Relating Self-report and Accelerometer Physical Activity with Application to NHANES 2003-2004

Nicholas Beyler[1], Sarah Nusser[1], Wayne Fuller[1], Gregory Welk[2]
[1]Department of Statistics, Iowa State University
[2]Department of Kinesiology, Iowa State University

Abstract
A measure of physical activity is time spent in moderate to vigorous physical activity (MVPA). Daily or weekly estimates of MVPA can be obtained with self-reports (e.g., recalls and questionnaires) and/or with monitoring devices (e.g., accelerometers). Self-reports are inexpensive in survey settings but estimate MVPA with considerable measurement error due to recall errors and social desirability effects. Monitoring devices such as accelerometers provide estimates with less error, but are more expensive to administer. Using data from the National Health and Nutrition Examination Survey (NHANES) 2003-2004, we develop a function that approximates MVPA as measured by accelerometer from self-reported physical activity.

Key Words: Physical Activity, NHANES, Measurement Error

1. Introduction

Researchers are interested in physical activity (PA) data in order to target exercise patterns and assess how PA levels relate to obesity, heart disease and cancer (U.S. Department of Health and Human Services 1996). Two common PA metrics are energy expenditure—measured in Kilocalories per day or week—and time spent in moderate to vigorous physical activity (MVPA)—measured in minutes per day or week. In survey settings, estimates of energy expenditure and MVPA are obtained from self-report instruments (e.g., recalls and questionnaires) and monitoring devices (e.g., accelerometers and pedometers). Self-reported PA data are subject to measurement error due to recall errors and social desirability effects (Welk 2002). Data collected from monitoring devices are subject to less measurement error due to the objective nature of measurement, but are more expensive to implement in survey settings and are a burden to survey participants (Ward et al. 2005, Matthews 2005).

In this paper we develop a function that predicts the monitoring device PA from self-reported PA. Using PA data from the 2003-2004 National Health and Nutrition Examination Survey (NHANES), we fit multiple regression models to produce a function that predicts accelerometer-based estimates of MVPA in minutes per day from self-reported MVPA estimates. In section 2 we describe NHANES and outline the PA data collection process for the 2003-2004 survey. In section 3 we examine the data and illustrate discrepancies between self-reported and accelerometer MVPA estimates. In section 4 we define multiple regression models for the data and present our function for predicting accelerometer-based MVPA. In section 5 we conclude with a discussion of the relationship between self-reported and accelerometer-based PA.

2. NHANES and Physical Activity

NHANES is an ongoing survey of the United States civilian non-institutionalized population sponsored by the National Center for Health Statistics (NCHS), a branch of the Centers for Disease Control and Prevention (CDC). Survey participants, selected with a complex multistage probability design, provide health and nutrition data during interviews and medical examinations. The data collected are used in a number of epidemiological and health studies (U.S. Department of Health and Human Services (DHHS) 2008).

In the 2003-2004 NHANES, PA data were collected from a PA questionnaire and from Actigraph model 7164 accelerometers. The PA questionnaire asks participants to recall their activity from the past 30 days. Participants are asked to report on frequency and duration of activities related to transportation ("getting to and from work or school, or to do errands"), household maintenance ("raking leaves, mowing the lawn or heavy cleaning") and leisure ("exercise, sports, and physically active hobbies") (U.S. DHHS 2008). For transportation and household maintenance, participants report on activity of at least moderate intensity (activity that causes at the least "light sweating or a slight to moderate increase in heart rate or breathing" (U.S. DHHS 2008). For leisure, participants are asked to specify both moderate activity and vigorous activity, where vigorous activity is defined as activity "causing heavy sweating, or large increases in breathing or heart rate" (U.S. DHHS 2008). Thirty day estimates of transportation MVPA, household MVPA, moderate leisure PA and vigorous leisure PA are obtained by adding minutes of activity based on reported frequency and duration. Estimates in minutes per day for these 4 categories are obtained by dividing the 30 day estimates by 30. The sum of transportation MVPA, household MVPA, moderate leisure PA and vigorous leisure PA represents an estimate of average daily MVPA in minutes per day based on self-reported data.

After completing the PA questionnaire, participants are asked to wear an accelerometer to monitor their PA. A total of 7176 of 9643 participants that were interviewed and examined agreed to wear accelerometers (Troiano et al. 2008). The willing participants are instructed to wear an accelerometer on an elastic belt around their waists during waking hours of the day for seven days and to take the accelerometer off for water activities such as swimming and showering. During wear time, the accelerometers keep track of duration and intensity of participants' activities. The accelerometer data are translated into activity periods of little or no intensity, moderate intensity (about 3-6 METs), and vigorous intensity (about 6 or more METs); and estimates of MVPA in minutes per day are obtained for each day of wear (Troiano et al. 2008). Only participants with 10 or more hours of wear on 4 or more days are considered in our analyses. Estimates of average daily MVPA for these participants are based on days with 10 or more hours of wear. So for example, the estimate of average daily MVPA for a participant who wore the accelerometer for 12 hours on the first 5 days and 8 hours on the remaining 2 days is equal to the average of the 5 MVPA estimates for the first 5 days.

We consider participants 20 years or older who completed the PA questionnaire and wore the accelerometer for 10 or more hours on 4 or more days. Of those participants, 3084 have complete data for reports on transportation, moderate leisure and vigorous leisure activity (the self-report variables for the first regression model: see section 4). Results reported in the subsequent sections are based on data from these 3084 participants.

3. Accelerometer vs. Self-report MVPA

The noticeable differences between estimates of MVPA based on accelerometer data and estimates of MVPA based on self-report data from the PA questionnaire are illustrated in Figure 1. The two measures are only slightly correlated (Pearson correlation coefficient of 0.17) and many of the accelerometer and self-report estimates are dissimilar. A majority of the points lie to the right of the identity line in the plot (about 76% of the points), suggesting that most participants report more activity than the accelerometers record. There is also evidence of extreme over-reporting: 8 participants have self-report estimates of average daily MVPA exceeding 700 minutes per day, which seems unrealistic.

In Table 1 the 3084 participants are classified into one of four groups based on whether their MVPA estimates are both zero, both positive, or one of each. The columns categorize participants by their self-report estimates and the rows categorize participants by their accelerometer estimates. The count and corresponding percent of participants in each of the four groups is provided along with row and column totals. About 42% of the 3084 participants have an estimate of zero MVPA from the accelerometers and a positive estimate of MVPA based on self-reporting. A little less than 5% have a positive MVPA estimate from the accelerometers and an estimate of zero from self-reporting. Therefore, almost half of the participants (46.5%) have contradicting estimates of zero and positive average daily MVPA. In addition, over half of the participants (55.7%) have MVPA estimates of zero based on the accelerometer, while less than one-fifth (18.6%) have MVPA estimates of zero based on self-reporting.

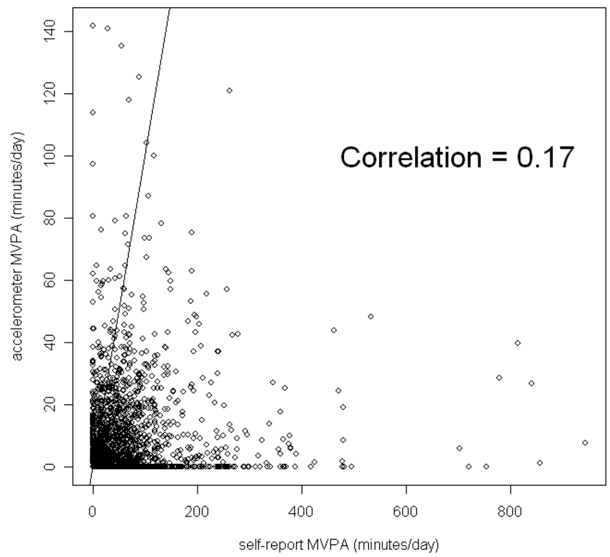

Figure 1: plot of self-report and accelerometer MVPA (n = 3084)
(solid line is the identity line)

Table 1: counts (percents) of zero and positive self-report and accelerometer MVPA (n = 3084)
(rows are for accelerometer MVPA, columns are for self-report MVPA)

	Zero MVPA	Positive MVPA	Row Totals
Zero MVPA	429 (13.9)	1288 (41.8)	1717 (55.7)
Positive MVPA	145 (4.7)	1222 (39.6)	1367 (44.3)
Column totals	574 (18.6)	2510 (81.4)	3084 (100.0)

4. Prediction Function

The function we develop is comprised of two fitted multiple regression models with model parameter estimates based on the NHANES 2003-2004 data. The first model compares accelerometer and self-report MVPA while accounting for gender, age and ethnicity effects. The second model is used to predict accelerometer MVPA using the predicted values from the first model. The regression models and their rationale are defined more formally in the subsequent paragraphs.

In Table 2 we provide a list of model variables for the first regression with brief descriptions. The three self-report variables (*Trans*, *Mod* and *Vig*) are truncated at the 99th percentiles, where the truncation values are provided in Table 2. Using these variables, the model equation for survey participant i is

$$y_i = x_i'\beta + e_i,$$

where e_i is an error term, y_i indicates the cube root of $Accel_i$, and $\beta = (\beta_0, \ldots, \beta_7)'$ is a vector of model parameters for the vector of covariates

$$x_i' = (1, Trans_i^{1/3}, Mod_i^{1/3}, Vig_i^{1/3}, Gend_i, Age_i, Hisp_i, (I_i^*)^2)\,. \qquad (1)$$

An estimator for the parameter vector is

$$\hat{\beta} = (X'W\Psi X)^{-1} X'W\Psi y, \qquad (2)$$

where X is the 3084x8 matrix with i^{th} row x_i', y is a 3084x1 column vector with i^{th} element y_i, W is a 3084x3084 diagonal matrix of survey weights with i^{th} diagonal element w_i, the inverse of participant i's probability of selection adjusted for non-response and post-stratification based on gender, age, and race/ethnicity, and Ψ is a 3084x3084 diagonal matrix. The i^{th} diagonal element of Ψ is $\hat{\phi}_i^{-1}$, where $\hat{\phi}_i$ is the model predicted value from the regression of $w_i \hat{\varepsilon}_i^2$ on z_{1i} and z_{2i}, with $\hat{\varepsilon}_i = y_i - x_i'\tilde{\beta}$, $z_{1i} = x_i'\tilde{\beta}$, and

$$z_{2i} = \begin{cases} 0, & z_{1i} \le 0.90 \\ z_{1i} - 0.90, & otherwise \end{cases},$$

for

$$\tilde{\beta} = (X'WX)^{-1} X'Wy .$$

The matrix Ψ is included in (2) to adjust for non-constant variance in the residuals for the first regression model.

Using the estimated parameter vector $\hat{\beta}$, a model predicted value for survey participant i is

$$\hat{y}_i = x_i'\hat{\beta} . \qquad (3)$$

Standard errors for parameter estimates are approximated by Taylor series linearization. Numerical values for parameter estimates and standard errors are provided in Table 3.

Table 2: variables for the first regression model

Variable	Description
Accel	Estimate of average daily MVPA (in minutes) based on accelerometer wear
Trans	Estimate of average daily MVPA (in minutes) for transportation activity as reported from the PA questionnaire (estimates larger than 120 minutes are truncated at 120)
Mod	Estimate of average daily PA (in minutes) of moderate intensity for leisure activity as reported from the PA questionnaire (estimates larger than 160 minutes are truncated at 160)
Vig	Estimate of average daily PA (in minutes) of vigorous or greater intensity for leisure activity as reported from the PA questionnaire (estimates larger than 100 minutes are truncated at 100)
Gend	Indicator variable for gender (1 if female, 0 if male)
Age	Indicator variable for age group (1 if 20-59, 0 if 60 or older)
Hisp	Indicator variable for ethnicity (1 if Hispanic, 0 if non-Hispanic)
*I**	Linear function of *Trans*, *Mod*, *Vig*, *Gend*, *Age*, and *Hisp* where coefficients in the function are approximately the coefficients in the regression

Table 3: parameter estimates and standard errors for the first regression model

Para.	β_0	β_1	β_2	β_3	β_4	β_5	β_6	β_7
Est. (S.E.)	0.372 (.023)	0.320 (.056)	0.173 (.018)	0.336 (.039)	-0.296 (.017)	0.411 (.047)	0.378 (.058)	-0.098 (.021)

The variables and variable transformations used in the first regression model are based on a model selection process in which we compared a number of different models using hypothesis testing before deciding on the 7 explanatory model variables listed in Table 2. Reported household MVPA, indicator variables for other ethnicities and/or races (in addition to Hispanic), and a variety of interaction terms were tested and excluded from the final model on the basis of non-significant tests. The cube root transformations on the PA variables provided the largest correlation between accelerometer MVPA and the self-report variables compared to other power transformations.

The second regression equation is

$$Accel_i = \alpha_1 \hat{y}_i + \alpha_2 \hat{y}_i^{\,3} + u_i ,$$

where $\hat{y}_i$ is the predicted value from the first regression equation, u_i is an error term, $\alpha = (\alpha_1, \alpha_2)'$ is a vector of model parameters, and $Accel_i$ is as defined in Table 2. An estimate for α is obtained using a least squares equation of the form (2). A predicted value from the second regression for participant i is

$$\hat{Accel}_i = (\hat{y}_i, \hat{y}_i^3)\hat{\alpha}, \tag{4}$$

where $\hat{\alpha}$ is the vector of parameter estimates. Standard errors for the parameter estimates are approximated with Taylor series linearization. Numerical values for parameter estimates and standard errors for this second model are provided in Table 4.

Table 4: parameter estimates and standard errors for the second regression model

Parameter	α_1	α_2
Estimate (S.E.)	4.705 (.468)	0.899 (.251)

The second regression model is used to construct an estimator of the expected value of accelerometer MVPA given the set of explanatory variables. In Figure 2 we provide a plot of 12 group means for predicted and observed accelerometer MVPA. The predicted values from the first model were sorted from smallest to largest and survey participants divided into 12 groups of equal size based on the sorted predicted values. Using the survey weights, weighted means for observed and predicted accelerometer MVPA are computed and plotted in Figure 2. The points fall about the identity line giving no reason to reject the model.

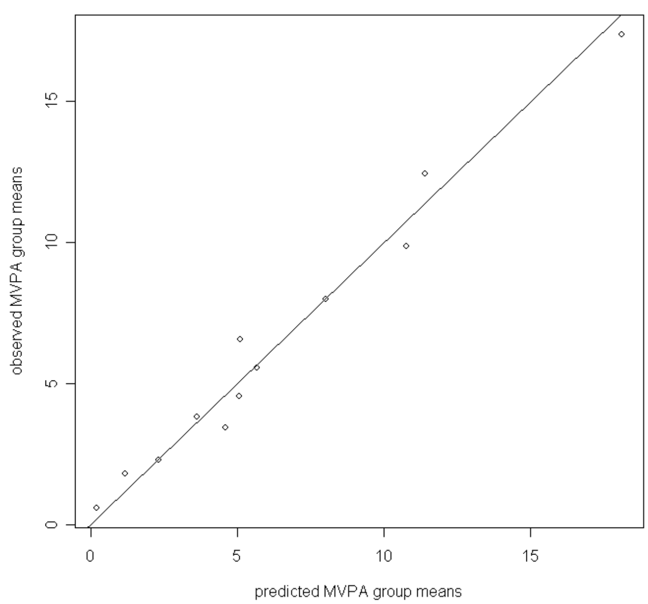

Figure 2: plot of group means for observed and predicted accelerometer MVPA
(solid line is the identity line)

The steps in Table 5 outline how to use the prediction function. A survey participant's demographic information (gender, age, and ethnicity) and self-report data (reports on transportation MVPA, moderate leisure PA, and vigorous leisure PA) are transformed into a vector of covariate data for the first regression model. Predicted values for the first and second regression models are obtained using the estimated parameter vectors. The predicted value from the second regression model is the predicted estimate of average daily MVPA as measured by accelerometer based on self-report and demographic data. The Pearson correlation coefficient between observed accelerometer MVPA estimates and predicted values from the function is 0.34. This is twice as large as the measured correlation between accelerometer MVPA estimates and self-report MVPA estimates (see Figure 1).

Table 5: steps for using the prediction function

Step 1: obtain self-report and demographic data via NHANES PA questionnaire
Step 2: transform to a vector of covariate data (x_i from (1))
Step 3: compute an initial predicted value ($\hat{y}_i$ from (3))
Step 4: compute a final predicted value ($\hat{Accel}_i$ from (4))
Result: prediction in minutes/day for estimate of MVPA based on accelerometer wear

In Table 6 we give predicted values from our function based on hypothetical self-report estimates—7 minutes of average daily transportation MVPA, 18 minutes of average daily moderate leisure PA, and 8 minutes of average daily vigorous leisure PA for a total of 33 minutes of self-reported average daily MVPA. In the table, predicted values for average daily MVPA as measured by accelerometer are displayed for various gender, age group, and ethnicity combinations. For example, a Hispanic female, age 20-59 is predicted to estimate 15.4 minutes of MVPA per day from the accelerometer, a non-Hispanic male, age 60 or older is predicted to estimate 11.8 minutes of MVPA per day from the accelerometer, and so on. The results offer two important points: predicted values are smaller than the corresponding self-report estimate and predicted values differ among demographic groups. The predicted values for all gender, age, and ethnicity combinations are smaller than the self-reported 33 minutes of MVPA, consistent with Figure 1 and Table 1—people report more MVPA than the accelerometers pick up. The predicted values also differ by gender, age group, and ethnicity specifications. In fact, predictions are smaller for females—compared to males—for the older age group—compared to the younger age group—and for non-Hispanics—compared to Hispanics. As an illustration of this second point, compare the prediction for younger Hispanic females (15.4 minutes per day) to the prediction for younger Hispanic males (17.4 minutes per day). When younger Hispanic males and females both report 33 minutes of MVPA per day, the females are predicted to have 2 minutes less average daily MVPA than the males. In other words, the function predicts a larger discrepancy between self-reported MVPA and accelerometer-based MVPA for females compared to males.

Table 6: numerical example for predicting accelerometer MVPA

Gender	Female	Male	Female	Female	Male	Male
Age Group	20-59	20-59	20-59	60+	60+	60+
Ethnicity	Hispanic	Hispanic	Non-Hisp	Non-Hisp	Hispanic	Non-Hisp
Prediction (min/day)	15.4	17.4	12.6	9.8	14.6	11.8

5. Discussion

The discrepancies between self-reported MVPA and accelerometer MVPA are disconcerting since self-reported estimates of PA are used to determine exercise guidelines and to study relationships between health outcomes and PA. Further investigation into why self-report estimates are larger than accelerometer-based estimates is warranted. In particular, it may be useful to compare self-reported duration and frequency of various activities with the accelerometer records for the same activities to see if there are certain types of activities that are reported but are not recorded with the accelerometers, and vice versa. A second research objective is to develop measurement error models that use both self-reported estimates and accelerometer estimates to model usual (long-term average) PA, a metric that is much more useful than daily or weekly PA.

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