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Self-reported vs. Device Measured Physical Activity and Sedentary Behavior

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B.S.
University of South Carolina
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Abstract

Self-reported vs. Device Measured Physical Activity and Sedentary Behavior

By Kristy Lagarde

Background: Accurate measurement of physical activity and sedentary behavior is difficult, and factors relating to agreement between self-report and objective measures are not well understood. This study assessed agreement between self-reported and accelerometer measured physical activity and sedentary behavior over a seven-day period to identify predictors of accurate self-report.

Methods: Self-reported and accelerometer (Actigraph GT3X) measured physical activity was recorded over seven days between 2015 and 2016 among 751 participants of the Cancer Prevention Study (CPS)-3 Activity Validation study from the CPS-3 cohort. Agreement for sedentary behavior, and light, moderate and vigorous intensity physical activity was calculated for each measurement separately as the difference in minutes per day reported in the diary *vs.* recorded on the Actigraph device. Demographic and lifestyle factors were investigated as predictors of accurate reporting using a multivariable marginal mixed linear model.

Results: Sedentary behavior and moderate intensity physical activity were under reported by the diary compared to the device, while light intensity and vigorous intensity physical activity were over reported by the diary compared to the device. Region and total annual moderate and vigorous physical activity (MVPA) were significant predictors of accurate reporting of sedentary behavior. Region and body mass index (BMI) were significant predictors of accurate reporting of light intensity behavior. Sex, race, and education were significant predictors of accurate reporting of moderate intensity physical activity. Total annual MVPA was a significant predictor of accurate reporting of vigorous intensity physical activity.

Conclusion: No major differences existed between sex, race or age for agreement in reporting of sedentary behavior, light, and vigorous intensity physical activity. Level of physical activity completed is an important factor in accurate reporting of both sedentary behavior and vigorous intensity physical activity. Region should be considered in evaluating the agreement of sedentary behavior and light intensity physical activity. Education is also an important factor in accurate reporting of moderate intensity physical activity.

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Table of Contents

Background

Physical activity, measured *via* either self-report or accelerometer, has been associated with a reduced risk of all-cause mortality, cardiovascular disease mortality, and cancer. An analysis of 2003-2006 data collected in the National Health and Nutrition Examination Survey (NHANES) identified that participants who completed at least 3.1 total minutes of moderate to vigorous physical activity (MVPA) per day as measured by an accelerometer were at reduced risk of all-cause mortality, compared to those who completed less than 3.1 minutes of MVPA per day[1]. An additional analysis of NHANES data determined that lower all-cause mortality and cardiovascular mortality were found among participants with higher accelerometer- measured MVPA as well as participants with higher self-reported MVPA[2] . Several recent meta-analyses and a pooled analysis from 12 prospective US and European cohorts found self-reported leisure-time physical activity to be associated with a reduced risk of 13 cancer types including three of the most common cancers in the US – breast, colon, and lung cancers[3-6].

While the preventative benefits of physical activity in terms of cancer and other chronic diseases is known and accepted, physical inactivity remains common, especially in the United States. The CDC and American Cancer Society recommend adults engage in at least 150 minutes of moderate or 75 minutes of vigorous activity per week[7, 8]. Despite these recommendations, only 49% of American adults meet physical activity guidelines for aerobic activity, and this proportion differs by race/ethnicity and sex. Specifically, White individuals complete more physical activity than Black or Hispanic individuals, and men are more physically active than women[9]. To understand potential health benefits, it is imperative that physical activity be measured accurately.

Self-reported physical activity

Self-report is the most common tool for measurement of physical activity in large-scale epidemiologic research studies, as this is the most inexpensive and convenient method[10]. Many validation studies of self-reported physical activity compared with objectively measured physical activity have found that while data may be qualitatively consistent between measures, self-report tends to overestimate physical activity and underestimate sedentary time when compared with an objective measure[11]. Self-reported physical activity is often influenced by cultural factors and social desirability of reporting particular behaviors[12]. It is possible that the effect of social desirability on physical activity reporting differs by demographic factors, such as age, sex, or race. Because self-report is not the most reliable measure of physical activity, validation of studies utilizing self-reported physical activity is essential.

Accelerometry

Accelerometry is a more accurate method of measuring most types of physical activity, but is different from self-report in that it captures actual movement instead of a behavior (e.g. movement during an hour of tennis vs. reporting an hour of tennis played). Tri-axial accelerometers and the Actigraph GT3X device in particular have been validated in a variety of epidemiologic studies[13-15]. While not as precise as doubly labeled water, the gold standard in physical activity measurement, accelerometry provides a balance between accuracy and cost-effectiveness in physical activity measurement, and therefore is the most common method of physical activity measurement validation[11].

Self-reported vs. Accelerometer measured physical activity

Recent literature in physical activity measurement has begun to focus on demographic and lifestyle influences of agreement between self-report and objective measures of physical activity, but at present consistent effects of demographic factors across studies have not been observed.

Agreement between self-reported and objectively-measured physical activity has been proven to differ by sex in several studies, although the pattern of over-reporting and under-reporting by sex is still not fully understood. A systematic review of studies comparing self-reported physical activity with various methods of objective measurement determined that women overestimate their physical activity by self-report more than men, when compared to accelerometer measured physical activity[11]. However, a cross-sectional study of agreement between self-reported and accelerometer measured physical activity in six countries found that women over reported moderate to vigorous physical activity when compared to men, yet under reported total physical activity when compared to men[16]. Yet another comparison of self-reported to accelerometer measured physical activity determined that men were more likely to over report time in moderate physical activity and total physical activity than women[17].

In studies with samples of only overweight and obese individuals, a systematic review identified self-reported physical activity was overestimated in all studies except those that used doubly-labeled water as an objective measure of physical activity, suggesting that overweight and obese individuals overestimate their physical activity by self-report when compared with accelerometry. However, in studies with samples including all weight categories, no clear association between weight status and quality of reporting was present[11]. Other studies have found that individuals with higher BMI tend

to under report physical activity, while individuals with lower BMI tend to over report physical activity[16, 18].

A preliminary analysis of NHANES data identified that individuals of higher education level were more likely to accurately report their physical activity when compared with the objective measure of VO2 max [19]. This analysis focused only on correlation of self-report to objective measure and therefore did not make conclusions regarding whether less education individuals were more likely to over or under report physical activity. An additional study identified those who over reported their physical activity compared to heart-rate monitored physical activity were more likely to have spent less time in full-time education [18], suggesting less educated individuals over report physical activity.

Age has previously been evaluated as a potential correlate of agreement between self-reported and objectively measured physical activity, but to date the literature is not consistent in its findings. Studies have found that over reporting is most extreme among adults younger than 35 years [17], while other studies have found that disagreement between self-reported and accelerometer measured physical activity increases with increasing age [16], and others have found no effect of age on correlation between self-reported and accelerometer measured physical activity[20].

Cerin and colleagues considered geographic location in their recent analysis of correlates of agreement between self-reported and accelerometer measured physical activity in eight cities from six countries. They found that differences between the two measures of total physical activity and sedentary behavior varied by city. Seattle and Baltimore were the two US cities considered in this analysis, and while both overestimated physical activity and underestimated sedentary behavior by self-report, the two cities

showed similar agreement between self-report and accelerometry when compared to the other six cities[16]. Current literature on agreement between physical activity self-report and objective measurement is lacking in consideration of geographic location, especially within the United States. It is expected that self-report of physical activity could differ by geographic region, due to the difference in level of physical activity and social desirability of physical activity in different regions[21].

Overall level of physical activity is a potential correlate of agreement between self-reported and objectively measured physical activity. Leisure-time physical activity is much easier to measure *via* self-report than occupational or transportation-related physical activity[22], likely because leisure-time physical activity is more intentional. Similarly, those who engage in intentional physical activity regularly may be better at accurately reporting that activity than an individual who is not intentionally or regularly active. Therefore, this topic requires further exploration.

The current literature does not explore the potential association between race and ethnicity and agreement of self-reported and objectively measured physical activity. It seems plausible that race would affect agreement between objective and self-reported measures of physical activity as physical activity levels in the US differ by race[21]. Further research is needed to establish whether physical activity reporting differ by race and ethnicity.

A few studies have assessed quality of self-reported sedentary behavior, and found that sedentary behavior is consistently underestimated by self-report, when compared with an objective measurement[23, 24]. Further exploration is needed into demographic factors that may influence quality of self-reported sedentary behavior.

Purpose

Gaps in literature on agreement of self-reported and accelerometer-measured physical activity by sociodemographic factors are evident. The CPS-3 physical activity validation study is uniquely positioned to evaluate several of these potential covariates of quality of self-reporting in a large sample (n=750) from a diverse US cohort. The purpose of this study is to compare the CPS-3 physical activity self-report seven-day diary to accelerometer measured physical activity to evaluate the quality of self-reported physical activity. Quality of self-report will be evaluated by sex, BMI, education, age, geographic location, overall level of physical activity, and race.

Methods

Participant Selection

The CPS-3 Activity Validation Sub-Study is a nested cohort study sampled from the nationwide CPS-3 cohort of approximately 300,000 men and women ages 30-65 with no history of cancer (not including basal or squamous cell skin cancer) at enrollment (2006-2013). The validation study aims to assess the validity and reliability of the physical activity, sedentary behavior, sleep, light exposure, and work habit questions assessed in CPS-3.

Ten thousand randomly selected CPS-3 participants stratified by sex and race/ethnicity were invited by mail to pre-register online to participate in the validation study after providing an electronic consent. Among the approximately 1,800 pre-registered participants, the first 300 White women, 150 White men, 150 Hispanic men and women, and 150 African American men and women who completed the routine CPS-3 follow-up survey were "activated" into the validation study. Activated participants were then sent a 4-page activity survey that included questions on a participant's typical 24-hour weekday and weekend day, different individual types of physical activity, walking pace, sleep quality, work, and light exposures. In total, 751 participants were enrolled to participate in the validation study by successfully completing the activity survey (144 African American, 113 Hispanic, 203 White men, 291 White women).

After completing the activity survey, four times between July 2015 and November 2016 (roughly once per quarter over the period of one year based on the individual start date for each participant), participants completed 7-days of data collection. During each quarter, the participant completed a 7-day diary where they recorded light exposure, sleep

and work habits, and physical activity behaviors. Two of the four quarters (roughly half of participants were assigned to quarters 1 and 3 and the others assigned quarters 2 and 4), the participants also wore monitors to measure physical activity. In total, 698 participants (of the 751 active participants) wore the Actigraph GT3X accelerometer device with valid data generated during one of the first two quarters of data collection (341 in quarter one and 357 in quarter two). This subset of 698 participants and their corresponding data were used for analysis (134 African American, 108 Hispanic, 456 White).

Diary-reported Physical Activity

Information on self-reported physical activity was collected at each quarter using a 7-day physical activity diary consisting of a grid divided into 24 rows to represent each hour of the day and 4 columns to represent every 15-minute interval within each hour. The physical activity grid was completed on seven consecutive days. Participants were instructed to record one value ranging from 1 to 9 in each box of the grid corresponding to the type and intensity of the physical activity that dominated the majority of that fifteen-minute interval (see supplementary Table 1: Physical activity code definitions). These data representing 15-minute bouts of physical activity during the participants waking hours were then categorized into sleep (code 1), sedentary (code 2), low-intensity (codes 3-4), moderate-intensity (codes 5-6), and vigorous intensity physical activity (codes 7-9) (see supplementary Table 1). These intensity categories were used to calculate the total minutes per day that each participant engaged in sedentary, low, moderate, and vigorous physical activity by summing the number of 15-minute grid boxes categorized to each intensity of physical activity, and multiplying that total by 15 minutes. Then, total hours per day in each intensity of physical activity was calculated by dividing the total minutes by 60. If the

total number of waking hours for a given day recorded in the grid was less than 10 hours, that day was excluded from this analysis due to insufficient data.

Device-measured Physical Activity

Concurrent with the physical activity diary for two of the four quarters, participants wore an Actigraph GT3X accelerometer (either during quarters 1 and 3 or quarters 2 and 4). Participants were advised to wear the accelerometer during all waking hours in which they were not engaged in a water activity (i.e. showering or swimming) for the same week that they completed the diary. Information regarding total wear time of the device for each participant was captured in two ways. First, participants self-reported the time they put the monitor on and time they removed it each day in the diary. Second, wear time was calculated by running raw Actigraph device data through the validated and widely-accepted Sojourn algorithm [25] in an R script using Rstudio statistical software [26]. Wear time calculated based on the device data using the Sojourn algorithm was used as the "true" wear time. However, self-reported wear time from the diary was compared to the device-generated wear time to assess concordance, and when the two measures differed, both the device and diary data were further evaluated to ensure reliability. If either the self-reported or device-recorded wear time variable was less than 10 hours, that day was excluded from this analysis due to insufficient data. The Sojourn algorithm was also used to generate total minutes per day that the device recorded the participant engaging in sedentary, low-intensity, moderate-intensity, and vigorous intensity physical activity. Total hours per day in each intensity was calculated by dividing the total minutes per day by 60.

Outcome Classification

The absolute difference in diary-reported and Actigraph-measured minutes per day in each intensity of physical activity was calculated by subtracting the device-recorded measure from the self-reported diary measure (Δ=diary-device). Negative values for the absolute difference indicated the participant under-reported their time spent in that intensity of physical activity in the diary compared to the device, and positive values indicated an over-estimation in the diary.

Demographic and Lifestyle Factors

Demographic and lifestyle data for the participants of the CPS-3 validation study were compiled from one of three sources: (1) the validation activity survey, (2) the 2015 routine follow-up CPS-3 survey, or (3) the CPS-3 baseline survey (administered between 2006-2013 at the time of initial enrollment in CPS-3 cohort). Factors of interest include: age (10-year age categories), body mass index (BMI, kg/m^2; normal weight, overweight, obese), sex (male, female), current smoking status (smoker, non-smoker), education (less than college education, college education or greater), race (non-Hispanic White, Black, Hispanic), geographic region (Northeast, Midwest, South, West), and total MVPA per week (below MVPA guidelines, 1-2x guidelines, 2x-4x guidelines, >4x guidelines).

BMI was classified using WHO guidelines, defining individuals as normal weight if their BMI was between 18.5 and 25 kg/m^2, overweight if their BMI was between 25 and 30 kg/m^2, and obese if their BMI was greater than 30 kg/m^2. Region was categorized based on the state listed as the current state of residence in the Activity Validation shipment report, using the four regional divisions as classified by the Census Bureau (See supplementary table 2: Region categorization). Total MVPA completed in the year that the validation study was conducted was ascertained using the validation post-survey data

which captured how active the participant reported being over the previous year. The ACS guidelines of 150 minutes of moderate or 75 minutes of vigorous activity per week translates to approximately 7.5 MET-hours/week and was used to define the total MVPA categories of inactive and active below guidelines, 1 - 2x guidelines, 2 - 4x guidelines, and >4x guidelines.

Statistical Analysis

Correlations between self-report and device measures

Correlations between self-reported/diary and device-recorded measures of physical activity were compared by calculating the Pearson correlation coefficients (Pearson r), as data were normally distributed. T-tests were used to compare differences in self-reported and device-recorded measures of physical activity among two-level covariates, and an ANOVA test and a Tukey's multiple comparisons test were used to assess differences in self-reported and device-recorded physical activity among multi-level covariates.

Absolute differences in self-report and device measures

Significant demographic and lifestyle predictors of quality of reported physical activity were identified using a marginal mixed linear model (MIXED) in SAS software [27] to conduct stepwise linear regression, regressing the quality of report variables onto the potential predictors, while adjusting for the repeated and unbalanced measures of days of data per participant. A compound symmetric correlation matrix was utilized to account for the correlation of days within each participant, since there was no reason to believe any two days would be more correlated than two others among participants, but repeated measures were collected for each participant and thus are likely correlated.

Sensitivity Analyses

Sensitivity analyses were conducted by restricting the analysis to participants (1) with all 7 days of device and diary data and (2) who reported on their validation study activity post-survey that they did not engage in non-ambulatory physical activity in the previous year (i.e. no biking or swimming). Additional sensitivity analyses restricted the analysis to days contributed by participants in which the participant (3) completed more than 0 minutes reported in the intensity of physical activity being modeled, and (4) had less than 10% discrepancy in the device recorded and self-reported device wear time variables.

Results

The 698 participants included in this analysis contributed a total of 4,598 days of data (observations), with an average of 6.59 days (min=1, max=7, std dev= 0.95) of data per participant. Each day of data had an average of 15.50 (std dev=1.36) hours of recorded device data and an average of 15.71 (standard deviation=1.07 hours) hours of self-reported diary data. Most participants were White, female, normal BMI, and between the ages of 50 and 59 years old. Most were from the Southern U.S., were non-smokers, and had a college education or greater. A large proportion of participants reported being physically active at four times or greater the ACS guidelines of 7.5 MET-hours per week (Table 1).

Total device wear time was over-estimated by the diary when compared to the device, with a mean total minutes of physical activity reported in the diary of 942.60 minutes (sd=64.2 minutes), and a mean total minutes of physical activity recorded by the device of 930.0 minutes (sd=81.6 minutes). When examining each intensity of PA separately, sedentary behavior and moderate intensity physical activity were under-estimated whereas light intensity physical activity was over-estimated in the diary compared to the device. Vigorous intensity physical activity was reported accurately, with a slight over-estimation in the diary when compared with the Actigraph device (Table 2).

Correlations between diary and Actigraph measures of physical activity

Total device wear time

Correlations between diary and Actigraph measures of total device wear time, sedentary behavior, light intensity, moderate intensity, and vigorous intensity physical activity by demographic and lifestyle characteristics are shown in Tables 3 and 4. The relative agreement between diary and Actigraph measures of total device wear differed by

category of smoking status (mean difference: smokers =47.46 minutes, nonsmokers =9.91 minutes; p =0.0149), BMI (mean difference: normal weight=2.03 minutes, overweight =14.53 minutes, obese =19.87 minutes; p<0.0001), and region of residence (mean difference: Northeast: =13.04 minutes, Midwest =18.5 minutes, South =6.63 minutes, West =2.53 minutes; p=0.0008). Non-smokers, participants with normal BMI, and participants from the West were more accurate in reporting their total physical activity, however all did slightly over-estimate the amount of total device wear time.

Sedentary behavior and light intensity physical activity

For both sedentary behavior and light intensity physical activity, the relative agreement between diary and Actigraph measures differed significantly by age, BMI, and region (Tables 3 and 4). While all BMI classes under-reported sitting time when compared with Actigraph measure, overweight participants were most accurate in reporting sitting time compared to normal weight or obese individuals, who both under-reported by at least 24 minutes (mean difference: normal BMI=-24.30 minutes, overweight=-6.89 minutes obese=-32.75 minutes; p=0.0004). Obese participants were least accurate in reporting light intensity physical activity, over-reporting by 30 minutes more than either normal or overweight participants (mean difference: normal=63.15 minutes, overweight=55.13 minutes, obese=92.63 minutes; p<0.0001). Participants from the Northeast, Midwest, and South all under-estimated sitting time, while participants from the West over-estimated sitting time (mean difference: Northeast= -34.87 minutes, Midwest= -30.10 minutes, South= -52.17 minutes, West= 73.37 minutes; p<0.0001). Conversely, participants from the West under-reported light intensity physical activity, while participants from all other regions over reported light intensity physical activity (mean difference: Northeast=86.36

minutes, Midwest=89.15 minutes, South=91.44 minutes, West= -36.38 minutes; p=<0.0001). In terms of age, older participants were more accurate in reporting sedentary behavior and light intensity physical activity than younger age groups. While all age groups under-estimated sedentary behavior, the 60+ age group under-estimated by the least (mean difference: 30-39 years= -24.72 minutes, 40-49 years= -29.27 minutes, 50-59 years= -21.73 minutes, 60+ years= -8.78 minutes; p=0.0332). In contrast, all age groups over-estimated light intensity physical activity, with the 60+ age group over-estimating by the least (mean difference: 30-39 years= 76.31 minutes, 40-49 years= 75.13 minutes, 50-59 years= 72.05 minutes, 60+ years= 50.70 minutes; p=0.0007). There were no other differences in the relative agreement between diary and device stratified by any other factors (Table 3 and 4).

Moderate intensity physical activity

Moderate intensity physical activity was consistently under-estimated among all covariate groups. The relative agreement between diary and Actigraph measures of moderate intensity physical activity differed by sex, age, and education, but not by any other factors examined (Tables 3 and 4). For example, men were more accurate in reporting moderate intensity physical activity than women (mean difference: men= -32.50 minutes, women=-39.26 minutes; p<0.0001). Individuals with a college education or greater were more accurate in reporting moderate intensity physical activity than those with less than a college education (mean difference: college education or greater= -35.05 minutes, less than college education= -40.83 minutes; p=0.0034). Individuals in the 60+ years age group were again most accurate in reporting moderate intensity physical activity (mean difference: 30-39 years=-33.36 minutes, 40-49 years=-34.93 minutes, 50-59 minutes= -42.33 minutes,

60+ years=-32.79 minutes; p<0.0001). While statistically significant differences in relative agreement existed among covariates of sex, education, and age, in general, differences were not large within these covariate levels. No other differences in the relative agreement by other demographic or lifestyle characteristics were observed.

Vigorous intensity physical activity

The relative agreement between diary and device measures of vigorous intensity physical activity differed significantly by sex, region (Table 3), and total moderate and vigorous physical activity (Table 4). Women on average under-reported vigorous intensity physical activity, while men on average over-reported vigorous intensity physical activity (mean difference: women=-0.09 minutes, men=1.67 minutes; p<0.0001). Participants from the Northeast and South generally over-reported vigorous intensity physical activity, while participants from the Midwest and West generally under-reported vigorous intensity physical activity; however, no group over or under-reported vigorous physical activity by more than 3 minutes (mean difference: Northeast=0.68 minutes, Midwest= -1.52 minutes, South= 2.97 minutes, West= -0.08 minutes; p=0.0064). Participants who were active at greater than four times the ACS physical activity guidelines over-reported vigorous intensity physical activity, while participants in all less active groups under-reported vigorous intensity physical activity (mean difference: >4x guidelines=7.26 minutes, 2-4x guidelines= -4.12 minutes, 1-2x guidelines= -4.40 minutes, inactive/active below guidelines= -4.71 minutes; p<0.0001). No other differences in the relative agreement by other factors were observed.

Absolute agreement of diary and Actigraph measures of physical activity

Sedentary behavior

Total physical activity, and region of residence were statistically significant predictors of absolute difference in diary and Actigraph measures of sedentary behavior (Table 5 and Figure 1). Physical inactivity or activity below ACS guidelines over the previous year was associated with over-reporting sedentary behavior by 36.90 minutes, when compared with those who were active at four times or more the ACS guidelines (Estimate: 2-4x guidelines= 13.21 minutes, 1-2x guidelines= 8.75 minutes, inactive, active below guidelines= 34.08minutes; p-value: 2-4x guidelines=0.2299, 1-2x guidelines=0.5346, inactive, active below guidelines=0.0153). Region of residence of Northeast, Midwest, and South were all associated with under-reporting sedentary behavior by greater than 100 minutes, when compared with participants who reside in the West (Estimate: Northeast= -109.56 minutes, Midwest= -104.23 minutes, South= -130.62 minutes; p-value: Northeast <0.0001, Midwest <0.0001, South <0.0001). Being woman, Hispanic, and from the Northeast, Midwest, and South were associated with under-reporting sedentary behavior by self-report. Being African American, older, inactive or active below guidelines, active at 1-2x guidelines, and active at 2-4x guidelines were associated with over-reporting sedentary behavior by self-report.

Light intensity physical activity

BMI, and region of residence were statistically significant predictors of absolute difference in diary and Actigraph measures of light intensity physical activity (Table 6 and Figure 2). Obese participants on average over-reported light intensity physical activity by 25 minutes (p =0.0323) when compared to participants of normal BMI. Participants from the Northeast, Midwest, and South on average over-reported physical by 124.25 minutes (p<0.0001), 124.90 minutes (p<0.0001), 129.69 minutes (p<0.0001), respectively, when

compared with participants from the West. Being African American, or older was associated with under-reporting light intensity physical activity, while being female, and Hispanic were associated with over-reporting light intensity physical activity; however, these associations were not statistically significant.

Moderate intensity physical activity

Sex, race, and education, were statistically significant predictors of absolute difference in diary and Actigraph measures of moderate intensity physical activity. Women on average under-estimated moderate intensity physical activity by 7.26 minutes (p=0.005) when compared with male participants (Table 7 and Figure 3). African American and Hispanic participants both over-estimated moderate intensity physical activity compared to White participants, with African Americans over-estimating by an average of 12.13 minutes (p=0.0644) and Hispanic participants over-estimating by an average of 13.70 minutes (p=0.0288). Participants with a college education or greater on average over-estimated moderate intensity physical activity by 9.74 minutes (p=0.0086). The effect of education on accuracy of reporting moderate physical activity differed by race (Table 8). African Americans with a college education or greater over-estimated by an average of only 2.50 minutes, and Hispanics with a college education or greater under-estimated moderate intensity physical activity by 1.98 minutes, when compared with Whites with a college education or greater. Age was not significantly associated with mis-reporting moderate intensity physical activity.

Vigorous intensity physical activity

Total physical activity was a statistically significant predictor of absolute difference in diary and Actigraph measures of vigorous intensity physical activity (Table 9 and Figure

4). Participants who were classified as inactive, or active below guidelines under-reported vigorous intensity physical activity by an average of 12.12 minutes ($p<0.0001$), participants who were classified as active at one to two times guidelines under-reported vigorous intensity physical activity by an average of 11.82 minutes ($p<0.0001$), and participants who were classified as active two to four times guidelines under-reported vigorous intensity physical activity by an average of 11.41 minutes ($p<0.0001$). No other predictors were significantly associated with mis-reporting of vigorous intensity physical activity.

Sensitivity analyses

Sensitivity analyses were conducted to ensure the validity of this analysis. Results were consistent among a subset of individuals who completed all seven days of their activity diary and successfully wore the Actigraph device for all seven days, however the interaction between race and education was no longer significant, nor was the effect of race on its own in the model for moderate intensity physical activity. This suggests that education is most important in predicting quality of self-reported moderate intensity physical activity. A second sensitivity analysis on a subset of days of data in which the self-reported device wear time differed from the device-measured wear time by ten percent or less also found the interaction term of race by education to be non-significant in the moderate intensity model. A third sensitivity analysis was limited to individuals who completed greater than zero minutes of moderate or vigorous intensity physical activity again found results consistent with the results of the analysis cohort. No meaningful differences between sensitivity analyses and the general analysis population were observed.

Discussion

Our study demonstrated moderate relative agreement between diary and device measures of sedentary behavior, light intensity, moderate intensity, and vigorous intensity physical activity, similar to the level of agreement observed in other studies [16, 17]. We found no meaningful differences in agreement of self-reported *versus* device-measured sedentary behavior, light intensity, moderate intensity, or vigorous intensity physical activity by sex, race, or age, thus, the CPS-3 Activity Validation Cohort data will not need adjustment by these factors.

Significant differences in agreement between diary and device measures of sedentary behavior by total annual MVPA were observed in our cohort. The most significant difference was among those who were classified as inactive, or active below physical activity guidelines compared to those who were classified as active at or above 4 times the ACS physical activity guidelines. We found that those who are most active under-report sedentary behavior the most. This seems counter-intuitive, as those who are least active may feel pressure to report lower estimates of sedentary behavior, a social desirability bias described in previous literature[12]. However, those who spend more time in sedentary behavior could be acutely aware that they do so, and therefore more likely to accurately report it, while those who spend a smaller proportion of their day sitting may have more trouble estimating that time.

Significant differences in agreement between diary and device measures of sedentary behavior and light intensity physical activity were observed by region. In our cohort, participants from the Northeast, Midwest, and South reported sedentary behavior differently than participants from the West. A possible explanation of this could be regional

differences in physical activity and sedentary behavior norms[28, 29]. In general, the West is more active than the Northeast, Midwest, or South, and the Midwest and South are the most sedentary [21]. It is possible the regional differences in reported physical activity in our study may account for the effect of the differences in physical activity and sedentary behavior by region. Another explanation could be that participants from the South feel more inclined to over-report physical activity and under-report sedentary behavior because they know that their level of activity and sedentary behavior does not meet recommended guidelines. Participants from the West, who likely are more active, may feel less inclined to mis-report physical activity and sedentary behavior for social desirability.

BMI status was significantly associated with differences in agreement of diary and device measures of light intensity physical activity, with obese participants being most likely to over-report light intensity physical activity. Cerin and colleagues found that participants with lower BMI over-report moderate and vigorous physical activity while participants with higher BMI under-report moderate and vigorous physical activity[16]. Our study separately considered light, moderate, and vigorous intensity physical activity, and while not statistically significant, our results did show obese participants under-reported both moderate and vigorous physical activity. When considered separately, obese participants over-report light intensity physical activity.

Analyses of differences in agreement of diary and device measures of moderate intensity physical activity resulted in significant differences by sex; this was the only level of physical activity or sedentary behavior for which differences by sex were significant. Additionally, the interaction between race and education level was found to be significant, with less educated individuals of non-White race/ethnicity over-reporting moderate

intensity physical activity most. This may be due to the possibility that moderate physical activity is not well understood and therefore often misclassified as light or vigorous intensity physical activity, both of which were over-estimated *via* diary in our cohort.

Significant differences between diary and device measures of vigorous intensity physical activity existed only by total annual MVPA. As expected, participants' total level of MVPA was most important in accurately reporting vigorous intensity physical activity. Vigorous intensity physical activity is typically intentional, and therefore those who engage in vigorous intensity physical activity are aware that they do, and report this activity most accurately. While adjustments need not be made by activity status, it is useful to know the most physically active individuals can be expected to report their vigorous physical activity best.

This study had several strengths. First, this analyses was conducted among a large, diverse sample, oversampled for race and sex to ensure representativeness. Second, sedentary behavior and each intensity of physical activity were considered independently, which allowed significant predictors of absolute differences in self-report and device-measurement to be parsed out by sedentary behavior, and light intensity, moderate intensity, and vigorous intensity physical activity. Third, each day contributed per participant was considered as an observation, and all observations contributed by the same participant were treated as correlated, rather than calculating a summary measure across days, allowing the information in the data to be used to its full extent.

A primary limitation of this study, and other studies of this nature, is that accelerometer physical activity and sedentary behavior data and self-reported survey physical activity and sedentary behavior data do not capture the exact same data. Self-

reported data *via* survey measures perceived physical activity and sedentary behavior, while accelerometers measure actual physical exertion, often MET-hours. Another limitation is that accelerometers do not completely capture bicycling and water activities, so agreement among participants who do these activities is expected to be less accurate [11]. However, in our cohort, only 36 participants reported biking or swimming regularly (for greater than 3 hours per week six or more months of the year) for the year in which they were active study participants, so the device misclassification of non-ambulatory physical activity is expected to be minimal.

Conclusions

Compared with accelerometer measurement, the CPS-3 Activity Validation Diary produces lower estimates of sedentary behavior and moderate intensity physical activity, and higher estimates of light intensity and vigorous intensity physical activity. Absolute differences exist by overall level of moderate and vigorous physical activity completed, region, and education. Such demographic factors should be considered when evaluating and interpreting self-reported physical activity data.

Future Directions

This analysis considered the effect of demographic and lifestyle predictors on the agreement between self-reported and accelerometer measured physical activity and sedentary behavior in a large, diverse cohort. The results of this study can be used to inform interpretation and analysis of self-reported physical activity data in the CPS-3 cohort, and in future studies utilizing self-reported physical activity collected in a similar manner.

In general, correlation between the self-report and device measures was moderate for sedentary behavior and all intensities of physical activity, demonstrating that a seven-day grid can effectively be used to collect self-reported physical activity data.

As expected, overall level of physical activity or sedentary behavior was associated with agreement between the two measures for sedentary behavior and vigorous intensity physical activity. In future analyses of self-reported physical activity data, baseline physical activity level should be considered, to allow for adjustment for these differences.

Education, and the interaction between race and education was associated with agreement between self-reported and accelerometer measured moderate intensity physical activity. Future studies should ensure that participants understand perceived exertion of any given activity, to ensure appropriate classification. In addition, studies should further explore the potential interaction between race and education in quality of self-reported moderate intensity physical activity data, to determine if such associations could be explained by education alone.

This study provided novel information on the relationship of region with agreement between self-reported and device measured light intensity physical activity and sedentary behavior. Additional exploration into the factors that influence the vast differences in self-

reported physical activity and sedentary behavior between the West and other regions of the United States is needed.

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Tables

Table 1. Descriptive characteristics of study population (n=698 participants)

Variable	**n**	**%**
Race		
Black or African American	134	19.2
Hispanic	108	15.47
White	456	65.33
Sex		
Female	417	59.74
Male	281	40.26
Age (years)		
30-39	115	16.48
40-49	162	23.21
50-59	230	32.95
60+	191	27.36
Education		
Less than college education	179	25.64
College education or greater	519	74.36
Current Smoking Status		
Non-smoker	680	97.42
Smoker	18	2.58
BMI (kg/m^2)*		
Normal weight	281	40.26
Overweight	242	34.67
Obese	175	25.07
Region		
Northeast	102	14.61
Midwest	227	32.52
South	247	35.39
West	122	17.48
Total Physical Activity		
> 4x guidelines**	295	42.26
2 to 4x guidelines	204	29.23
1 to 2x guidelines	98	14.04
Below guidelines/missing	101	14.47

*BMI classified based on WHO guidelines; normal: 18.5-25 kg/m^2, overweight: 25-30 kg/m^2, obese: >30 kg/m^2

**Total physical activity classified based on ACS guidelines of 7.5 MET-hrs/wk

Table 2. Comparison of self-reported and device-recorded summary measures of device wear, sedentary behavior, and physical activity minutes per day (days=4598)

Measure	**Mean**	**SD**	**Pearson r* *(p**)***
Total device wear time (minutes/day)			
Device	932.90	114.47	0.53
Diary	943.67	96.12	(<0.0001)
Sedentary physical activity (minutes/day)			
Device	585.96	141.86	0.53
Diary	565.68	205.45	(<0.0001)
Light intensity physical activity (minutes/day)			
Device	271.83	106.73	0.42
Diary	339.25	189.44	(<0.0001)
Moderate intensity physical activity (minutes/day)			
Device	60.56	35.25	0.38
Diary	24.04	58.06	(<0.0001)
Vigorous intensity physical activity (minutes/day)			
Device	14.06	19.83	0.35
Diary	14.69	38.08	(<0.0001)

Abbreviations: SD = standard deviation

*Pearson r = Pearson correlation coefficient for comparison of device and diary measure

**p= Prob > |r| under H0: r = 0

Table 3. Mean differences and correlations between self-reported diary and Actigraph measures of device wear, sedentary behavior, and physical activity (minutes/day) by demographic characteristics

	Device wear time	Sedentary behavior	Light intensity	Moderate intensity	Vigorous intensity
	Mean difference (diary-device) ± SD (r*)				
Sex					
Female	9.03±100.38 (0.55)	-22.38±170.37 (0.53)	71.28±170.74 (0.43)	-39.26±47.47 (0.35)	-0.09±29.54 (0.40)
Male	13.31±107.13 (0.51)	-17.18±186.13 (0.53)	61.77±178.64 (0.39)	-32.50±64.68 (0.42)	1.67±44.17 (0.31)
P-value**	0.1683	0.3281	0.0688	<0.0001	<0.0001
Race					
White	10.1±92.68 (0.57)	-22.29±166.92 (0.55)	69.87±164.48 (0.47)	-37.64±51.60 (0.42)	0.62±36.28 (0.33)
Black	15.12±218.15 (0.45)	-19.54±195.56 (0.50)	66.14±192.82 (0.33)	-33.42±64.62 (0.29)	2.50±40.46 (0.32)
Hispanic	8.41±112.54 (0.51)	-12.31±194.93 (0.49)	58.25±189.60 (0.34)	-35.37±57.86 (0.36)	-1.65±29.69 (0.49)
P-value	0.3694	0.4021	0.2744	0.1204	0.0811
Age (years)					
30-39	17.45±90.43 (0.65)	-24.72±158.14 (0.65)	76.31±165.01 (0.50)	-33.36±54.98 (0.43)	-0.46±35.69 (0.43)
40-49	9.03±124.38 (0.42)	-29.27±181.90 (0.53)	75.13±172.65 (0.48)	-34.93±63.51 (0.36)	-1.39±31.31 (0.42)
50-59	9.78±97.11 (0.57)	-21.73±184.15 (0.49)	72.05±182.51 (0.35)	-42.33±51.09 (0.33)	2.26±41.38 (0.31)
60+	9.55±98.01 (0.52)	-8.78±174.02 (0.51)	50.70±168.97 (0.41)	-32.79±52.18 (0.46)	0.95±33.48 (0.32)
P-value	0.3030	0.0332	0.0007	<0.0001	0.0688
Education					
Less than college education/missing	11.64±126.90 (0.45)	-20.96±197.23 (0.47)	74.14±185.75 (0.40)	-40.83±59.72 (0.29)	-0.27±28.48 (0.41)
College education or greater	10.47±93.76 (0.57)	-20.04±169.49 (0.56)	65.14±169.82 (0.43)	-35.05±53.49 (0.42)	0.93±38.47 (0.34)
P-value	0.7390	0.8772	0.1268	0.0034	0.3296
Region					
Northeast	13.04±110.57 (0.49)	-34.87±174.06 (0.56)	86.36±167.87 (0.40)	-38.66±48.86 (0.40)	0.68±37.21 (0.39)
Midwest	18.57±90.67 (0.59)	-30.10±167.96 (0.57)	89.15±163.48 (0.52)	-38.55±51.32 (0.39)	-1.52±29.44 (0.40)
South	6.63±114.58 (0.49)	-52.17±178.10 (0.54)	91.44±173.21 (0.43)	-35.03±61.96 (0.33)	2.97±42.44 (0.33)
West	2.53±93.49 (0.56)	73.37±161.35 (0.57)	-36.38±162.00 (0.49)	-33.90±52.75 (0.48)	-0.08±32.96 (0.35)
P-value	0.0008	<0.0001	<0.0001	0.1096	0.0064

Abbreviations: SD = standard deviation; *r = correlation coefficient, **P-value=p-value for test of difference

Table 4. Mean differences and correlations between self-reported diary and Actigraph measures of device wear, sedentary behavior, and physical activity (minutes/day) by lifestyle characteristics

	Device wear time	Sedentary behavior	Light intensity	Moderate intensity	Vigorous intensity
	Mean difference (diary-device) ± SD (r*)				
Total	10.77±103.18 (0.53)	-20.27±176.93 (0.53)	67.42±174.03 (0.42)	-36.52±55.19 (0.38)	0.62±36.20 (0.35)
Current Smoking Status					
Non-smoker	9.91±101.53 (0.54)	-20.32±175.76 (0.53)	66.64±173.80 (0.42)	-36.63±54.94 (0.39)	0.71±36.25 (0.36)
Smoker	47.46±154.67 (0.35)	-18.16±222.13 (0.53)	100.81±181.20 (0.47)	-31.72±65.09 (0.29)	-2.86±33.87 (-0.01)
P-value**	0.0149	0.9213	0.0586	0.4448	0.3182
BMI (kg/m^2)					
Normal weight	2.03±85.73 (0.62)	-24.30±167.21 (0.55)	63.15±163.67 (0.49)	-37.07±44.60 (0.43)	0.98±34.52 (0.47)
Overweight	14.53±106.29 (0.49)	-6.89±177.22 (0.55)	55.13±169.24 (0.42)	-34.16±64.65 (0.40)	0.96±36.00 (0.25)
Obese	19.87±123.16 (0.48)	-32.75±191.11 (0.46)	92.63±194.58 (0.29)	-39.00±56.66 (0.30)	-0.49±39.20 (0.15)
P-value	<0.0001	0.0004	<0.0001	0.0695	0.5036
Total Physical Activity					
> 4x guidelines	10.52±103.15 (0.51)	-28.28±179.92 (0.51)	69.76±176.01 (0.43)	-37.75±59.51 (0.41)	7.26±49.90 (0.32)
2 - 4x guidelines	9.94±98.13 (0.57)	-12.42±168.31 (0.55)	62.57±168.80 (0.42)	-35.5±43.98 (0.38)	-4.12±22.90 (0.26)
1 - 2x guidelines	7.00±99.45 (0.57)	-25.42±176.49 (0.48)	75.71±171.92 (0.39)	-38.61±60.80 (0.19)	-4.40±16.56 (0.29)
Below guidelines /missing	17.11±116.55 (0.48)	-6.94±184.65 (0.57)	62.08±180.73 (0.38)	-32.61±56.57 (0.42)	-4.71±12.38 (0.29)
P-value	0.3383	0.0126	0.3252	0.1390	<0.0001

Abbreviations: SD = standard deviation; *r = correlation coefficient, **P-value=p-value for test of difference

Table 5. Absolute difference in self-reported and Actigraph measured sedentary behavior (minutes/day) using best fit model

Effect	Estimate	SE	95% CI	t Value*	Pr > |t|**
Intercept	54.19	18.73	(17.40, 90.97)	2.89	0.0039
Women (*vs* men)	-12.65	9.39	(-31.08, 5.79)	-1.35	0.1785
Race					
White	Ref.				
African American	16.53	12.50	(-8.02, 41.08)	1.32	0.1866
Hispanic	-1.53	13.47	(-27.97, 24.91)	-0.11	0.9096
Age	6.01	4.39	(-2.61,14.63)	1.37	0.1715
Total MVPA per week***					
>4x guideline	Ref.				
Inactive, Active below guidelines	34.08	14.01	(6.57, 61.59)	2.43	0.0153
Active, 1-2x guidelines	8.75	14.08	(-18.90, 36.40)	0.62	0.5346
Active, 2-4x guideliens	13.21	10.99	(-8.37, 34.78)	1.2	0.2299
Region of residence					
West	Ref.				
Northeast	-109.56	16.25	(-141.46, -77.66)	-6.74	<.0001
Midwest	-104.23	13.84	(-131.40, -77.05)	-7.53	<.0001
South	-130.62	13.50	(-157.12, -104.12)	-9.68	<.0001

Abbreviations: SE = standard error; CI = confidence interval; MVPA = moderate and vigorous physical activity

*t-value for test of significance of estimate

**P-value for t-test of significance, evaluated using α=0.05

***Classified based on American Cancer Society guidelines of 7.5 MET-hrs/week of MVPA

Table 6. Absolute difference in self-reported and Actigraph measured light intensity physical activity (minutes/day) using best fit model

Effect	Estimate	SE	95% CI	t Value*	Pr > |t|**
Intercept	-23.07	18.36	(-59.12,12.99)	-1.26	0.2095
Women (*vs* men)	14.80	9.23	(-3.32, 32.93)	1.6	0.1092
Race					
White	Ref.				
African American	-15.61	12.48	(-40.12, 8.90)	-1.25	0.2116
Hispanic	2.88	13.11	(-22.85, 28.62)	0.22	0.8261
Age	-8.04	4.32	(-16.51, 0.44)	-1.86	0.0630
BMI***					
Normal	Ref.				
Overweight	-10.32	10.48	(-30.89, 10.26)	-0.98	0.3251
Obese	25.00	11.65	(2.12, 47.88)	2.15	0.0323
Region of residence					
West	Ref.				
Northeast	124.25	15.86	(93.10, 155.39)	7.83	<.0001
Midwest	124.90	13.54	(98.31, 151.48)	9.23	<.0001
South	129.69	13.19	(103.79, 155.58)	9.83	<.0001

Abbreviations: SE = standard error; CI = confidence interval; BMI = Body Mass Index

*t-value for test of significance of estimate

**P-value for t-test of significance, evaluated using α=0.05

***BMI classified based on WHO guidelines; normal=18.5-25kg/m^2, overweight=25-30 kg/m^2, obese=30+ kg/m^2

Table 7. Absolute difference in self-reported and Actigraph measured moderate intensity physical activity (minutes/day) using best fit model

Effect	Estimate	SE	95% CI	t Value*	Pr > |t|**
Intercept	-40.42	5.17	(-50.56, -30.28)	-7.82	<.0001
Women (*vs* men)	-7.26	2.58	(-12.33. -2.20)	-2.82	0.005
Race					
White	Ref.				
African American	12.13	6.55	(-0.73, 24.99)	1.85	0.0644
Hispanic	13.70	6.25	(1.42, 25.98)	2.19	0.0288
Age	-0.21	1.22	(-2.60, 2.19)	-0.17	0.8666
College education or greater (*vs* less than college)	9.74	3.70	(2.48, 17.00)	2.64	0.0086

Abbreviations: SE = standard error; CI = confidence interval

*t-value for test of significance of estimate

**P-value for t-test of significance, evaluated using α=0.05

Table 8. Absolute difference in self-reported and Actigraph measured of minutes/day moderate intensity physical activity accounting for interaction of race and education*

	Race					
	White		African American		Hispanic	
Effect	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI
Education						
Less than college	1.0 (ref)	-	12.13	(-0.73, 24.99)	13.70	(1.42, 25.98)
College or greater	1.0 (ref)	-	2.50	(-4.97, 9.98)	-1.98	(-10.63, 6.67)

Abbreviations: CI = confidence interval

*Adjusted for Sex, Race, and age

Table 9. Absolute difference in self-reported and Actigraph measured vigorous intensity physical activity (minutes/day) using best fit model

Effect	Estimate	SE	95% CI	t Value*	Pr > |t|**
Intercept	5.06	3.10	(-1.02, 11.15)	1.63	0.1027
Women (*vs* men)	-0.35	1.88	(-4.04, 3.34)	-0.19	0.8515
Race					
White	Ref.				
African American	2.03	2.39	(-2.67, 6.72)	0.85	0.3965
Hispanic	-0.72	2.61	(-5.86, 4.41)	-0.28	0.7819
Age	0.84	0.88	(-0.89, 2.58)	0.95	0.3404
Total MVPA per week***					
> 4x guidelines	Ref.				
Inactive, Active below guidelines	-12.12	2.81	(-17.64, -6.60)	-4.31	<.0001
Active, 1-2x guidelines	-11.82	2.83	(-17.38, -6.26)	-4.17	<.0001
Active, 2-4x guidelines	-11.41	2.21	(-15.75, -7.07)	-5.16	<.0001

Abbreviations: SE = standard error; CI = confidence interval; MVPA = moderate and vigorous physical activity

*t-value for test of significance of estimate

**P-value for t-test of significance, evaluated using α=0.05

***Classified based on American Cancer Society guidelines of 7.5MET-hrs/week of MVPA

Supplementary Table 1: Physical activity code descriptions

Code	Activity Description
1	Sleeping/Resting in bed/Lying down
2	Sitting while eating, watching television, reading, driving, using a computer/smartphone, etc.
3	Standing, very light activity, showering, dressing, etc.
4	Walking (at a pace of less than 3 mph), light activity, stretching, yoga, childcare, cooking, light yard work, household chores, light weightlifting, calisthenics
5	Walking (at a pace of 3 to 3.9 mph), dancing, cycling (less than 10 mph), gardening, heavy yard work, mowing lawn, golfing without a cart
6	Walking (at a pace of at least 4 mph), recreational basketball, softball, baseball, hiking
7	Cycling (at 10 to 13.9 mph), swimming, recreational sports (doubles tennis, racquetball, soccer), aerobics, skiing, heavy weightlifting
8	Jogging (less than 6 mph), elliptical or stair climbing machine, competitive sports (singles tennis, basketball, flag football), boxing
9	Vigorous lap swimming, running (at least 6 mph), cycling (at 14 or more mph), intense manual work

Supplementary Table 2: Regional state categorizations

Region	States Included
Northeast	Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont
Midwest	Kansas, Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, Wisconsin
South	Alabama, Arkansas, Delaware, District of Columbia, Florida, Georgia, Kentucky, Louisiana, Maryland, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, Virginia, West Virginia,
West	Alaska, Arizona, California, Colorado, Hawaii, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Wyoming, Washington

Figures

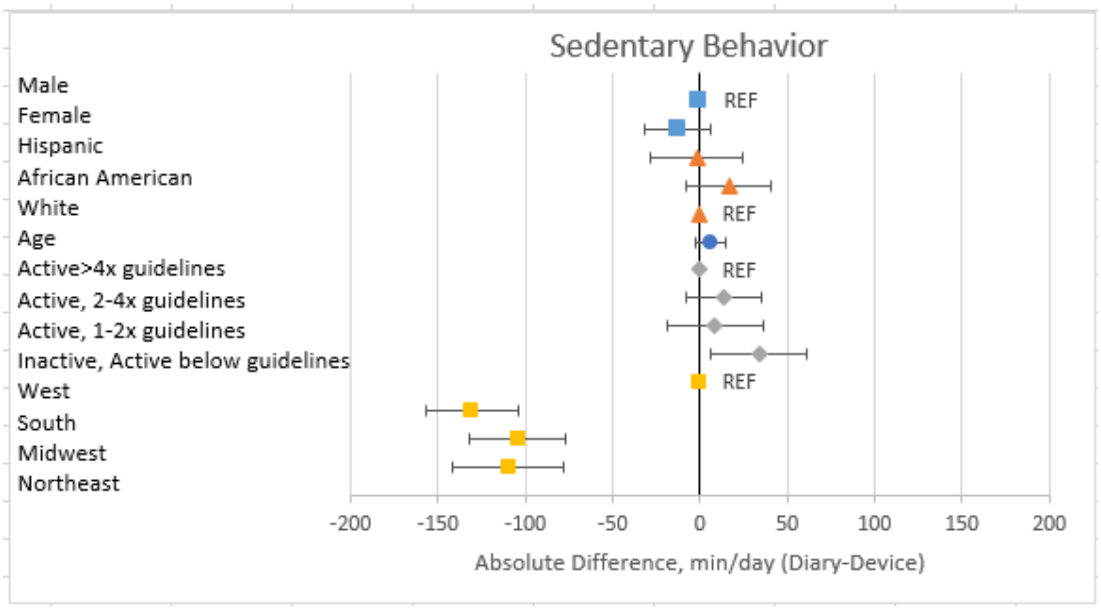

Figure 1: Differences between diary reported and Actigraph measured total minutes per day sedentary behavior (Diary-Device). Solid lines represent 95% confidence intervals.

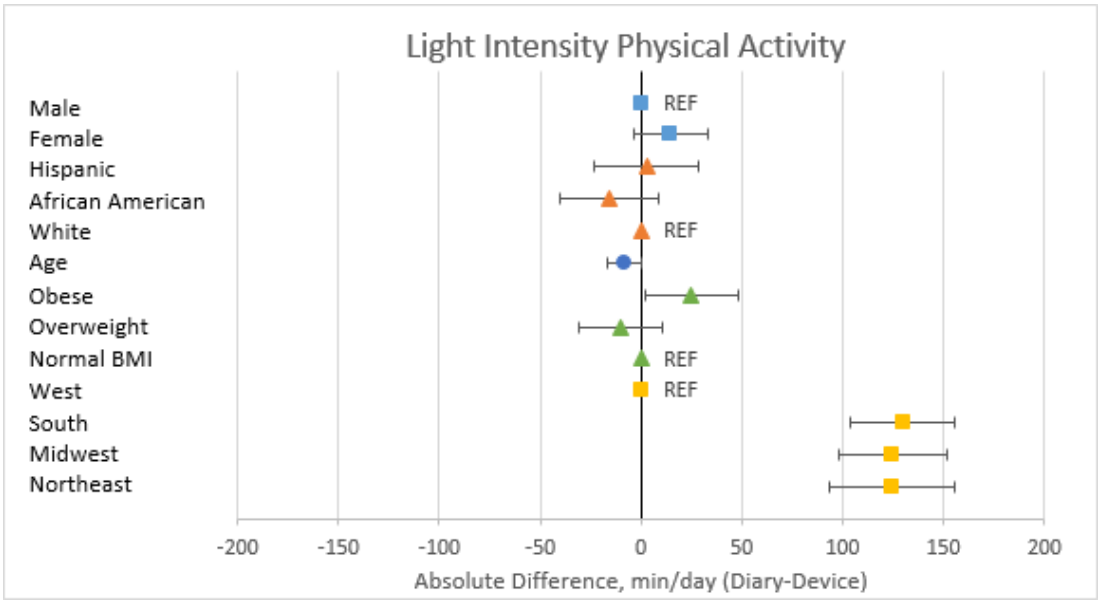

Figure 2: Differences between diary reported and Actigraph measured total minutes per day light intensity physical activity (Diary-Device). Solid lines represent 95% confidence intervals.

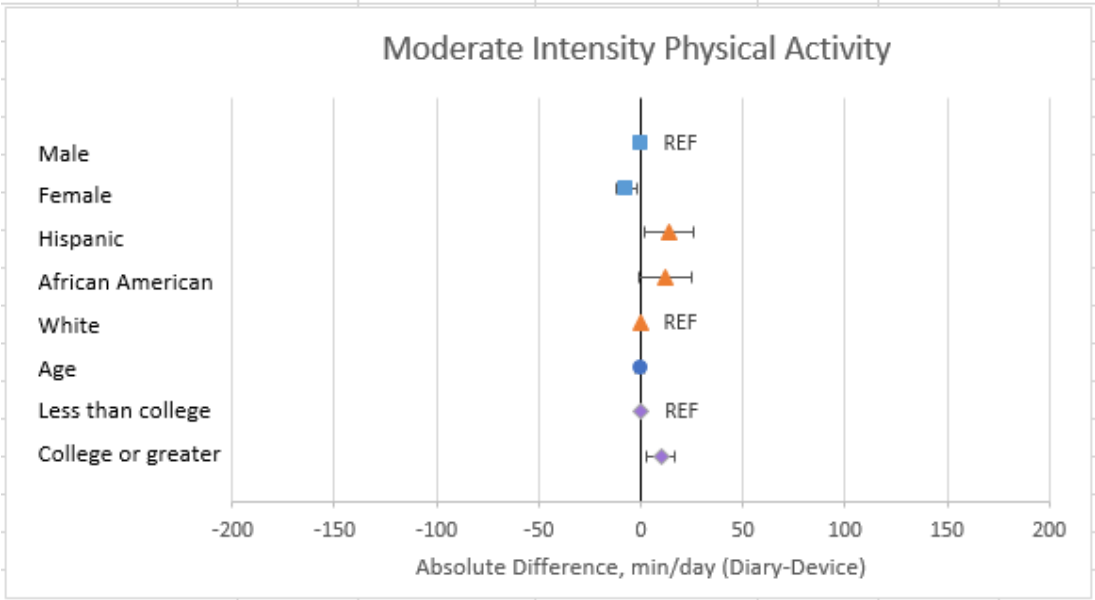

Figure 3: Differences between diary reported and Actigraph measured total minutes per day moderate intensity physical activity (Diary-Device). Solid lines represent 95% confidence intervals.

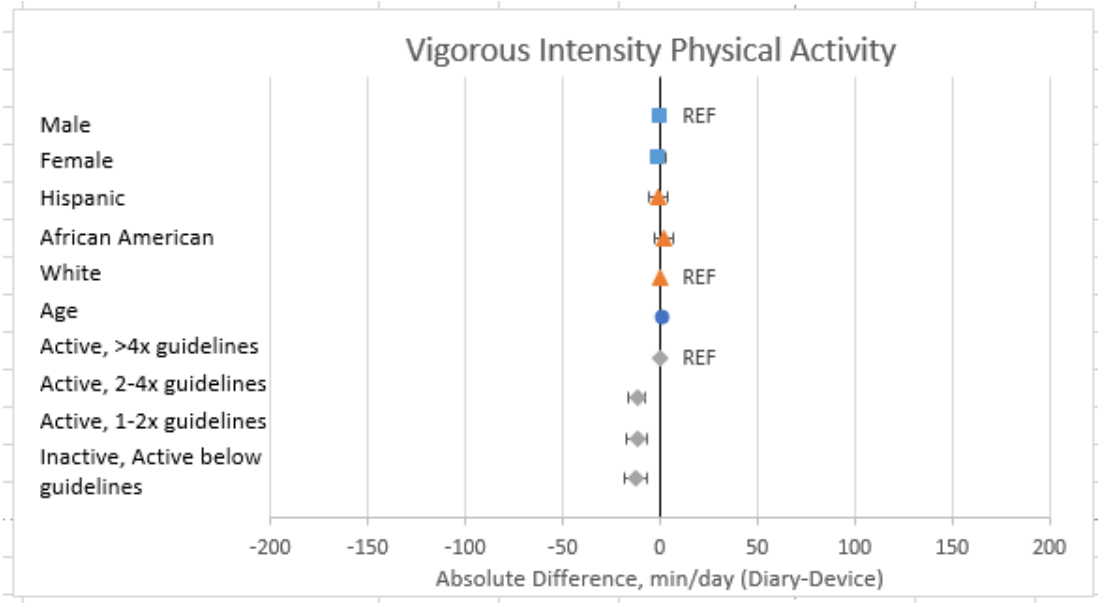

Figure 4: Differences between diary reported and Actigraph measured total minutes per day vigorous intensity physical activity (Diary-Device). Solid lines represent 95% confidence intervals.