ORIGINAL RESEARCH ARTICLE

Effect of body mass and physical activity volume and intensity on pedometry-measured activity energy expenditure in rural black South Africans in the Limpopo Province

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Abstract

Objectives. We developed a novel approach to investigate patterns of pedometry-measured total weekly activity energy expenditure (EE_{Act}) in rural black South Africans in the Limpopo Province.

Design. We analysed 7-day pedometry data in 775 subjects (female: *N*=508; male: *N*=267). Variance components models for EE_{Act} were used to estimate the variance explained by body mass (BM), total weekly steps (volume) and estimated intensity (kcal.kg^{-1}.step^{-1}). Univariate General Linear Models, adjusting for age, BM and physical activity (PA) volume, were used to determine if EE_{Act} was primarily affected by volume or intensity.

Results. BM (13.1%), PA intensity (24.4%) and PA volume (56.9%) explained 94.4% of the variance in EE_{Act}. Adjusted EE_{Act} did not differ between sexes (78 kcal.week^{-1}, p =0.2552). There were no significant differences across activity categories (sedentary to very active) for adjusted EE_{Act} (62 - 287 kcal.week^{-1}, p>0.1). Adjusted EE_{Act} for 6 - 7 days of compliance (≥10 000 steps.day^{-1}) differed significantly from 1 - 2 days of compliance (266 - 419 kcal.week^{-1}, p<0.04). Obese (body mass index ≥30 kg.m^{-2}) and normal weight (body mass index 18.5 - 24.9 kg.m^{-2}) women did not differ significantly across activity categories for EE_{Act} (200 - 592 kcal.week^{-1}, p>0.30).

Conclusions. We have highlighted an intensity effect for days of compliance and at very active ambulatory levels (≥12 500 steps.day^{-1}). A volume effect appeared to dominate between sexes, across activity categories and weight-by-activity categories. It is important that *post hoc* statistical adjustments be made for body mass and PA volume when comparing EE_{Act} across groups.

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Introduction

Pedometry is considered a valid and reliable objective measure of free-living physical activity (PA).[1] However, a disadvantage of this methodology is that the primary measure which is usually reported, namely the number of steps, provides no information as to the intensity of the ambulation. Consequently, it is not possible to disentangle the effects of volume and intensity of PA on outcome variables if statistical analyses only consider the number of steps (volume).

We recently reported high ambulation levels (average steps.day^{-1}) for a rural African population in transition but could not provide definitive data pertaining to the intensity at which steps were accumulated.[2] The study used a piezo-electric based pedometer (NL-2000) which stored both the number of steps and activity energy expenditure (EE_{Act}).[2] The NL-2000 is produced by the Suzuken-Kenz Company (http://www.suzuken-kenz.com) for a North American distributor (New Lifestyles, http://www.new-lifestyles.com) and is identical in function to the Suzuken-Kenz e-STEP products (personal communication: Hitoshi Ozawa, Suzuken-Kenz, 17-05-2007). Therefore calibration results for the NL-2000 would also be applicable to the Suzuken-Kenz e-STEP products.[3-5] Moreover, because the Suzuken-Kenz range includes the Lifecorder EX, which has been validated,[6,7] and the technology in this high-end product is essentially the same as the lower-end products (except for the download capacity to a personal computer), the algorithms for all Suzuken-Kenz products would be identical. For instance, the NL-2000 (e-STEP) (personal communication: Operations Manager, New Lifestyles, 02-09-2005) and the Lifecorder EX [6] sense steps when there are three or more acceleration pulses for four consecutive seconds and calculate EE_{Act} using body mass (W) and an intensity dependent factor (Ka) such that EE_{Act} (kcal) = $Ka \times W$ (kg).

TABLE I. Descriptive characteristics for rural and urban women

	Residence		
	Female (*N*=508)	**Male (*N*=267)**	$p^{\dagger}$
Continuous variables			
Age (years)	40.1 ± 20.7	28.4 ± 17.6	<0.0001
Body-mass-index (kg.m^{-2})	26.6 ± 6.4	21.2 ± 3.9	<0.0001
Average steps.day^{-1}	11 086 ± 4 538	14 028 ± 5 434	<0.0001
Average activity EE (kcal.day^{-1})	393 ± 189	491 ± 213	<0.0001
Intensity factor (kcal.kg^{-1}.step^{-1} x1000)	0.58 ± 0.28	0.65 ± 0.41	0.0032
Categorical variables *			
Body mass index classification			
Normal weight (<25 kg.m^{-2})	47.8 (243)	87.6 (234)	<0.0001
Obese (≥30 kg.m^{-2})	27.2 (138)	4.1 (11)	<0.0001
Physical activity classification			
Inactive (<5000 steps.day^{-1})	10.2 (52)	3.0 (8)	0.0006
Active (≥10 000 steps.day^{-1})	59.4 (302)	77.9 (208)	<0.0001
Completion of secondary school (≥Grade 12)	16.5 (58)	14.1 (29)	0.5420
Ownership of motor vehicle (Yes)	21.2 (99)	18.1 (45)	0.3911
Electricity available inside house (Yes)	75.4 (353)	65.3 (162)	0.0055
Water collected outside dwelling (Yes)	8.5 (40)	8.1 (20)	0.9363

Data are reported as mean ± SD for all continuous variables and % (*N*) for * categorical variables, †*p*-values evaluate female v. male differences.

Consequently, the EE_{Act} displayed on the NL-2000 output is a function of the PA intensity (*Ka*), PA volume (number of steps) and the individual's body mass. It is thus not possible to ascertain if an EE_{Act} difference between two individuals is due to increased PA (volume and/or intensity) or because of body mass differences. One approach to circumvent this problem is to use statistical methods to adjust for body mass and PA volume to ascertain whether EE_{Act} differences between two individuals are possibly intensity dependent. Therefore the objective of this study was to explore the patterns of pedometry-measured total weekly EE_{Act} by statistically adjusting for body mass and PA volume to determine if PA intensity could be an important factor in explaining the high ambulatory levels in a rural African setting.

Methods

This analysis uses data for which the study protocol, subjects, field site, sample size and measurements have been described in detail elsewhere.[2] Briefly, 830 participants from the Dikgale Health and Demographic Surveillance System field site (DHDSS) [8-11] were conveniently recruited and contacted twice over a 9-day period between January 2005 and December 2007. On the first occasion, subjects were recruited and completed the informed consent, relevant sections of a health questionnaire and provided anthropometric data. Standard anthropometric measurements and interviews were performed by trained, local fieldworkers and included measures of stature (nearest 1 cm) and body mass (nearest 1 kg). We categorised subjects using body mass index (BMI = body mass ÷ stature^2, underweight: <18.5 kg.m^{-2}, normal weight: 18.5 - 24.9 kg.m^{-2}, overweight: 25 - 29.9 kg.m^{-2}, obese: ≥30 kg.m^{-2}).[12] Finally, subjects were instructed on the required procedures for wearing the pedometer over 9 consecutive days. We used piezo-electric pedometers (NL-2000, New Lifestyles Inc., Kansas City, MO, USA) not affected by pedometer tilt or adiposity level[13] to objectively measure PA. Data for day 1 and day 9 were omitted because these were incomplete days. The pedometer was worn on the right waist, securely attached to a nylon belt and sealed with surgical tape. The pedometers could be removed for sleeping and bathing purposes by unclipping the nylon belt. Ambulation PA volume was defined as the average steps.day^{-1} or steps.week^{-1}. Energy expenditure was defined as total activity energy expenditure.week^{-1} (EE_{Act}, kcal.week^{-1}). We calculated a PA intensity factor (I_{FR}, kcal.kg^{-1}.step^{-1}) from the total weekly steps, total weekly EE_{Act} and body mass. Public health indices (thresholds) for steps.day^{-1} were defined as follows:[14] sedentary: <5 000 steps.day^{-1}, low active: 5 000 - 7 499 steps.day^{-1}, somewhat active: 7 500 - 9 999 steps.day^{-1}, active: 10 000 - 12 499 steps.day^{-1}, and very active: ≥12 500 steps.day^{-1}. A summary variable was created indicating the number of days a subject was compliant or not for 0 - 7 days (≥10 000 steps.day^{-1}). Subjects received a small honorarium on completion of the study. The study was approved by the Ethics Committee of the University of Limpopo (Turfloop Campus).

Statistical analysis

Descriptive statistics comprised means and 95% confidence intervals (95% CI) or one standard deviation (SD). Independent *t*-tests were used to compare variables across gender. Variance components were estimated for inter-individual variance (body mass = kg, PA volume = total weekly steps and I_{FR} = kcal.kg^{-1}.step^{-1}) and residual (intra-individual) variance. The variance components were also expressed as a percentage of the total variance. Inter-individual variance represents true variation between subjects while intra-individual variance represents unexplained variation within subjects. To identify additional variables that could affect the inter-individual variance we entered age and stature as covariates and sex, village and season as fixed factors. Multiple linear regression models, using backward selection, were used to examine the relative importance of PA volume, PA intensity and body mass to EE_{Act}. In addition to PA and body mass variables, age and sex were included in all initial models. Significance for variable entry into and exit out of the model were set at p=0.05 and p=0.1, respectively. Univariate General Linear Models (GLM) were used to compare ambulation (steps.day^{-1}) and

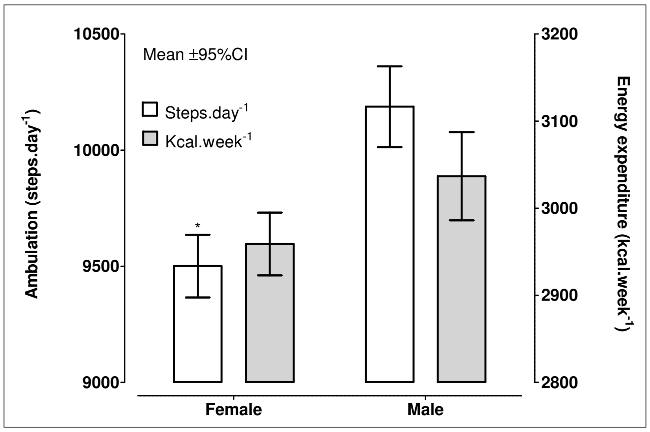

Fig. 1. Ambulatory and energy expenditure levels for males and females. Steps.day^{-1} adjusted for age and body mass. Kcal. week^{-1} adjusted for age, body mass and steps.week^{-1}. * Steps. day^{-1}: males > females, *p**<0.0001.***

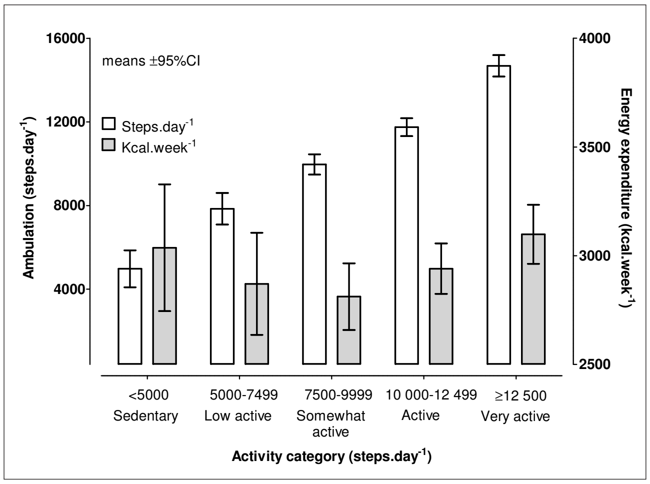

Fig. 2. Ambulatory and energy expenditure levels across activity categories. Steps.day^{-1} adjusted for age and body mass. Kcal. week^{-1} adjusted for age, body mass and steps.week^{-1}. Steps. day^{-1}: all activity categories significantly different, *p**<0.0001.***

EE_{Act} (kcal.week^{-1}) across gender, activity categories (sedentary to very active), days of non-compliance/compliance with public health guidelines (≥10 000 steps.day^{-1}), and obese- or normal-weight inactive (<7 500 steps.day^{-1}), active (10 000 - 12 499 steps.day^{-1}) and very active (≥12 500 steps.day^{-1}) participants. All initial models adjusted for age and body mass. Additional EE_{Act} models were also constructed which adjusted for age, body mass and steps.week^{-1}. *Post hoc* multiple comparison analyses (Sidak's *t*-test) assessed group differences. Data were analysed using appropriate statistical software (SPSS version 17.0.2). Significance for all inferential statistics was set at $p<0.05$.

Results

We excluded 14 outliers identified during exploratory data analysis. Because of very few obese males in the sample (Table I), only adult (19 - 65 years) female subjects were used in the obese/normal weight comparison across activity categories.

The sizeable variance attributed to body mass (13.1%), PA volume (total weekly steps, 56.9%) and I_{FR} (kcal.kg^{-1}.step^{-1}, 24.4%) suggested further analysis was warranted to determine if EE_{Act} group differences persist, possibly due to an intensity effect, by adjusting for body mass and PA volume. The 5.5% error variance was likely due to the rather crude I_{FR} that was calculated. Entering age or stature as covariates, and sex, village or season as fixed factors, made no difference to variances (<1%). Because the data were collected over 2 years in a number of villages that differ in terms of infrastructure and access to public transport, it was important to test whether season and village could explain part of the variance. PA volume, I_{FR} and body mass were significant predictors of EE_{Act} (model and coefficients: $p<0.0001$, model adjusted R^2=0.814) and part correlations were 0.887, 0.355 and 0.259, respectively. The multiple linear regression analysis revealed no collinearity between variables (variance inflation factors <1.2).

The adjusted R^2 for the partially (age and body mass) and fully (age, body mass and steps.wk^{-1}) adjusted EE_{Act} GLM models ranged from 0.130 to 0.564 and 0.690 to 0.695, respectively ($p<0.0001$). Males accumulated significantly more steps than females (687 steps.day^{-1}, $p<0.0001$). (Fig. 1). The fully adjusted EE_{Act} was not significantly different (78 kcal.wk^{-1}, p=0.2552) between sexes, suggesting no intensity effect (Fig. 1). However, adjusting for age and body mass only resulted in a significant difference (224 kcal. week^{-1}, p=0.0017), suggesting that volume plays a more significant role in EE_{Act} differences between sexes.

Age and body mass-adjusted differences in steps across categories (sedentary - very active) were significant for all pairwise comparisons (1 783 steps.day^{-1} to 9 710 steps.day^{-1}, $p<0.0001$) (Fig. 2). Adjusted for age and body mass, the middle three categories (low-active to active) resulted in relatively similar EE_{Act}, ($p>0.1$), but not so for two the extreme EE_{Act} categories (sedentary v. very active, $p<0.04$). However, the fully adjusted model yielded no significant differences across activity categories, suggesting a significant volume effect ($p>0.1$) (Fig. 2).

Age and body mass-adjusted steps.day^{-1} for 6 - 7 days of compliance with public health guidelines (≥10 000 steps.day^{-1}) were significantly different to all other levels of compliance ($p<0.003$) but there were no significant differences between 0 days (non-compliance) and 1 - 5 days of compliance ($p>0.4$) (Fig. 1). Adjusted for age and body mass, EE_{Act} differed significantly for days of compliance ≥6 compared with non-compliance (0 days) and lower levels of compliance (1 - 5 days) ($p<0.03$). Significant differences persisted only for EE_{Act} for 6 - 7 days of compliance versus 1 - 2 days of compliance ($p<0.04$), suggesting an intensity effect only for 6 - 7 days of compliance (Fig. 3).

The EE_{Act}, adjusted for age and body mass of highly active normal weight and obese women was significantly higher than inactive normal weight and obese women (difference: 2 224 - 2 403 kcal.wk^{-1}, $p<0.0001$). Adjusted for age, body mass and steps. week^{-1}, obese and normal weight adult females did not differ in EE_{Act} for the three PA categories, suggesting that there are no statistical differences in PA intensity (Fig. 4). However, there was a tendency for normal weight females to have higher EE_{Act} (200 kcal.week^{-1} to 592 kcal.week^{-1}, $p>0.30$).

Discussion

This is a novel study reporting for the first time volume and intensity effects from data obtained using pedometers. The analysis has highlighted an intensity effect for days of compliance and especially at very active ambulatory levels (≥12 500 steps.day^{-1}). Interestingly, there did not seem to be a significant intensity effect between sexes, activity categories or obese versus normal weight across activity

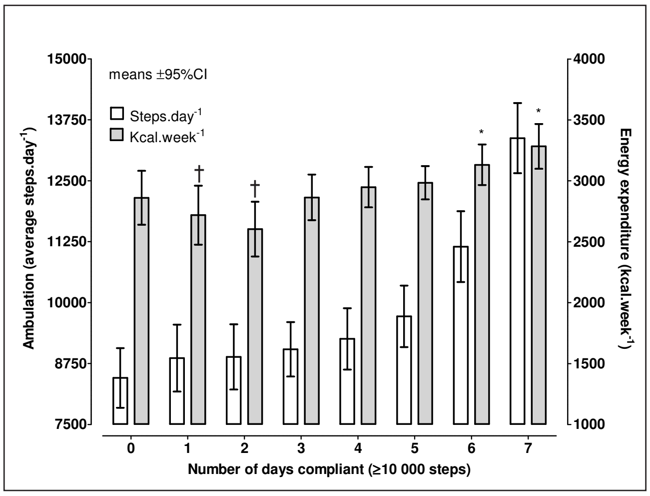

Fig. 3. Ambulatory and energy expenditure levels across number of days compliant (≥10 000 steps.day^{-1}). Steps.day^{-1} adjusted for age and body mass. Kcal.week^{-1} adjusted for age, body mass and steps.week^{-1}. * Steps.day^{-1}: 6 days and 7 days significantly different to all other days,** p**<0.003. † Kcal.week^{-1}: 1 - 2 days significantly different to 6 - 7 days,** p**<0.04.

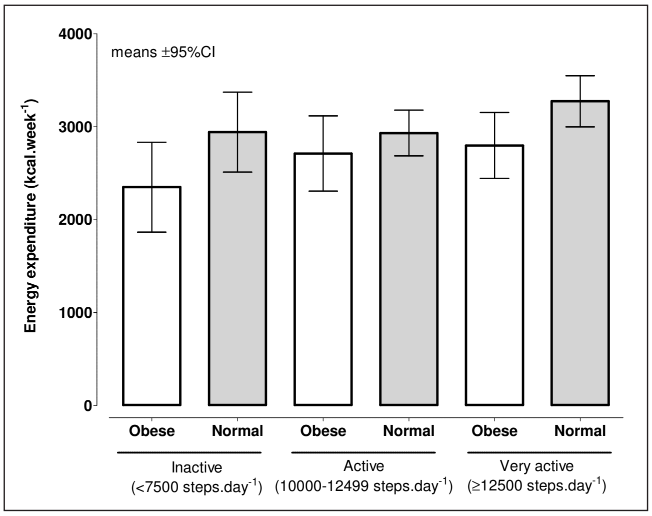

Fig. 4. Ambulatory and energy expenditure levels for normal weight and obese women across activity categories. Kcal. week^{-1} adjusted for age, body mass and steps.week^{-1}.

categories once age, body mass and accumulated steps had been adjusted for.

Differences in accumulated steps between males and females have been reported.[15,16] Our results suggest that it is the difference in PA volume, and not PA intensity, that explains the difference in EE_{Act} between males and females from this rural, African setting. Although average step totals increased significantly across activity categories, adjusted EE_{Act} did not increase accordingly. We also did not find markedly increased adjusted EE_{Act} between obese and normal weight females across activity categories, which is in agreement with findings of similar gross EE for walking and jogging at the same speed between normal weight and overweight/obese women, once adjusted for body mass and free fat mass.[17] Furthermore, non-compliance or compliance on 1 - 5 days of the week with public health guidelines (≥10 000 steps.day^{-1}) [18] did not seem to reveal differences in EE_{Act}. However, complying on 6 - 7 days, required significant increases in volume and intensity. These results suggest that public health PA guidelines of at least 5 times per week, 30 minutes per session,[19] which equates to approximately 10 000 steps.day^{-1},[20-22] were likely met through increases in accumulated steps throughout the day instead of increasing PA intensity. It was interesting that these findings would seem to provide non-intervention, free-living support for the feasibility of promoting moderate intensity PA such that the lack of a vigorous intensity requirement would not be a barrier to increasing PA. In other words, our results suggest that within this rural African population, walking behaviours are naturally modelled according to public health PA guidelines. However, highly active groups such as those achieving ≥12 500 steps on 6 or more days a week, required increases in intensity. This finding is in accord with the significantly higher accelerometer-measured moderate-to-vigorous PA recorded for subjects achieving ≥11 762 steps.day^{-1} compared with those achieving ≤8 123 steps.day^{-1}; 68.6 min v. 23.6 min, respectively (p=0.000).[22] Le Masurier *et al*. also reported higher moderate-to-vigorous activity for subjects achieving ≥10 000 steps. day^{-1} compared with <10 000 steps.day^{-1} whether accumulated in bouts ≥1-, ≥5- or ≥10 min (difference: p<0.05).[20] Recently, Dugas *et al*. suggested that PA intensity and not PA volume was a greater determinant of adiposity in young, black South African urban dwellers.[23] Our results would suggest that the PA volume is the dominant contributor to EE_{Act} in rural dwellers. Moreover, we have shown that average steps.day^{-1} is significantly associated with adiposity levels in rural African women (r=-0.20, p=0.032).[24]

Several limitations must be acknowledged. Firstly, we could not compare our statistical adjustment against actual volume and intensity measures. Future analyses using uni-axial accelerometer data to ascertain at which intensity levels steps are being accumulated would provide more definitive answers as to the relative importance of PA volume and intensity, specifically within the context of a rural African setting. Secondly, the absolute EE_{Act} values reported in this study should be carefully interpreted because treadmill calibration studies for the NL-2000 suggest an overestimation of approximately 25% for EE_{Act}.[3]

In conclusion, we have highlighted an intensity effect for 6 - 7 days of compliance and at very active ambulatory levels. A volume effect appeared to dominate between sexes, across activity categories and weight-by-activity categories and would suggest that public health messages in this specific rural setting should focus on maintaining PA volume through daily living rather than advocating increases in PA intensity. It is important that *post hoc* statistical adjustments be made for body mass and PA volume when comparing EE_{Act} data across groups.

Acknowledgements

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