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Original Research Article

Accelerometer-Measured Physical Activity Among Older Adults in Urban India: Results of a Study on global AGEing and adult health Substudy

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ABSTRACT: Objectives: Accelerometry provides researchers with a powerful tool to measure physical activity in population-based studies, yet this technology has been underutilized in cross-cultural studies of older adults. The present study was conducted among older adults in an urban setting in India with the following three objectives: (1) to compare average activity levels obtained through different durations of monitoring (1, 3, and 7 days); (2) to document differences in physical activity patterns by sex and age; and (3) to evaluate links between measures of physical activity and anthropometrics, as well as between activity parameters and measures of household size, work status, and social cohesion.

Methods: The present study uses data from a physical activity substudy of the World Health Organization's Study on global AGEing and adult health (SAGE-PA). This study of 200 older adults (49–90 years old; 72 males, 128 females) in urban India combines 7 continuous days of ActiGraph GT3X accelerometry with anthropometric and sociodemographic data.

Results: Results reveal overall low activity levels, with significantly lower activity energy expenditure (AEE) among females ($P < 0.05$). No significant differences were documented in activity level by monitoring duration. Age was negatively correlated with AEE in men ($P < 0.01$) and women ($P < 0.001$). AEE was positively correlated with BMI in men ($P < 0.01$) and women ($P < 0.05$). Finally, women who were more socially integrated had greater AEE ($P < 0.01$).

Conclusions: This study illustrates the utility of accelerometry for quantifying activity levels in aging populations in non-Western nations. Am. J. Hum. Biol. 28:412–420, 2016. © 2015 Wiley Periodicals, Inc.

INTRODUCTION

Recent technological advances in accelerometry have provided researchers with a useful tool for accurately measuring energy expenditure and documenting physical activity patterns in population-level studies (Plasqui and Westerterp, 2007; Troiano et al., 2008). However, this technology has been underutilized in the study of physical activity patterns among non-Western groups (cf. Cook et al., 2012; Gurven et al., 2013; Luke et al., 2011; Madimenos et al., 2011; Tudor-Locke et al., 2003) and relatively few studies have examined older adults (≥50 years old) in these populations (cf. Peters et al., 2010). This is unfortunate given evidence that accelerometry accurately and reliably distinguishes activity levels between older adults and enables the comparison of activity patterns between diverse populations (Copeland and Esliger, 2009; Davis and Fox, 2007; Miller et al., 2010; Taraldsen et al., 2012; Westerterp, 1999). Furthermore, accelerometers allow the accurate measurement of sedentary and sleep time, which have emerged as independent predictors of many negative health outcomes (Owen et al., 2010; Sadeh, 2011; Santos et al., 2012).

To date, most data on physical activity among older adults is based on self-report, yet these activity calculations can underestimate energy expenditure because they do not consider spontaneous physical activities and often fail to record the complexity and multidimensional nature of active behavior that occurs during normal daily life (Kashiwazaki et al., 2009; Leonard et al., 1997; Snodgrass, 2012). Moreover, population studies such as NHANES in the United States have documented marked overestimations of activity by self-report compared to accelerometry (Troiano et al., 2008; Tucker et al., 2011). In fact, a panel of experts recently concluded that self-report physical activity energy expenditure measurements "are so poor that they are wholly unacceptable for scientific research" (Dhurandhar et al., 2015: 1109). In addition to these and other well-documented limitations of self-report activity data, studies of older adults have shown that memory recall and cognitive challenges can affect measurements, as can physical and mental health status (Harada et al., 2001; Sallis and Saelens, 2000). Likewise, light and moderate intensity activities are the most difficult to recall, yet these are precisely the activities that are the most common among older adults (Jørstad-Stein et al., 2005; Rikli, 2000; Taraldsen et al., 2012; Theou et al., 2012; Washburn et al., 1993). Finally, objective measures of physical activity are more strongly associated with health status, including frailty, compared to self report (Harris et al., 2009; Theou et al., 2012).

Notably, higher levels of physical activity are associated with increased survival, better physical functioning and mobility, lower risk of frailty, and better mental health

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among older adults (Buchman et al., 2012; Morie et al., 2010; Santos et al., 2012; Theou et al., 2012; Vallance et al., 2011). A number of studies have documented a significant decline in the duration and intensity of physical activity with age (Brown et al., 2005; Davis and Fox, 2007; Evenson et al., 2012; Hansen et al., 2012; Westerterp and Meijer, 2001); however, most studies have used self-report data and those that use objective measures such as accelerometry or doubly labeled water (DLW) have been conducted almost exclusively among populations in high-income countries such as the United States. Self-report activity data, which appear particularly problematic when used in low- and middle-income countries (Hallal et al., 2010, 2012), do document a pattern of increased inactivity with advancing age (Dumith et al., 2011; Hallal et al., 2012). Given the lack of objectively measured activity data, it is unclear whether the marked age-related decline in physical activity seen in the United States and Europe is as pronounced among older adults in low- and middle-income countries, who may have radically different lifestyles with dissimilar transportation options, occupations, and leisure-time behaviors, or whether this pattern is related to behavioral shifts seen principally in high-income countries. This is an important topic given that many populations are currently experiencing rapid economic development and adopting Western diets and lifestyles, which are increasing the burden of chronic conditions such as cardiovascular disease and diabetes among older adults.

The accurate assessment of physical activity is essential to understand the increasing global prevalence of obesity and associated conditions and for designing effective strategies for interventions (Taraldsen et al., 2012). Obesity is now a major health issue throughout the world, with prevalence at unprecedented levels in most economically developing countries, as well as a rate of increase in much of Asia, Latin American, and North Africa that far outpaces that seen among high-income nations (Kelly et al., 2008; Popkin, 2003; WHO, 2000; WHO/FAO, 2003). Obesity also appears to be a growing problem for older adults, especially in high-income nations such as the United States where approximately 37% of men and 34% of women over 60 are classified as obese (based on data from NHANES 2007-2008; Flegal et al., 2010). This rise in obesity prevalence does not appear limited to these populations, and recent data suggest that risk of overweight and obesity is on the rise in most countries (Salihu et al., 2009; Villareal and Shah, 2009; Zamboni et al., 2005). Self-report data from the International Physical Activity Questionnaire and Global Physical Activity Questionnaire (GPAQ) show relatively low physical activity in high-income countries (Hallal et al., 2012), which may help explain increasing prevalence of obesity coincident with economic development and lifestyle change. Furthermore, although there are minimal data available, there is suggestive evidence from self-report and objective measurements for a recent decline in physical activity among adults of several economically developing nations, which is likely the result of societal changes such as decreases in occupational energy expenditure (Knuth et al., 2010; Snodgrass et al., 2006; Snodgrass, 2012; Sun et al., 2013). For example, a recent study that examined trends in physical activity patterns over time in a diverse set of nations (e.g., India, Brazil, China, and the United States) concluded that activity has recently declined and is likely contributing to increasing obesity and declines in cardiovascular and metabolic health; yet, this meta-analysis used self-report data on activity domains and noted this critical limitation by calling for "concerted efforts to monitor PA [physical activity] in a consistent manner globally" (Ng and Popkin, 2012: 659).

To address these issues, the present study was conducted among older adults in an urban setting in India with the following three objectives. First, the study compares average activity levels obtained through different durations of monitoring (1, 3, and 7 days). Previous research on this topic has demonstrated that because activity levels and patterns vary by population and subgroup, there can be no "one-size-fits-all" recommendation for the number of days of monitoring necessary to assess habitual energy levels. Unfortunately, few studies have addressed this topic among older adults and none have examined this issue among older adults in low- or middle-income countries. Second, the study aims to document differences in physical activity patterns by sex and age. An important question is whether older adults in low- and middle-income countries, who generally have markedly different patterns of behavior and activity than those in high-income countries, experience similar declines in physical activity and energy expenditure with age as seen in the United States and several European countries. Finally, the study evaluates links between measures of physical activity and anthropometrics (height, weight, and body mass index [BMI]), as well as between activity parameters and measures of household size (number of people living in the household), work status (whether worked for at least two days within the past 7 days), and social cohesion (frequency of community involvement and social engagements outside of the house over the past 12 months). These analyses allow the preliminary evaluation of the role of low activity levels in overweight and obesity and consider links between lifestyle variables and patterns of activity.

METHODS

The present study reports data from a physical activity substudy of the World Health Organization's Study on global AGEing and adult health (SAGE-PA; see Kowal et al., 2012). SAGE-PA was designed to compare objectively measured data obtained through accelerometry with self-report information from the GPAQ, included as part of the core SAGE interview materials.

Study location and participants

The SAGE-PA substudy was implemented in 2010 as a face-to-face household interview among urban dwelling adults in Jodhpur, Rajasthan, India. This substudy sample was randomly selected from the SAGE pilot study conducted in Jodhpur ($n = 492$) in 2005. Data were collected from 200 adults (72 men, 128 women) between the ages of 49 and 90 years old. One hundred and thirteen participants (33 men, 80 women) were considered young older adults (49–60 years old), while 87 (39 men, 48 women) were considered old older adults (>60 years old).

SAGE and related substudies were approved by the World Health Organization's Ethical Review Board, which are reviewed annually. Additionally, the partner organization (Department of Medicine, Dr. S.N. Medical College, Jodhpur, India) that implemented the SAGE-PA substudy obtained ethical clearance through its internal review body. Informed written consent was obtained from all study participants.

Survey measures and anthropometrics

SAGE-PA combined accelerometry as a measure of physical activity with a short face-to-face interview, using a set of modules and questions taken from the main SAGE questionnaire (see www.who.int/healthinfo/sage/cohorts/en/index2.html). This survey instrument covered a range of topics, including household characteristics, economic well-being and work history, health state and functioning, preventive health behaviors, social cohesion, and time-use. In this preliminary study, measures of household size (number of individuals living in household) and work status (whether worked for at least two days within the past 7 days) were used to acquire an indication of household composition and employment outside of the home. Furthermore, a social cohesion measure was included in analyses, which was based on nine questions examining community involvement and social engagements outside of the home over the past 12 months, using the following response options: 1 = Never; 2 = Once or twice per year; 3 = Once or twice per month; 4 = Once or twice per week; and 5 = Daily. Values assigned to each of the nine items were summed to create an overall social cohesion score for the past year, with higher scores indicating more social cohesion. As part of the face-to-face interview, self-report anthropometric measurements (height and weight) were also recorded, and BMI (kg/m^2) was calculated.

Physical activity

Participants wore ActiGraph (Pensacola, FL) GT3X accelerometers at the hip (~1 cm toward the midline from the iliac crest) for 7 consecutive days, with the accelerometer set to record data for all three axes at 60 second epochs. Accelerometers were programmed to start data collection at midnight (12:01 am) the day after the participant was given the device. The participant then started wearing the accelerometer upon waking the next morning. Participants were instructed to wear the accelerometer at all times except when showering, bathing, or swimming; participants also removed the device when sleeping. At the end of the 7-day period, an interviewer visited the participant's home, retrieved the accelerometer, and conducted an interview using the SAGE-PA questionnaire. Data from the accelerometers were then downloaded to a computer using ActiLife v.4.1.1 software.

Data processing and interobserver error

Data were processed by two trained analysts (TJC and AH) to differentiate between periods of inactivity and periods when individuals removed the device for any reason. Because raw data must be viewed to identify the difference between these two outcomes, analysts used the raw data output file to look for periods of complete inactivity that lasted longer than 3 h during the day; when this inactivity occurred, these periods were removed because the accelerometer had likely been removed. Night-time inactivity was also removed in order to only include activity while awake to standardize data in case some individuals forgot to remove the device upon going to bed. Using the 60-s epoch data from the raw output file, researchers summed the minutes of activity remaining to calculate the total minutes of activity throughout each day.

From these analyses, counts per minute active, counts per hour active, calories per minute active, and calories per hour active were calculated based on the summed counts or ActiLife equations (see below). Paired samples *t*-tests (two-tailed) were used to compare the minutes awake, counts per minute/hours, and calories per minute/hour data provided by the ActiLife v.4.1.1 program to check for possible errors between observers. Output from the two observers was then averaged and subsequent data analyses used the cleaned data, with counts and calories associated with inactivity during sleep and not wearing the device removed. Daily average activity counts (ACs) were measured based on the frequency and intensity of acceleration events that occurred during the 60-s epoch for the duration of activity monitoring. Calorie counts were determined using ActiLife v.4.1.1 through a combination of the Freedson and Work Energy Theorem equations; these equations use counts per minute and body mass to calculate calories per minute. Recent research supports the use of published predictive equations to determine activity intensity among adults of all ages, including older adults (Miller et al., 2010).

In addition to ACs, three activity variables were calculated and used in analyses: (1) activity energy expenditure (AEE; kcal/day), which represents an estimate of the caloric costs of physical activity based on the ActiLife calculations of daily average calories; (2) total energy expenditure (TEE; kcal/day), which is estimated as AEE + basal metabolic rate (BMR); and (3) physical activity level (PAL), which reflects TEE/BMR and helps to adjust for body size differences between individuals. To allow estimation of TEE and PAL, BMR was estimated based on the age- and sex-specific Oxford equations (Henry, 2005). In addition to AC (in counts per day), we chose to present results of this study primarily in energy expenditure terms, focusing on average AEE, TEE, and PAL per day. We follow the lead of a recent review of accelerometry research among older adults (Taraldsen et al., 2012) that found no consensus in presentation of accelerometry-determined physical activity data but determined that energy expenditure was the most commonly reported activity parameter. Energetic parameters also have the greatest utility in directly linking activity and health (Snodgrass, 2012). Finally, alternate approaches that use time in physical activity categories have been shown to be problematic because selection of cut points (e.g., the activity intensity used to assign activities into the moderate-to-vigorous physical activity [MVPA] or vigorous physical activity [VPA] categories) influences results considerably, thereby affecting associations between activity and other measures (Loprinzi et al., 2012).

Statistical analyses

Prior to analysis, all variables were examined for accuracy of meeting standard parametric assumptions. Variables that were skewed were $\log_{10}$-transformed and retested for normality. Retested $\log_{10}$-transformed variables were normal, with a skew and kurtosis between ± 1. Accordingly, transformed measures of physical activity (TEE, PAL, AC, and AEE) were used in all subsequent analyses.

Activity measures (AC, AEE, TEE, and PAL) were calculated from different durations of activity monitoring (1, 3, and 7 days) and compared using one-way repeated measures

TABLE 1. Physical activity measures compared between 1, 3, and 7 days of monitoring with all ages and both sexes combined for the subset of individuals (N = 165) with 7 days of monitoring[a]

Physical activity measures	1 Day Mean (SD)	3 Days Mean (SD)	7 Days Mean (SD)
Total energy expenditure (TEE; kcal/day)	1538.3 (279.4)	1542.5 (278.2)	1543.6 (275.8)
Physical activity level (PAL; TEE/BMR)	1.15 (0.08)	1.16 (0.08)	1.16 (0.07)
Activity counts (Average per day)	165,282.8 (84,888.5)	167,930.8 (81,101.2)	170,225.8 (81,213.1)
Activity energy expenditure (AEE; kcal/day)	204.2 (115.4)	208.4 (110.0)	209.5 (105.8)

[a]Values are based on original, non-transformed scales.

analysis of variance (ANOVA) and Bonferroni post hoc analyses; only participants with 7 days of activity monitoring ($n = 165$) were included in these analyses. Evaluation of Mauchly's test indicated that all of the physical activity variables violated assumptions of sphericity; thus, the degrees of freedom of the ANOVA tests were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = 0.69$ for TEE, $\varepsilon = 0.69$ for PAL, $\varepsilon = 0.66$ for AC, and $\varepsilon = 0.66$ for AEE).

Two-way ANOVA tests were used to evaluate the main and interaction effects of age group and sex on activity measurements (AC, AEE, TEE, and PAL) over 7 days of monitoring. Simple effects tests—a common technique to examine the effect of one independent variable at individual levels of the other independent variable—were also conducted to analyze the effect of sex at each level of age group (younger and older) as well as the effect of age group at each level of sex (men and women). Due to multiple comparisons, all simple effects tests used a Bonferroni correction method. Independent-samples t-tests (two-tailed) were conducted to examine sex differences in age, anthropometrics, household size, and social cohesion scores. For variables that violated homogeneity of variance assumptions, significance values based on equal variances not assumed are presented. Work status was measured as frequency counts and compared between sexes with Pearson's χ^2 tests.

Bivariate correlations (with pairwise deletion) were computed to examine the relationships between age and physical activity measures, while pairwise partial correlations (controlling for age) were calculated to examine the associations among anthropometrics, household size, social cohesion scores, and activity measurements. All correlations were evaluated separately for men and women. Independent-samples t-tests (two-tailed) were used to examine differences in physical activity measures by work status; tests were conducted separately for the younger and older men and women.

Comparisons were considered statistically significant at $P < 0.05$. All statistical analyses were performed using SPSS 21.0 (Chicago, IL).

RESULTS

Two participants (one male, one female) were excluded due to corrupt data files, likely caused by an error made during accelerometer initialization. Minutes active, active counts per minute, and active calories per minute were calculated by two observers (TJC and AH) with their individual results compared using paired samples t-tests (two-tailed). All measures were highly correlated ($P < 0.001$): minutes active ($r = 0.995$, $P < 0.001$), active counts per minute ($r = 0.955$; $P < 0.001$), and active calories per minute ($r = 0.953$; $P < 0.001$). There were no significant differences between the observers for minutes active [$t(197) = 0.423$, $P = 0.673$], active counts per minute [$t(197) = 0.912$, $P = 0.363$], and active calories per minute [$t(197) = -1.044$, $P = 0.298$].

Durations of monitoring

Results did not identify significant differences between 1, 3, and 7 days of activity monitoring for TEE [F(1.38, 226.81) = 1.10, $P = 0.315$], PAL [F(1.38, 226.81) = 1.10, $P = 0.315$], AC [F(1.32, 216.29) = 2.33, $P = 0.119$], and AEE [F(1.32, 216.28) = 2.37, $P = 0.116$] (Table 1). Bonferroni post hoc tests also revealed nonsignificant pairwise comparisons between the different durations of monitoring for all activity variables.

Physical activity patterns by age and sex

The mean age of the overall sample was 60.4 (8.9) years, with a mean age of 62.2 (8.0) for men and 59.4 (9.3) for women. Descriptive statistics for the physical activity measures by age and sex groups are provided in Table 2. For men, age was negatively correlated with TEE ($r = -0.49$, $P < 0.001$) and AEE ($r = -0.31$, $P = 0.008$). For women, age was negatively correlated with TEE ($r = -0.50$, $P < 0.001$), PAL ($r = -0.30$, $P = 0.001$), AC ($r = -0.38$, $P < 0.001$), and AEE ($r = -0.44$, $P < 0.001$).

A series of two-way independent ANOVA tests were conducted to compare the physical activity levels over 7 days of monitoring of men and women from the 49–60 year age group and the 61-plus year age group. The ANOVA for TEE revealed that men had significantly higher levels than women (F(1, 194) = 71.55, $P < 0.001$), while the younger age group had significantly higher levels than the older age group ($F(1, 194) = 40.42$, $P < 0.001$). The interaction between sex and age group was non-significant ($F(1,194) = 0.10$, $P = 0.748$); however, simple effects tests demonstrated that younger ($F(1,194 = 40.71$, $P < 0.001$) and older ($F(1,194) = 31.44$, $P < 0.001$) men had significantly higher TEE levels than younger and older women, respectively, while younger men ($F(1,194) = 17.81$, $P < 0.001$) and younger women ($F(1,194) = 24.38$, $P < 0.001$) had significantly higher levels than older men and older women, respectively. For PAL, the younger group had higher physical activity levels than the older age group ($F(1, 194) = 5.88$, $P = 0.016$), yet the main effect of sex ($F(1, 194) = 0.18$, $P = 0.674$) and the interaction between sex and age group ($F(1,194) = 0.23$, $P = 0.631$) were nonsignificant. Simple effects tests indicated that younger women had significantly higher PALs than the older women ($F(1,194) = 5.65$, $P = 0.018$). Similarly, the younger group had significantly higher AC levels than the older group ($F(1, 194) = 9.41$, $P = 0.002$), with younger women having higher activity counts than older women $F(1,194) = 10.56$, $P = 0.001$). The sex difference ($F(1, 194) = 2.38$, $P = 0.125$) and the interaction effect ($F(1,194) = 0.82$, $P = 0.367$) for AC were

TABLE 2. Physical activity measures over 7 days of monitoring for the younger and older age groups of men and women[a,b]

Physical activity measures	Younger adults (49–60 years old) Men ($N = 33$) Mean (SD)	 Women ($N = 80$) Mean (SD)	Older adults (>60 years old) Men ($N = 38$) Mean (SD)	 Women ($N = 47$) Mean (SD)
Total energy expenditure (TEE; kcal/day)	1,865.4* (289.5)	1,529.3 (203.2)	1,618.4* (322.5)	1,333.5 (166.6)
Physical activity level (PAL; TEE/BMR)	1.17 (0.09)	1.17 (0.07)	1.15 (0.09)	1.14 (0.08)
Activity counts (average per day)	194,895.1 (103,847.6)	178,868.7 (77,740.7)	159,329.3 (77,632.8)	141,191.9 (89,966.6)
Activity energy expenditure (AEE; kcal/day)	269.4 (152.4)	222.3 (102.7)	212.3*** (153.5)	159.0 (93.2)

[a] Values are based on original, non-transformed scales for 198 participants (after exclusion of two individuals for data quality issues).
[b] Differences between men and women from the same age category were tested with simple effects tests with a Bonferroni correction and are statistically significant at: *$P < 0.001$; **$P < 0.01$; ***$P < 0.05$.

TABLE 3. Descriptive statistics for age, anthropometrics, household size, social cohesion score, and work status for younger and older men and women[a,b]

Measures	Younger adults (49–60 years old) Men ($N = 33$) Mean (SD) or %	 Women ($N = 80$) Mean (SD) or %	Older adults (>60 years old) Men ($N = 38$) Mean (SD) or %	 Women ($N = 47$) Mean (SD) or %
Age	55.6** (2.9)	53.6 (3.8)	68.1 (6.1)	69.3 (7.2)
Height (cm)	172.0* (6.3)	159.0 (7.4)	171.8* (6.4)	155.9 (5.1)
Weight (kg)	71.5*** (15.4)	64.9 (14.0)	66.3 (16.3)	60.3 (12.0)
BMI (kg/m^2)	24.1 (5.0)	25.7 (5.3)	22.4*** (5.0)	24.9 (4.9)
Household size	4.5 (1.7)	4.9 (2.4)	5.1 (2.2)	5.2 (2.2)
Social cohesion score	20.6* (4.2)	17.1 (3.7)	18.7** (3.8)	16.6 (3.4)
Work status				
Yes	42.4%	58.8%	34.2%	42.6%
No	57.6%	41.3%	65.8%	57.4%

[a] Differences between men and women from the same age category were tested with independent-samples *t*-tests and χ^2 tests. Results are statistically significant at: *$P < 0.001$; **$P < 0.01$; ***$P < 0.05$.

nonsignificant. For AEE, men had significantly higher levels than women ($F(1, 194) = 6.91$, $P = 0.009$), and the younger group demonstrated higher levels than the older group ($F(1, 194) = 16.24$, $P < 0.001$). The interaction between sex and age group was nonsignificant ($F(1,194) = 0.45$; $P = 0.504$); however, simple effects tests revealed that older men had higher AEE levels than older women ($F(1,194) = 5.17$, $P = 0.024$), while younger men ($F(1,194) = 4.51$, $P < 0.035$) and younger women ($F(1,194) = 14.78$, $P < 0.001$) had significantly higher levels that older men and older women, respectively.

Anthropometrics and activity

Table 3 displays descriptive statistics for age, anthropometrics (height, weight, and BMI), household size, work status, and social cohesion scores for the younger and older aged men and women. Results indicate that both younger and older men were significantly taller than their female counterparts ($t(111) = 8.88$, $P < 0.001$ and $t(83) = 12.72$, $P < 0.001$), respectively. Furthermore, younger men weighed significantly more than younger women ($t(111) = 2.21$, $P = 0.029$), while older women had significantly higher BMI levels than older men ($t(83) = -2.31$, $P = 0.023$). Men in both age groups had significantly higher social cohesion scores than women from the same age groups ($t(111) = 4.32$, $P < 0.001$ and $t(83) = -2.73$, $P = 0.008$), suggesting that men are more involved in community and social activities outside of the house than women. Self-report measures of work status did not significantly differ between younger men and women (χ^2 $(1) = 2.51$, $P = 0.113$) or older men and women (χ^2 $(1) = 0.62$, $P = 0.433$); however, a greater number of younger and older women (58.8% and 42.6%, respectively) reported working at least 2 days within the past 7 days compared to their male counterparts (42.4% and 34.2%, respectively).

With younger and older men combined, partial correlations (controlling for age) were conducted among the physical activity measures (AC, AEE, TEE, and PAL), anthropometrics (height, weight, and BMI), household size, and social cohesion scores. These findings are presented in Table 4. TEE was positively correlated with height ($r = 0.354$; $P = 0.003$), weight ($r = 0.878$; $P < 0.001$), and BMI ($r = 0.817$; $P < 0.001$). Similarly, AEE was positively correlated with height ($r = 0.265$; $P = 0.027$), weight ($r = 0.357$; $P = 0.002$), and BMI ($r = 0.299$; $P = 0.012$). PAL and AC were not significantly associated with anthropometric values. Correlations between physical activity measures and household size and social cohesion scores were not significant for men.

Partial correlations (controlling for age) were conducted among the physical activity measures (AC, AEE, TEE, and PAL), anthropometrics (height, weight, and BMI), household size, and social cohesion scores with younger and older women combined; these results are displayed in Table 5. For women, TEE was positively correlated with height ($r = 0.258$; $P = 0.003$), weight ($r = 0.844$; $P < 0.001$), and BMI ($r = 0.767$; $P < 0.001$). AEE was also positively correlated with weight ($r = 0.228$; $P = 0.010$) and BMI ($r = 0.181$; $P = 0.043$), while AC was negatively correlated with weight ($r = -0.238$; $P = 0.007$) and BMI ($r = -0.248$; $P = 0.005$). Social cohesion scores were positively correlated with PAL ($r = 0.226$; $P = 0.011$), AC ($r = 0.210$; $P = 0.019$), and AEE ($r = 0.231$; $P = 0.009$) for women.

Independent samples *t*-tests indicated that all physical activity measures (AC, AEE, TEE, and PAL) did not differ significantly by self-report work status for younger or older men and women.

TABLE 4. Partial correlations (controlling for age) between physical activity measures and anthropometrics (height, weight, BMI), household size, and social cohesion score for men only[a]

Measures	Physical activity measures			
	Total energy expenditure (TEE; kcal/day)	Physical activity level (PAL; TEE/BMR)	Activity counts (Average per day)	Activity energy expenditure (AEE; kcal/day)
Height (cm)	0.354**	0.184	0.099	0.265***
Weight (kg)	0.878*	0.142	−0.126	0.357**
BMI (kg/m^2)	0.817*	0.094	−0.162	0.299**
Household size	−0.080	−0.083	−0.036	−0.055
Social cohesion score	−0.046	−0.114	−0.083	−0.066

[a]Correlations are statistically significant at: *$P \leq 0.001$; **$P \leq 0.01$; ***$P \leq 0.05$.

TABLE 5. Partial correlations (controlling for age) between physical activity measures, and anthropometrics (height, weight, BMI), household size, and social cohesion score for women only[a]

Measures	**Physical Activity Measures**			
	Total energy expenditure (TEE; kcal/day)	Physical activity level (PAL; TEE/BMR)	Activity counts (average per day)	Activity energy expenditure (AEE; kcal/day)
Height (cm)	0.258**	0.071	−0.035	0.106
Weight (kg)	0.844*	0.062	−0.238**	0.228**
BMI (kg/m^2)	0.767*	0.022	−0.248**	0.181***
Household size	−0.086	−0.042	−0.003	−0.031
Social cohesion score	0.130	0.226**	0.210***	0.231**

[a]Correlations are statistically significant at: *$P \leq 0.001$; **$P \leq 0.01$; ***$P \leq 0.05$.

DISCUSSION

The present study used accelerometry to examine physical activity patterns among older adults in Jodhpur, India. Our findings reveal that activity levels for both men and women in this sample are extremely low (PAL averages of 1.14–1.17). These are below the lower limits for what is generally considered a sedentary or light activity lifestyle (PAL = 1.4; FAO/WHO/UNU, 2004), yet a number of studies, including among hospital patients, have shown values (~1.2) similar to the present study (Snodgrass, 2012). The overall low activity levels in the present study are almost certainly attributable, at least in part, to the underestimates of activity due to limitations of accelerometry. For instance, accelerometers do not detect many upper body movements and cannot estimate load-carrying effort, while entirely missing certain activities such as swimming that generally require the accelerometer to be removed (Kumahara et al., 2004; Schutz et al., 2001; Snodgrass, 2012; Troiano et al., 2008; Warren et al., 2010); however, it should be noted that swimming is not a common activity in this population. Given that populations living in hot climates often have depressed BMRs (Henry and Rees, 1991), it is possible that the use of the Oxford equations (Henry, 2005) in the present study overestimated BMR and thus resulted in underestimation of activity levels; however, the Oxford equations more accurately estimate BMR in tropical populations compared to previously used predictive equations (Schofield, 1985; FAO/WHO/UNU, 2004). Despite the limitations inherent with accelerometry, the current study provides a robust measure of activity, which allows for comparisons between individuals.

Duration of monitoring

An important question in population-based physical activity research is the number of days of monitoring necessary to assess habitual energy levels. Although this topic has been debated for years, accelerometry-based studies have helped clarify this issue (Baranowski et al., 2008). Most work among adults in the United States and other high-income countries has shown that 3 to 7 days of accelerometry data are needed to reliably document habitual activity patterns (i.e., to capture typical intraindividual variation) (Matthews et al., 2002). However, few studies have been conducted among older adults. An exception is a study in the United States among older adults (aged 55–86 years), which demonstrated that three days of accelerometer monitoring was adequate for the accurate capture of habitual physical activity data in older adults, but that 5 days were needed to accurately measure sedentary behavior (Hart et al., 2011). No studies to date have addressed this issue in low- or middle-income countries.

The present study did not find significant differences in AC, AEE, TEE, or PAL between 1, 3, and 7 days of activity monitoring. This is likely a result of an extremely sedentary population with relatively low activity levels throughout and little day-to-day variability in activity. Although this result suggests that only 1–3 days of activity monitoring could provide a reasonable picture of typical activity, there is clearly a need for more research in this area to ascertain whether these results are extraordinary. Furthermore, the present research was conducted among a community-based sample of older adults in an urban setting in India, but it is unclear whether rural communities in India would display greater day-to-day variation in physical activity. The issue of monitoring duration is also important because accelerometry studies must strike a pragmatic balance between the desire for more days of monitoring to assess variation and the need to minimize participant burden (Baranowski et al., 2008).

Physical activity patterns by age and sex

Studies in the United States and several European countries have shown a pattern of decreasing physical activity levels with advancing age; in many studies, this decline begins in the seventh decade and then accelerates with increasing age (Evenson et al., 2012; Hansen et al., 2012; Marquez et al., 2011; Sun et al., 2013; Troiano et al., 2008). This is well illustrated by the results of a large population-based, multicenter study of Norwegian adults using accelerometry, which shows an initial decline in activity in older adults (~10% from 50–64 years to 65–74 years) that is then followed by a steeper drop in later age groups (>30% from 65–74 years to 75–85 years) (Hansen et al., 2012). Almost no information on population-level trends in physical activity using objective measures is available for older adults in low- or middle-income countries. A critical issue is whether groups in low- and middle-income countries, who generally have markedly different patterns of behavior and activity than those in high-income countries, experience similar declines in physical activity and energy expenditure with age. Self-report questionnaire-based data do show lower activity levels with increasing age in all regions of the globe, yet this masks considerable variation in certain regions such as relatively high activity levels among older adults from Southeast Asia (Hallal et al., 2012). The one study that used accelerometry to study changing activity patterns with age among older adults in a non-Western setting—a study by Peters et al. (2010) of urban adults (40–74 years old) in China—documented a significant decline in physical activity levels and increased sedentary behavior with increasing age.

The present study identified significant differences in physical activity levels by age, with the younger group (49–60 years old) having higher AC, AEE, TEE, and PAL compared to the older group (>60 years old). Since body weight is used in the calculation of several energetic parameters (e.g., TEE), some differences between age groups is the result of lower body weights among older participants. The results reported here are consistent with studies in high-income nations showing lower activity levels in more advanced age groups (Brown et al., 2005; Davis and Fox, 2007; Evenson et al., 2012; Hansen et al., 2012; Troiano et al., 2008; Westerterp and Meijer, 2001) as well as with the minimal accelerometry data collected in non-Western populations (Peters et al., 2010) and self-report data from low- and middle-income nations (Dumith et al., 2011; Hallal et al., 2012). However, caution is warranted because the present study was conducted among older adults in an urban setting, where occupations and lifestyles may more closely approximate those of high-income nations.

Another area of intense interest is the extent of sex differences in physical activity and the question of whether these differences show similar patterns across different age groups. Again, few studies have focused exclusively on older adults and the different methods of data collection (self-report questionnaire, accelerometry, DLW, and heart rate monitoring) make it difficult to compare between studies and across populations. A compilation by Leonard (2008) of adults in industrialized populations—based on an analysis of DLW data from the Institute of Medicine (2002)—showed similar activity levels between men and women (PALs of 1.73 and 1.72, respectively); however, TEEs were significantly higher among men (2,873 versus 2,234 kcal/day), yet these differences were primarily attributable to differences in body size. Research outside of high-income nations is even more sparse, but when activity data for adults are compiled from subsistence groups (e.g., Ache foragers of Paraguay and Evenki reindeer herders of Siberia) and farmers in economically developing nations, men on average are modestly more physically active than women (1.98 versus 1.82) (Leonard, 2008); however, these differences are small and the patterns are not universal (Dufour and Piperata, 2008; Madimenos et al., 2011; Leonard, 2008; Panter-Brick, 2002; Snodgrass, 2012). Furthermore, self-report data generally document greater inactivity in women compared to men (Hallal et al., 2012), including among older adults (Sun et al., 2013), yet several studies have shown that measured differences tend to be more modest than when objectively obtained using accelerometry (Sun et al., 2013).

The present study identified modest sex differences, with men having higher TEEs and AEEs than women, and is consistent with the majority of findings from other studies (see Peters et al., 2010). Some of these energetic differences, such as in TEE, are partially attributable to larger body sizes in men compared to women; however, AEE is significantly higher in men compared to women, which appears largely attributable to the particularly low AEEs among the oldest group of women.

Anthropometrics and household/lifestyle correlates of activity

A number of studies have examined links between anthropometric dimensions and physical activity, many with a focus on delineating the contribution of low activity levels to the risk of overweight and obesity (Dugas et al., 2011; Prentice et al., 1986, 1996; Westerterp, 1999, 2010). Several studies using objective measures, such as accelerometry and DLW, have shown higher TEEs among obese adults compared to normal weight individuals, yet when AEE or PAL are examined, the results become far more variable. In fact, studies have not consistently found the expected negative associations between BMI and activity measures such as AEE and PAL, and several large, population-based studies have documented no or positive associations between activity measures and BMI (see review in Dugas et al., 2011). This has led some (e.g., Dugas et al., 2011; Westerterp, 2010) to conclude that low activity levels are not a major contributor to recent increases in obesity prevalence in high-income countries or differences in obesity prevalence between high-income countries and economically developing nations. This topic has not been extensively studied in older adults or among individuals in low- and middle-income nations. One exception is the study by Peters et al. (2010) in urban China that demonstrated that physical activity levels were lower among those with greater BMI; interestingly, those with greater BMI were also more likely to report greater physical activity than among those with lower BMI.

The findings from the present study document significant links between physical activity levels and anthropometric dimensions. In both the sexes, BMI and body weight are positively correlated with TEE and AEE. Although the cross-sectional design of this study makes it impossible to draw definitive conclusions, these results do suggest that elevated BMI (and greater risk for obesity) is not being driven primarily by low activity levels. Combined prevalence of obesity and overweight in this study using standard classification (WHO, 2000) was of 38.0% in men and 49.6% in women, though these rates were considerably higher (47.8% and 68.5%, respectively) when applying the modified BMI cutoffs (overweight: 23.0–27.5; obesity: >27.5) suggested for use with Asian populations (WHO, 2004). Unfortunately, this preliminary study relied on a brief face-to-face interview and did not collect dietary information, which makes it impossible to examine relationships among energy intake, BMI, and physical activity.

Moreover, the present study obtained information on economic well-being, work history, and social cohesion to examine preliminary associations between these lifestyle variables and activity measures. Specifically, this study used questions on household size and recent (7-day) work history, as well as a composite social cohesion measure focused on community involvement and social engagement. Results indicate that none of the household or lifestyle characteristics were significantly related to activity measures among men. Among women, household size and recent work history were also not associated with any of the activity measures, yet those women most socially integrated had higher activity levels, including AEE and PAL. This domain should be further investigated as a possible target of intervention for increasing physical activity. More detailed questionnaire data and ethnographic information are needed to understand why this same relationship was not seen among men.

Limitations

This study suffers from several weaknesses. First, the sample size is relatively small and limited to urban, community-dwelling adults in one metropolitan area in India. As such, it must be viewed as preliminary, and the results presented here cannot be generalized to all older adults, even in urban India. Second, the study used self-report body mass and height data, which could have contributed to inaccuracies in the BMI variable. Third, BMR was not measured—but instead estimated using predictive equations—and no information was available on diet-induced thermogenesis; this could have led to inaccuracies in calculation of energetic variables used in this study. Fourth, the present study included minimal information on socioeconomic status, such that it was impossible to examine how income levels or education influence patterns of activity in this population. Future research will incorporate additional queries and modules from the SAGE questionnaire, which is designed to collect extensive information on sociodemographics and household characteristics. Finally, the cross-sectional design of the study limits our ability to draw firm conclusions about differences in activity by age, since age group differences may reflect cohort differences.

Conclusion

This study demonstrates the utility of accelerometry for quantifying physical activity levels among older adults in non-Western settings. In addition to documenting patterns of physical activity, objectively measured energy expenditure data provide valuable public health information with which policymakers can target interventions that increase physical activity and minimize sedentary time. Interventions informed by objectively measured activity data, which utilize diverse approaches such as behavioral self-monitoring, increased social support, and modifications to the built environment, have shown promise for minimizing risk for frailty and reducing chronic disease burden (e.g., Carlson et al., 2012; Gardiner et al., 2011). The potential for identifying new targets of intervention and testing their efficacy will only increase as accelerometers continue to drop in cost and grow in accuracy.

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