Calibration of activity-related energy expenditure in the Hispanic Community Health Study/Study of Latinos (HCHS/SOL)

Pamela A. Shaw[a,*], **Robert McMurray**[b], **Nancy Butte**[c], **Daniela Sotres-Alvarez**[d], **Hengrui Sun**[d], **Mark Stoutenberg**[e], **Kelly R. Evenson**[f], **William W. Wong**[c], **Ashley E. Moncrieft**[g], **Lisa A.P. Sanchez-Johnsen**[h], **Mercedes R. Carnethon**[i], **Elva Arredondo**[j], **Robert C. Kaplan**[k,l], **Charles E. Matthews**[m], and **Yasmin Mossavar-Rahmani**[k]

[a]Department of Biostatistics, Epidemiology and Informatics, Perelman School of Medicine, University of Pennsylvania, USA

[b]Department of Exercise and Sports Science, College of Arts and Sciences, University of North Carolina at Chapel Hill, USA

[c]USDA/ARS Children's Nutrition Research Center, Department of Pediatrics, Baylor College of Medicine, USA

[d]Department of Biostatistics, Gillings School of Global Public Health, University of North Carolina at Chapel Hill, USA

[e]Department of Public Health Sciences, Miller School of Medicine, University of Miami, USA

[f]Department of Epidemiology, Gillings School of Global Public Health, University of North Carolina at Chapel Hill, USA

[g]Department of Psychology, University of Miami, USA

[h]Departments of Psychiatry and Surgery, Biological Sciences Division, University of Illinois at Chicago, USA

[i]Department of Preventive Medicine, Feinberg School of Medicine, Northwestern University, USA

[j]Institute of Behavioral and Community Health, Graduate School of Public Health, San Diego State University, USA

[k]Department of Epidemiology & Population Health, Albert Einstein College of Medicine, USA

[l]Public Health Sciences Division, Fred Hutchinson Cancer Research Center, Seattle, USA

[m]Division of Cancer Epidemiology and Genetics, National Cancer Institute, USA

Abstract

Objectives: Usual physical activity (PA) is a complex exposure and typical instruments to measure aspects of PA are subject to measurement error, from systematic biases and biological variability. This error can lead to biased estimates of associations between PA and health

*Corresponding author., shawp@upenn.edu (P.A. Shaw).

outcomes. We developed a calibrated physical activity measure that adjusts for measurement error in both self-reported and accelerometry measures of PA in adults from the US Hispanic Community Health Study/Study of Latinos (HCHS/SOL), a community-based cohort study.

Design: Total energy expenditure (TEE) from doubly labeled water and resting energy expenditure (REE) from indirect calorimetry were measured in 445 men and women aged 18–74 years in 2010–2012, as part of the HCHS/SOL Study of Latinos: Nutrition & Physical Activity Assessment Study (SOLNAS). Measurements were repeated in a subset (N = 98) 6 months later.

Method: Calibration equations for usual activity-related energy expenditure (AEE = 0.90 × TEE-REE) were developed by regressing this objective biomarker on self-reported PA and sedentary behavior, Actical accelerometer PA, and other subject characteristics.

Results: Age, weight and height explained a significant amount of variation in AEE. Actical PA and wear-time were important predictors of AEE; whereas, self-reported PA was not independently associated with AEE. The final calibration equation explained fifty percent of variation in AEE.

Conclusions: The developed calibration equations can be used to obtain error-corrected associations between PA and health outcomes in HCHS/SOL. Our study represents a unique opportunity to understand the measurement characteristics of PA instruments in an under-studied Hispanic/Latino cohort.

1.   Background

There is a large body of evidence demonstrating that regular physical activity (PA) is an important determinant of health. Higher PA levels have been associated with lower risks of coronary heart disease, diabetes, and some cancers, such as colon and breast; and it has been associated with better mental health, better bone health and overall functional health.[1] PA can also be an important factor for energy balance and weight control.[2] In order to assess the association between PA and disease, an accurate measure of individual PA is vital.

PA in free-living individuals is variable and difficult to measure. Previous studies have shown that the instruments commonly used in epidemiologic studies for PA assessment, such as self-reported questionnaires or accelerometers, are subject to systematic measurement error.[3–5] Weight lifting, biking, swimming or levels of activity while sitting, are more difficult to track with accelerometry. Systematic error related to participant characteristics such as gender, body mass index (BMI, body mass/height2 (kg/m2)), and age, has been observed in self-reported PA data, and this type of error can create negative or positive bias in estimated exposure-disease associations.[3,6] The day-to-day variability (random error) in an individual's PA level limits the precision with which an instrument can capture habitual PA, which can attenuate estimates of associations between PA and health outcomes and reduce the power to detect such associations. Objective biomarkers following

a classical measurement error model (random error), such as doubly labeled water (DLW) for total energy expenditure (TEE), can be used to calibrate other measures that encompass both systematic and random error.[6] These types of studies have been conducted for dietary exposures,[7–9] but PA has been less studied in this context. Previous studies validating measures of PA from self-report or accelerometry in free-living persons with DLW have been conducted in small and/or very specific cohorts of individuals, and participant characteristics have been shown to be important factors in the degree of correlation with the objective biomarkers.[10–12]

As part of the Hispanic Community Health Study/Study of Latinos (HCHS/SOL),[13,14] we performed the Study of Latinos Nutrition & Physical Activity Assessment Study (SOLNAS), in which a biomarker measure of activity-related energy expenditure (AEE) and dietary factors were obtained on a subset of participants.[9] The purpose of SOLNAS was to use biomarker measures to characterize the error/reliability in the HCHS/SOL study instruments of diet and PA and derive calibration equations for use in epidemiologic investigations in the HCHS/SOL cohort. We previously reported on the calibration equations for self-reported dietary nutrients, including energy, protein, sodium and potassium, derived using the objective dietary recovery biomarkers[9,15] Here, we present the measurement properties and derive regression calibration equations for the self-reported PA and accelerometer instruments used in HCHS/SOL, which provide a measurement-error corrected measure of an individual's activity-related PA level.[6] SOLNAS presents a unique opportunity to understand the nature of measurement error in these commonly used PA instruments in an under-studied Hispanic population, given that the types of physical activities they engage in may differ from those of non-Hispanic populations.[16] The calibration equations we develop can be used in future studies to better understand the relationship between PA and health outcomes in this cohort.[17–19]

2. Methods

HCHS/SOL is a community-based cohort study of 16,415 adults aged 18–74 years who self-identified as Hispanic/Latino and were recruited in 2008–2011 from randomly selected households in four US urban centers (Chicago, IL; Miami, FL; Bronx, NY; San Diego, CA). [13,14] Four of the metropolitan areas within the US with the largest number of Hispanics/Latinos were selected as sites to study the health status, as well as study associations between baseline risk factors and disease, in several Hispanic/Latino backgrounds. Individuals had a comprehensive baseline examination that included biological, behavioral and social-demographic assessments, yearly follow-up and a second clinic visit (October, 2014–2017). Four hundred eighty-five HCHS/SOL participants were enrolled in the SOLNAS study in 2010–2012.[9] SOLNAS enrollment targets at each site were set by specific categories for age, BMI, and Hispanic/Latino background to mirror the characteristics of the parent study. All participants provided informed consent and study procedures were approved by the institutional review board at each participating institution.

Individuals eligible for SOLNAS were those whose baseline HCHS/SOL study visit was within 7 months, extended for one site to 12 months (Supplemental Fig. 1). Participants were excluded for having any medical condition that could affect weight stability or

performance of the biomarkers, including pregnancy or breast feeding, weight change >15 pounds in past four weeks, taking medication for diabetes, irregular use of diuretics, recent initiation of medications that affect energy expenditure (EE) (e.g. thyroid medication) or energy intake (e.g. chemotherapy), having extended travel planned during the study period, or claustrophobia (since the indirect calorimetry measurement required participants to lie under a hood for 30 min). Of the 1360 individuals invited, 342 (25.1%) declined, 176 (12.9%) could not be contacted, 227 (16.7%) were ineligible, 603 agreed (44.3%), and 485 (35.7%) signed an informed consent. A total of 477 completed the protocol and a subsample of 98 individuals (20%) repeated the study protocol approximately 6 months later to provide data for reliability analyses.

The SOLNAS protocol included two study visits on all participants. At Visit 1, participants provide an informed consent, underwent anthropometry, initiated a DLW protocol and completed a 24-h dietary recall and questionnaires on sedentary behavior and body image.[9] Visit 2 occurred twelve days later to complete the DLW protocol and obtain weight and indirect calorimetry. SOLNAS participants, as part of the HCHS/SOL baseline, self-reported their PA and were asked to wear an Actical accelerometer. Self-reported PA in a typical week was assessed using a modified Global Physical Activity Questionnaire (GPAQ).[20,21] The GPAQ had both an English and Spanish version. Details regarding DLW, indirect calorimetry and accelerometer protocols are provided in the Supplemental Materials. Participants selected to participate in the reliability subsample repeated procedures for the Actical accelerometer, DLW, indirect calorimetry, and 24-h dietary recall at Visits 3 and 4, five to seven months later (Supplemental Fig. 1).

Self-reported min/day of moderate and vigorous activities were reported across three domains: recreation, work, and transportation. The amount of time spent sitting or reclining was also self-reported, which was coded in the analysis as time spent in sedentary behavior. From accelerometry, counts/min were used to categorize time in sedentary behavior, as well as light, moderate or vigorous activity. Light PA was defined as 100–1534 counts/min, moderate as 1535–3961 counts/min, vigorous as >3961 counts/min, and sedentary behavior as <100 counts/min.[22,23] The average wear-time (minutes/day) was calculated for those participants with at least three days each with 10 or more hours of wear-time. Biomarker AEE in kcal/day was derived as TEE, measured by DLW, minus resting energy expenditure (REE), measured by indirect calorimetry, with a correction for the thermic effect of food (AEE = $0.9 \times$ TEE-REE).

We develop a regression model to predict usual AEE using the SOLNAS main study visit biomarkers (Visit 1). We assume that the biomarker measurement of AEE (M), as a measure of the true underlying usual AEE (Y), adheres to the classical measurement error model (random (mean 0) error independent of Y and other personal characteristics). That is, we assume no systematic trends in AEE over time, only random day-to-day variation — an assumption consistent with the SOLNAS eligibility requirement that individuals be weight stable. Under this assumption, coefficients for the regression of Y on predictors X can be estimated by regressing M on the same predictors. We also calculated the Pearson's correlation between the repeat measures and used the method of Prentice et al.[24] to estimate the R-squared coefficients adjusted for the random variability (measurement error). This

measurement-error adjusted R-squared coefficient estimates the amount of variation explained by the model covariates if the day-to-day variability of AEE could be removed.

Because our analysis approach was to build a statistical prediction model for usual AEE, we sought a regression model that had many predictors in order to leverage the correlation between usual AEE and personal characteristics, as well as measures of PA and sedentary behavior. The Akaike information criterion (AIC) was used to select the functional form for the AEE predictors, including those summarizing PA and sedentary behavior (see Supplemental Methods and Supplemental Table 1). The final calibration model included predictors for both PA instruments. All models were adjusted for the same participant characteristics collected at the HCHS/SOL baseline visit, including age, sex, Hispanic/Latino background, BMI, language preference, education, income, employment status, and other health factors (See Supplementary Materials). As a sensitivity analysis, we fit a parsimonious calibration model using backwards model selection requiring p-value <0.20. We also considered whether interaction terms between language preference and level of self-reported PA; however, these interactions did not improve the predictive performance of the model (see Supplemental Materials Table 1).

Inverse probability weighting (IPW) was used to account for missingness in the regression models that included accelerometry predictors, as 14.4% had missing or unacceptable accelerometry (Supplemental Fig. 2). Further details are provided in the Supplemental Materials. Regressions based only on GPAQ and other participant characteristics were performed as a complete case analysis, as 408 participants (92%) had complete covariates in the full prediction model that excluded Actical (Supplemental Fig. 2).

All tests of significance were two-sided and performed at the 0.05 level. Statistical analyses were conducted with SAS, version 9.3, (SAS Institute, Inc., Cary, North Carolina) and R, version 3.2.4 (R Foundation for Statistical Computing, Vienna, Austria).

3. Results

Sociodemographic characteristics of SOLNAS participants are shown in Table 1. Participants were 62% female, had a mean age of 46 years and mean BMI of 30 kg/m^2 at baseline. Median yearly household income was between $20–40,000 and 56% did not have education beyond high school. Supplemental Table 2 shows other lifestyle and health-related characteristics. Notably, 66% of males and 43% of female self-reported a high level of PA based on the 2008 Physical Activity Guidelines for Americans,[25] with another 9–10% reporting medium level activity.

According to DLW, females and males expended an average (SD) of 2196 (354) and 2772 (502) kcal/day, respectively; females and males had an average AEE of 581 (253) and 741 (357) kcal/day, respectively (Table 1). The work domain explained much of the higher levels of the GPAQ vigorous activities for males, with an average (SD) 89 (147) min reported for males and only 33 (88) min for females (Supplemental Table 3).

Participants wore the Actical device for an average of 16.2 (3.0) hours per day, with no meaningful differences in wear-time by sex. There were 64 of 445 individuals (14.4%) who

were missing accelerometry, which was a slightly lower missingness rate than the 22% observed for the entire HCHS/SOL cohort.[26] Supplemental Tables 4 and 5 examined the association between missing accelerometry and patient characteristics. Similar to the parent cohort, missingness was significantly associated with Hispanic/Latino background and appeared higher for women and younger participants, though these differences were not significant in the SOLNAS cohort.

Accelerometer estimates of time spent in moderate and vigorous PA levels were lower than those self-reported, with participants having an average (SD) of 23 (23) min/day of moderate or vigorous activity, compared to 107 (167) min/day estimated by the GPAQ. This was true for both males and females; however, the difference between instruments was larger for males, resulting in a smaller difference between genders in the amount of moderate or vigorous activity measured by the Actical compared to GPAQ. The age-adjusted difference in the amount of time (min/day) spent in moderate or vigorous activity was 77.6 fewer minutes for females versus males according to GPAQ ($p < 0.0001$) and 9.2 fewer minutes according to the Actical ($p = 0.0001$) (Table 1).

Table 2 displays the calibration equations with PA predictor variables measured by GPAQ alone, Actical alone, and the full model with both GPAQ and Actical. The adjusted R-squared coefficient was highest at 0.19 for the model with only the Actical PA predictors, suggesting little to no additional predictive value for usual AEE from the self-reported PA and sedentary behavior. The amount of time spent in light activity was the most important Actical predictor (Table 2). Age, body mass and height were important predictors that significantly explained variation in AEE; other borderline significant predictors included female gender ($p = 0.09$), Hispanic/Latino background ($p = 0.06$), and employment ($p = 0.10$). Supplemental Table 6 provides the reduced calibration model from the backwards selection ($p < 0.20$). Coefficients and significance were similar for this reduced model. Since our goal is to build a prediction model for usual AEE, we included many predictors in our main model and de-emphasize the interpretation of individual beta coefficients, which can be complex given the relationship between variables and potential systematic error in self-reported and accelerometer measures in PA and sedentary behavior.

Fig. 1 compares the reliability of the TEE, REE, and AEE measures, showing the Pearson's correlation between the baseline and 6-month visit values for individuals in the reliability subset ($N = 86$). Correlation was 0.80, 0.88, and 0.50 for TEE, REE, and AEE, respectively. The measurement-error corrected R-squared coefficients for the three models in Table 4 were 0.42, 0.49 and 0.50 for the models with PA based on GPAQ alone, Actical alone and the combination, respectively.

4. Discussion

Hispanics/Latinos in the United States have a high burden of obesity, heart disease and diabetes.[27–29] It is important to understand to what extent the level of PA in this population contributes to these risks. This is the first detailed study in the United States that compared self-reported PA and accelerometry to a DLW-assessed value of AEE in a diverse cohort of Hispanic/Latino men and women. This study provides information on the performance of

these instruments in this population and also developed a set of regression calibration equations for AEE, which can be used in studies of the prospective HCHS/SOL cohort that aim to estimate the level of PA and provide a measurement-error adjusted association of PA with health outcomes.[6]

An important finding of this study is that little to no association was found between usual AEE and self-reported level of PA measured by the GPAQ. Further, there were systematic differences in the level of PA by the accelerometry and self-reported instruments. For example, men had more moderate PA than women according to self-report; whereas according to accelerometry, men and women had similar levels. Such systematic differences, if not accounted for, can cause bias in analyses that focus on relating AEE with health outcomes. Adjusted associations with the accelerometer measures of PA were also modest. Our study also revealed that overall AEE has an appreciable amount of within-person variability (reliability coefficient 0.50). This finding suggests that within-person variability, if ignored, would cause an appreciable amount of dilution bias in analyses using PA exposures.

There are relatively few large prospective cohort studies that have compared PA study measures to an objective and unbiased biomarker measure of AEE. Neuhouser et al.[10] is one such study from the Women's Health Initiative (WHI); in this cohort, self-reported PA did explain a small amount of variation in the objective measure of AEE, in contrast to our population. This finding emphasizes that cohort-specific calibrations are useful and necessary. The WHI is a relatively healthy, non-Hispanic white and well-educated cohort; in contrast, our population is Hispanic/Latino, with relatively low education and income, and overall had very little moderate to vigorous activity.

Our study has some limitations. We assumed that the error terms in the objectively measured AEE would not be correlated with those in the accelerometer or self-reported PA. It is uncertain to what degree such correlations between the multiple measures of PA exist in our cohort. Our prediction models explained a relatively low amount of variability in AEE, which had an appreciable amount of within-person variability. Future studies that desire a more accurate estimate of AEE may want to consider an average of repeated measures over time. Light activity, which comprises a substantial amount of PA in our cohort, was not assessed by the GPAQ, which may have limited its ability to capture the main sources of PA in this cohort. This finding is noteworthy as GPAQ is a commonly used PA instrument in current cohort studies. Another limitation is that the timing of the Actical and GPAQ measures was about 7 (IQR, 6.5,7.1) months earlier than the AEE in the primary study; however, Actical and AEE measures were performed at about the same time period in the reliability study. We assume there were no systematic differences in the average PA level during this time period, although seasonality and temporal differences could have lowered the correlation between these different PA measures. There was little change in AEE (Fig. 1) and the SOLNAS reliability Actical measure, which occurred a median of 12.7 (IQR 12.2, 13.4) months after the HCHS/SOL baseline measure, had an average change from baseline in MVPA of 1.7 min/week (95% CI: −4.6, 8.1).

5. Conclusion

Many previous studies of PA and health outcomes have relied on error-prone measures of PA, with no adjustment for measurement error. In a recent systematic review, roughly 40% did not acknowledge the impact that mismeasurement of PA could be having on their studies' results and almost no studies adjusted their statistical analyses for measurement error.[30] The developed biomarker-calibrated PA, which relies on an unbiased and objective biomarker, provides such an adjustment that can be used to adjust estimated associations for bias from error-prone exposures.[6] Future work will enhance efforts to study the association between calibrated PA and chronic health outcomes, such as diabetes and heart disease, in the HCHS/SOL cohort.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments and funding

Appendix A.: Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.jsams.2018.07.021.

References

1. World Health Organization. Global recommendations on physical activity for health, Geneva, Switzerland, WHO Press, 2010.

2. Hall KD, Heymsfield SB, Kemnitz JW et al. Energy balance and its components: implications for body weight regulation. Amer J Clin Nutr 2012; 95(4):989–994. [PubMed: 22434603]

3. Neilson HK, Robson PJ, Friedenreich CM et al. Estimating activity energy expenditure: how valid are physical activity questionnaires? Am J Clin Nutr 2008; 87(2):279–291. [PubMed: 18258615]

4. Plasqui G, Westerterp KR. Physical activity assessment with accelerometers: an evaluation against doubly labeled water. Obesity 2007; 15(10):2371–2379. [PubMed: 17925461]

5. Leenders NY, Sherman WM, Nagaraja HN et al. Evaluation of methods to assess physical activity in free-living conditions. Med Sci Sports Exerc 2001; 33(7):1233–2140. [PubMed: 11445774]

6. Carroll RJ, Ruppert D, Stefanski LAet al. Measurement Error in Nonlinear Models: A Modern Perspective, 2nd ed. New York, CRC Press, 2006.

7. Subar AF, Kipnis V, Troiano RP et al. Using intake biomarkers to evaluate the extent of dietary misreporting in a large sample of adults: the OPEN study. Am J Epidemiol 2003; 158:1–13. [PubMed: 12835280]

8. Neuhouser ML, Tinker L, Shaw PA et al. Use of recovery biomarkers to calibrate nutrient consumption self-reports in the Women's Health Initiative. Am J Epidemiol 2008; 167:1247–1259. [PubMed: 18344516]

9. Mossavar-Rahmani Y, Shaw PA, Wong WW et al. Applying recovery biomarkers to calibrate self-report measures of energy and protein in the Hispanic Community Health Study/Study of Latinos. Am J Epidemiol 2015; 181(12):996–1007. [PubMed: 25995289]

10. Neuhouser ML, Di C, Tinker LF et al. Physical activity assessment: biomarkers and self-report of activity-related energy expenditure in the WHI. Am J Epidemiol 2013; 177(6):576–585. [PubMed: 23436896]

11. Maddison R, Mhurchu CN, Jiang Y et al. International Physical Activity Questionnaire (IPAQ) and New Zealand Physical Activity Questionnaire (NZPAQ): a doubly labelled water validation. Int J Behav Nutr Phys Act 2007; 4:62 10.1186/1479-5868-4-62. [PubMed: 18053188]

12. Plasqui G, Joosen A, Kester AD et al. Measuring free-living energy expenditure and physical activity with triaxial accelerometry. Obes Res 2005; 13(8):1363–1369. [PubMed: 16129718]

13. Lavange LM, Kalsbeek WD, Sorlie PD et al. Sample design and cohort selection in the Hispanic Community Health Study/Study of Latinos. Ann Epidemiol 2010; 20(8):642–649. [PubMed: 20609344]

14. Sorlie PD, Avilés-Santa LM, Wassertheil-Smoller S et al. Design and implementation of the Hispanic Community Health Study/Study of Latinos. Ann Epidemiol 2010; 20(8):629–641. [PubMed: 20609343]

15. Mossavar-Rahmani Y, Sotres-Alvarez D, Wong WW et al. Applying recovery biomarkers to calibrate self-report measures of sodium and potassium in the Hispanic Community Health Study/Study of Latinos. J Hum Hypertens 2017; 31(7):462–473. [PubMed: 28205551]

16. Arredondo EM, Sotres-Alvarez D, Stoutenberg M et al. Physical activity levels in US Latino/Hispanic adults: results from the Hispanic Community Health Study/Study of Latinos. Am J Prev Med 2016; 50(4):500–508. [PubMed: 26597505]

17. Prentice RL, Shaw PA, Bingham S et al. Biomarker-calibrated energy and protein consumption and increased cancer risk among postmenopausal women. Am J Epidemiol 2009; 169(8):977–989. [PubMed: 19258487]

18. Prentice RL, Huang Y, Kuller LH et al. Biomarker-calibrated energy and protein consumption and cardiovascular disease risk among postmenopausal women. Epidemiology 2011; 22:170–179. [PubMed: 21206366]

19. Tinker L, Sarto G et al. Biomarker-calibrated dietary energy and protein intake associations with diabetes risk among postmenopausal women from the Women's Health Initiative. Amer J Clin Nutr 2011; 94(6):1600–1606. [PubMed: 22071707]

20. Hoos T, Espinoza N, Marshall S et al. Validity of the Global Physical Activity Questionnaire (GPAQ) in adult Latinas. J Phys Act Health 2012; 9(5):698–705. [PubMed: 22733873]

21. Bull FC, Maslin TS, Armstrong T. Global physical activity questionnaire (GPAQ): nine country reliability and validity study. J Phys Act Health 2009; 6(6):790–804. [PubMed: 20101923]

22. Colley RC, Tremblay MS. Moderate and vigorous physical activity intensity cut-points for the Actical accelerometer. J Sports Sci 2011; 29(8):783–789. [PubMed: 21424979]

23. Wong SL, Colley R, Connor Gorber S et al. Actical accelerometer sedentary activity thresholds for adults. J Phys Act Health 2011; 8(4):587–591. [PubMed: 21597132]

24. Prentice RL, Mossavar-Rahmani Y, Huang Y et al. Evaluation and comparison of food records, recalls and frequencies for energy and protein assessment by using recovery biomarkers. Am J Epidemiol 2011; 174(5):591–603. [PubMed: 21765003]

25. Physical Activity Guidelines Advisory Committee. Physical activity guidelines for Americans Washington, DC : US Department of Health and Human Services 2008, 15–34.

26. Evenson KR, Sotres-Alvarez D, Deng YU et al. Accelerometer adherence and performance in a cohort study of US Hispanic adults. Med Sci Sports Exerc 2015; 47:725–734. [PubMed: 25137369]

27. Daviglus ML, Talavera GA, Avilés-Santa ML et al. Prevalence of major cardiovas-cular risk factors and cardiovascular diseases among Hispanic/Latino individuals of diverse backgrounds in the United States. JAMA 2012; 308(17):1775–1784. [PubMed: 23117778]

28. Schneiderman N, Llabre M, Cowie CC et al. Prevalence of diabetes among Hispanics/Latinos from diverse backgrounds: the Hispanic Community Health Study/Study of Latinos (HCHS/SOL). Diabetes Care 2014; 37(8):2233–2239. [PubMed: 25061138]

29. Kaplan RC, Avilés-Santa ML, Parrinello CM et al. Body mass index, sex, and cardiovascular disease risk factors among Hispanic/Latino adults: Hispanic Community Health Study/Study of Latinos. J Am Heart Assoc 2014; 3(4):e000923. [PubMed: 25008353]

30. Shaw PA, Deffner V, Keogh RH, Tooze JA, Dodd KW, Kuechenhoff H, Kipnis V, Freedman LS for members of STRATOS TG4. Measurement Error and Misclassification: Understanding and Improving Current Practice 2018; arXiv:1802.10496 [stat.AP].

Practical implications

- Typical measures of usual physical activity in epidemiologic studies, *i.e.* self-report or accelerometry, have systematic error and day-to-day variability that can bias measures of association between PA and health.

- In an understudied Hispanic cohort, we provided calibration equations that adjust for both systematic error and day-to-day variability in AEE.

- The developed calibration equations provide an error-corrected measure of PA that can be used in future studies to better understand the relationship between PA and health.

Total Energy Expenditure (KCAL/d)

r =0.80

Resting Energy Expenditure (KCAL/d)

r =0.88

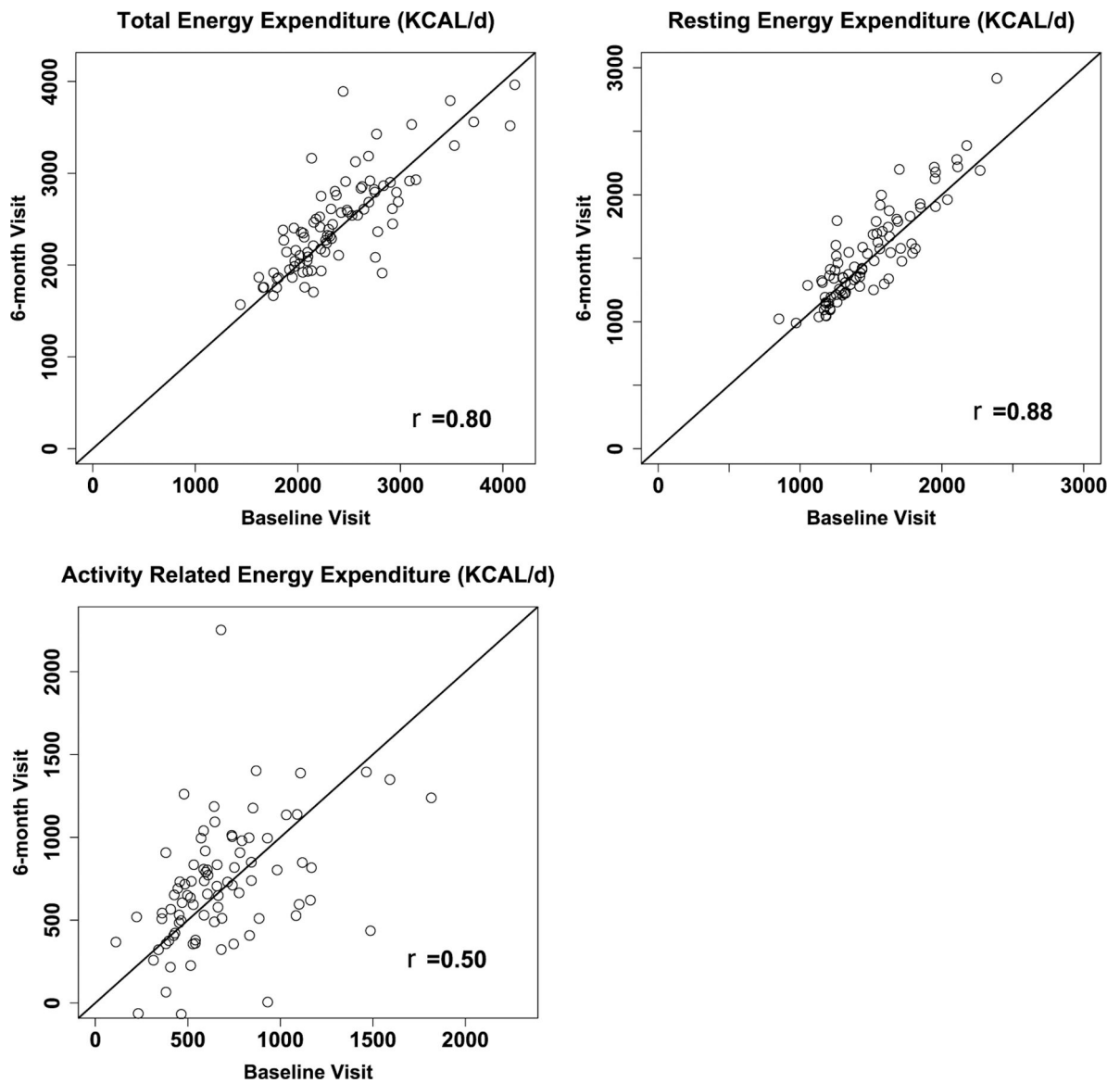**Activity Related Energy Expenditure (KCAL/d)**

r =0.50

Fig. 1.
Comparison of total, resting, and activity-related energy expenditure between baseline and 6-months. TEE, total energy expenditure; AEE, activity-related energy expenditure. TEE was measured by doubly-labeled water, resting energy expenditure (REE) by indirect calorimetry, and AEE = 0.90xTEE − REE (n = 86).

Table 1

Demographic characteristics of SOLNAS participants (n = 445) [a].

Variable	Overall (n = 445)	Female (n = 273)	Male (n = 172)
Mean Age (SD), in years	45.9 (13.1)	46.9 (12.4)	44.3 (14.1)
Mean Body Mass Index (SD), kg/m^2	29.7 (5.9)	30.1 (6.0)	29.1 (5.8)
Mean total body water (SD), kg	36.8 (7.5)	32.2 (3.8)	44.0 (6.0)
Hispanic/Latino background			
Central American	48 (10.8)	29 (10.6)	19 (11.0)
Cuban	65 (14.6)	36 (13.2)	29 (16.9)
Dominican	43 (9.7)	26 (9.5)	17 (9.9)
Mexican	137 (30.8)	91 (33.3)	46 (26.7)
Puerto Rican	112 (25.2)	67 (24.5)	45 (26.2)
South American	40 (9.0)	24 (8.8)	16 (9.3)
Spanish language preference	342 (76.9)	220 (80.6)	122 (70.9)
Yearly household income [b]			
$10,000	61 (13.7)	43 (15.8)	18 (10.5)
$10,001–$20,000	151 (33.9)	96 (35.2)	55 (32.0)
$20,001–$40,000	129 (29.0)	74 (27.1)	55 (32.0)
$40,001–$75,000	55 (12.4)	34 (12.5)	21 (12.2)
>$75,000	9 (2.0)	2 (0.7)	7 (4.1)
Education status			
Less than high school	142 (31.9)	96 (35.2)	46 (26.7)
High school or equivalent (GED)	111 (24.9)	65 (23.8)	46 (26.7)
Trade/Vocational school	67 (15.1)	45 (16.5)	22 (12.8)
University/College	125 (28.1)	67 (24.5)	58 (33.7)
Activity measures	Mean (SD)	Mean (SD)	Mean(SD)
Total energy expenditure (kcal/day)	2418.4 (502.7)	2195.7 (354.3)	2771.9 (501.6)
Activity-related energy expenditure (kcal/day)	642.7 (307.2)	580.9 (252.8)	740.7 (357.2)
GPAQ [c] activity			
Sedentary (min/day)	262.0 (188.2)	256.1 (195.1)	271.4 (176.9)
Moderate (min/day)	81.4 (134.8)	65.5 (122.7)	106.8 (148.8)

Variable	Overall (n = 445)	Female (n = 273)	Male (n = 172)
Vigorous (min/day)	25.4 (67.7)	11.4 (46.9)	47.7 (87.0)
Actical activity			
Sedentary (min/day)	727.9 (178.1)	718.1 (172.7)	743.3 (185.7)
Light (min/day)	221.3 (94.1)	223.3 (96.4)	218.1 (90.4)
Moderate (min/day)	20.5 (18.9)	17.9 (17.2)	24.6 (20.7)
Vigorous (min/day)	2.7 (6.8)	1.7 (5.3)	4.2 (8.4)
Counts/min	162.3 (99.3)	182.8 (105.3)	149.2 (93.1)

[a]Numbers as N (%) unless otherwise stated.

[b]Percentages do not add up to missing data: income (missing 40).

[c]Global physical activity questionnaire.

Table 2

Calibration model of activity-related expenditure (AEE = 0.90xTEE-REE)[a,b].

Variable	GPAQ Model R² = 0.227, Adj R² = 0.150 (n = 409)			ACTICAL Model R² = 0.275, Adj R² = 0.189 (n = 350)			GPAQ and ACTICAL Model R² = 0.283, Adj R² = 0.187 (n = 350)			
	β	SE	P Value	β	SE	P Value	β	SE	P Value	P Value[d]
Intercept[c]	797.7	63.13	<.0001	673.1	87.28	<.0001	681.6	88.97	<.0001	—
ACTICAL: % Light Activity	—	—	—	4.6	1.93	0.0170	3.8	1.99	0.0555	0.0208
% Moderate Activity	—	—	—	17.1	10.33	0.0979	17.9	10.52	0.0905	—
% Vigorous Activity	—	—	—	-31.9	30.86	0.3024	-36.0	31.07	0.2478	—
ACTICAL: Total Wear Time, hours	—	—	—	11.9	5.90	0.0437	11.8	5.94	0.0487	—
GPAQ: Sedentary	-0.1	0.08	0.1295	—	—	—	-0.1	0.09	0.4070	0.5217
Work	0.3	0.15	0.0533	—	—	—	0.2	0.15	0.2833	—
Transportation	-0.2	0.21	0.3739	—	—	—	-0.2	0.22	0.3091	—
Recreational	-0.2	0.33	0.5699	—	—	—	-0.2	0.33	0.5964	—
Age, years	4.3	1.56	0.0069	5.0	1.58	0.0016	4.7	1.61	0.0040	—
Sex, female	-89.4	45.95	0.0524	-93.5	48.47	0.0547	-84.0	49.58	0.0910	—
Weight, kg	2.1	0.95	0.0265	3.0	1.04	0.0040	2.9	.05	0.0057	—
Height, cm	5.5	2.59	0.0336	6.7	2.75	0.0151	7.1	2.78	0.0116	—
Background: Central American	-64.8	52.47	0.21175	-60.8	55.05	0.2706	-61.9	56.01	0.2700	0.0626
Cuban	-102	53.57	0.0565	-115	57.29	0.0459	-107	58.08	0.0670	—
Dominican	51.0	56.96	0.3707	-35.1	62.92	0.5771	-31.7	64.01	0.6213	—
Puerto Rican	-39.3	45.86	0.3925	-80.1	51.56	0.1213	-77.1	51.78	0.1375	—
South American	-157	55.63	0.0049	-165	56.61	0.0038	-164	57.35	0.0046	—
Language preference: English	21.6	41.39	0.6028	15.3	43.85	0.7281	17.9	4.60	0.6881	—
Education: Less than high school	42.5	41.08	0.3017	32.4	42.46	0.4465	26.3	42.91	0.5400	0.3005
Trade school	18.9	49.96	0.7051	23.6	52.29	0.6520	16.2	52.65	0.7585	—
University/college	-56.9	40.78	0.1638	-45.2	42.17	0.2842	-48.9	42.51	0.2508	—
Income: Missing	39.7	58.71	0.4995	62.2	59.92	0.3001	58.7	60.49	0.3324	0.8325
Less than $10,000	12.1	52.10	0.8167	-1.6	52.86	0.9762	-4.4	54.06	0.9348	—
$10,001-$20,000	-24.8	37.33	0.5065	-14.4	38.90	0.7123	-15.9	39.11	0.6850	—
$40,001-$75,000	-40.4	50.40	0.4233	-10.7	52.55	0.8390	-16.3	52.91	0.7582	—

	GPAQ Model R² = 0.227, Adj R² = 0.150 (n = 409)			ACTICAL Model R² = 0.275, Adj R² = 0.189 (n = 350)			GPAQ and ACTICAL Model R² = 0.283, Adj R² = 0.187 (n = 350)			
More than $75,000	−98.1	106.1	0.3557	−93.4	111.1	0.4012	−77.8	112.3	0.4890	–
Employment: Retired	−178	68.18	0.0096	−188	69.35	0.0071	−165	71.49	0.0220	0.1045
Not retired	−33.6	42.10	0.4250	−21.9	42.40	0.6052	−11.5	44.99	0.7982	–
Part-time	−8.1	45.00	0.8570	11.0	46.81	0.8152	10.8	47.54	0.8211	–

[a] AEE, activity related energy expenditure; TEE, total energy expenditure; REE, resting energy expenditure. Adj Rsq, Adjusted R-squared coefficient; HS, high school. Actical is an accelerometer (Phillips, Respironics, Bend, Oregon); GPAQ, Global Physical Activity Questionnaire.

[b] Each model was also adjusted for alcohol use, cigarette use, sleep duration, SF-12 physical health score, CESD-10 depression score, and presence of: diabetes, hypertension, hypercholesterolemia, asthma, COPD; coefficients are not shown. See Supplemental materials for further information.

[c] Reference group is Mexican background, Spanish speaking, high school diploma, employed full-time and income $20,001–$40,000.

[d] P-values in rightmost column are for the bundled variables in the "GPAQ and ACTICAL" Model.