heuristic produced more minutes in inactivity and overall had the greatest impact on minutes in inactivity (defined as 0 activity counts) compared with time spent in either light activity (defined as lower than MVPA) or MVPA (definitions of inactivity and light activity obtained by personal communication with L.C. Masse). We therefore would also expect that using the more restrictive definition for the present analysis would have its greatest impact on conclusions about time spent in sedentary behaviors.

Since the NHANES, like many others, instructs participants to “remove the device at bedtime,” any amount of identified nonwear time logically includes sleep. Unfortunately, PAM participants do not record when they go to sleep or when they wake up, so we are unable to directly remove recorded sleep time from nonwear time. Although the 2005–2006 NHANES did ask (for the first time) a general sleep question (“How much sleep do you usually get at night on weekdays or workdays?”) as part of its broader health survey, our attempts to use these self-reported generalized behavior data to adjust nonwear time for sleep were less than satisfactory (eg, producing negative values) and prudence dictated that we abandon this approach (data not shown). It appears that 24-hour monitoring may be necessary to assess participation in the full spectrum of human movement behaviors, but especially so if we are to accurately capture a true representation of time spent in sedentary behaviors. As Schmidt et al\(^4\) has previously pointed out, error related to wear time is ultimately dependent on participants’ activity level when not wearing a motion sensor. If those people who wear it for a short time also do little physical activity when it is off, then the magnitude of error is minimal, at least in terms of determining who is physically active (eg, taking more steps). Unfortunately, if the researcher is expressly interested in assessing time spent in sedentary behaviors, the error related to wear time is potentially much greater.

The sharper downward evening slope of the uncensored steps compared with the censored steps (apparent in both the full and reduced data sets) suggests that the impact of the censoring process (ie, removing steps of very low intensity) is more apparent later in the day. Specifically, earlier in the evening more people who are monitored take relatively more low intensity steps. However, the discrepancy between uncensored and censored steps decreases throughout the evening suggesting that, increasingly, those few steps that are taken are purposeful. Stated another way, there is decreasing amounts of “puttering” as the evening draws to an end.

The usual limitations of these data must be acknowledged, including the fact that as a waist-mounted motion sensor, the ActiGraph model used in the NHANES PAM is most sensitive to lower body movements and specifically ambulatory behaviors. It therefore misses complex movements that include upper body actions, load carrying, and any activities performed in water (where participants were necessarily asked to remove the device). Although there are a number of alternative cut point values available for defining different intensities of activity, we selected those cut points that have previously been used to evaluate the NHANES data\(^1,2,4\). Obviously, reducing the data set to only those who are actually wearing the device will provide inflated population estimates of each of the physical activity variables considered herein. For example, steps accumulated in any hour of the day peak around 700 in Figure 2A but
around 800 in Figure 2B. However, the purpose of this analysis was to explore patterns of data accumulation over the course of the day uninfluenced by nonwear. Findings retrieved from analyses of the reduced data set are ultimately only representative of those who actually wore the device during each considered hour, and the number of individuals fitting this description varies systematically throughout the day (fewer at night and the most during the day). Unfortunately, NHANES does not provide sufficient information to evaluate regional effects or the effects of seasonality, daylight savings time, or shift work. In summary, using the 2005–2006 NHANES PAM data we demonstrate that a population profile comprising a full roster of time-stamped accelerometer outputs is influenced by wear time over the course of a 24-hour day. As people remove the device, real data are lost, however, it appears that time in sedentary behaviors is most likely to be misclassified compared with all other indicators of physical activity intensity and volume. It will be difficult to determine “how much sedentary behavior is too much,” and differentiate it from the well-known healthy effects of sleep, if we are unable to accurately capture this unique behavior by objective means.

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References