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RESEARCH

Evaluation of Three Accelerometer Devices for Physical Activity Measurement Amongst South Asians and Europeans

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We recruited 62 South Asians and 40 Europeans aged 25 to 75 years, to assess the potential validity of three physical activity accelerometers for use amongst South Asians. Participants completed an exercise treadmill test (following Bruce protocol) while wearing the 3 accelerometers: Actigraph GT3X+ [GT3X+] and Geneactiv [GA] on ankle, waist and wrist; and Actiheart [AH] on chest. We compared relationships between energy expenditure (EE) measured by accelerometers (Measured) and actual EE on the treadmill (Actual) in the two ethnicities and tested for potential confounding effects. All accelerometers under-reported EE. Difference between Measured and Actual EE was smallest for $GT3X+_{ankle}$ (Measured – Actual at peak exercise [Mets]: $GT3X+_{ankle}$ –6.52 (1.77); $GT3X+_{waist}$ –8.46 (1.29); $GT3X+_{wrist}$ –11.17 (1.03); GA_{ankle} –8.17 (1.19); GA_{waist} –10.24 (0.64); GA_{wrist} –11.21 (1.10); AH_{chest} –9.09 (1.43), $P < 0.001$). Difference between Measured and Actual EE was similar amongst South Asians and Europeans ($P > 0.05$). Relationship between Measured and Actual EE was not influenced by age, gender, height, waist, weight or waist-hip ratio (all $P > 0.05$). Amongst the devices and positions tested, $GT3X+_{ankle}$ is the most accurate device for measuring EE during an exercise treadmill test. Accelerometer performance is similar in South Asians and Europeans and is not influenced by anthropometric differences between the two populations.

Keywords: Accelerometer; Actigraph GT3X+; South Asians; physical activity; lifestyle; Metabolic Equivalents; Europeans; GeneActiv; Actiheart; Pakistan; India; Sri lanka; Bangladesh

Introduction

Physical inactivity is a major risk factor for type 2 diabetes (Balkau et al., 2008, Irwin et al., 2000, Kriska et al., 2003). Cross-sectional and prospective studies report a ~30% lower risk of type 2 diabetes amongst physically active people compared to those with sedentary lifestyles (Jeon et al., 2007). Furthermore, intervention studies show that increased physical activity reduces the risk of developing type 2 diabetes by almost 58% (Knowler et al., 2002, Lindstrom et al., 2003). Almost 60% of the adult global population fail to reach the WHO minimum physical activity recommendations (2013), and physical inactivity may account for ~18% of type 2 diabetes worldwide (Lee et al., 2012).

Previous studies report that physical activity is ~50% lower amongst South Asians (people originating from India, Pakistan, Bangladesh and Sri lanka) than Europeans (Hayes et al., 2002, Jepson et al., 2012, Pomerleau et al., 1999), suggesting that physical inactivity may be an important contributor to increased risk of type 2 diabetes amongst South Asians(Chambers and Kooner, 2002, Katulanda et al., 2008). However, previous studies, comparing physical activity levels between South Asians and other populations, have mostly relied on physical activity questionnaires, a measurement tool limited by low accuracy, poor reproducibility, linguistic, cultural and reporting bias (Shephard, 2003, Altschuler et al., 2009). There is an urgent need for more accurate quantification of physical activity and its contribution to type 2 diabetes amongst South Asians.

Direct measurement of physical movement using triaxial accelerometers offers the potential for objective quantification of energy expenditure during physical activity in both laboratory (Rothney et al., 2008a, Santos-Lozano et al., 2012, Esliger et al., 2011) and free-living settings (Hendelman et al., 2000, Leenders et al., 2001). Several devices that measure physical activity using accelerometery have been validated in European populations (Rothney et al., 2008b), through comparisons with metabolic measurement of energy expenditure. However, body habitus is known to influence the accuracy of accelerometers (Westerterp, 2013). Given the well-documented anthropometric differences between South Asian and European populations (McKeigue et al., 1991, Tillin et al., 2012), this raises the possibility that accelerometers may provide biased or less accurate results amongst South Asians compared to Europeans. The purpose of the present study was therefore to investigate the performance of 3 accelerometers: the Actigraph GT3X+, Geneactiv and Actiheart amongst South Asians and Europeans.

Methods

We completed an observational study to assess the accuracy of three commercially available accelerometers for measuring physical activity amongst South Asians and Europeans. Graded physical activity was induced by a standard exercise treadmill test (Bruce protocol), and the devices positioned on the recommended anatomical locations to assess the importance of positioning on device performance. The study was approved by Wales Research ethics committee (Ref: 12/WA/0400) and all participants gave written consent to take part.

Participants

We studied 62 South Asian and 40 European men and women, aged 25 to 75 years. Participants were recruited from amongst patients undertaking an exercise treadmill test for clinical indications at Ealing Hospital NHS Trust. Participants were excluded if they stopped before 3 minutes (stage 1) of the treadmill test or had any physical limitation that would affect their performance on the treadmill.

Data Collection

Data was collected regarding personal, behavioural, family and medical history through an interviewer-administered questionnaire. Physical measurements included height, weight, waist circumference and hip circumference. Height was recorded to the nearest 0.1cm using a stadiometer, mounted on a hard, flat surface. Weight was recorded to the nearest 0.1kg. Waist and hip measurements were recorded to the nearest 0.1cm using a non–stretchable measuring tape. Waist circumference was defined as the minimum circumference between iliac crest and lowest rib. Hip circumference was defined as the maximum circumference over the greater trochanters and buttocks.

Accelerometers

We investigated three commercially available accelerometers: i. the Actigraph GT3X+, ii. Geneactiv and iii. Actiheart**.** The Actigraph GT3X+ and Geneactiv are tri-axial accelerometers. Actiheart is a chest worn monitor that records both accelerometery and heart rate to estimate physical activity.

To enable comparison between devices and positions, each participant wore three Actigraph GT3X+ devices (wrist, ankle and waist), three Geneactiv devices (wrist, ankle and waist) and one Actiheart (chest, no alternate positions possible) while completing the treadmill test (i.e. a total of seven devices across four positions). All devices were used according to manufacturer instructions and using the manufacturer's software for data processing and analysis.

Physical activity monitoring accelerometers were initialized to capture acceleration at a frequency of 100 Hz in 1 minute epochs. Data from the accelerometers were downloaded to the computer and saved as Microsoft excel files. Freedson Treadmill Adult (1998) equation was used to calculate energy expenditure for Actigraph GT3X+ and Geneactiv. Actiheart software uses the branched chain equation (Brage et al., 2004) for calculating energy expenditure. The energy expenditure measured by the devices was calculated as the average of minutes 2 and 3 for each completed 3-minute stage of the treadmill test.

Exercise treadmill test

Participants completed a graded exercise treadmill test with 12-lead ECG and blood pressure monitoring. The speed and incline of the treadmill increased at 3-minute intervals according to the standard Bruce protocol (Bruce, 1974, Bruce et al., 1973). The test was concluded according to clinical indication (Myers et al., 2009).

Actual energy expenditure (METs) was derived by exercise testing software (GE Cardiac Assessment System for Exercise Testing 8000) based on the speed and grade of the stage completed on the Bruce protocol (Steven N. Blair, 1986). The equation for Metabolic Equivalents follows: METs = speed × 26.8 × (0.1 + 1.8 × grade/100) + 3.5/3.5, where grade is given in percent and speed is given in miles per hour. MET levels are extrapolated between stages of exercise. Two minutes of a stage must be completed to obtain full stage MET values. At any point thereafter, full credit is given for the stage.

Data analysis

Data were analysed using SPSS 22.0. We analysed the relationship between Measured and Actual energy expenditure using two complementary approaches. First, we made bland Altman plots for determining the agreement between Measured and Actual energy expenditure. We calculated the *difference* between measured and observed energy expenditure for each participant at each stage. We then compared the difference between Measured and Actual between devices and positions (using Analysis of Variance) and investigated whether the difference varied between the two ethnic groups. Next, we used linear regression to quantify the *relationship* between Measured and Actual energy expenditure across all stages of the treadmill test for each participant; here the beta co-efficient from linear regression provides an estimate of the change in Actual energy expenditure per unit change in Measured energy expenditure during exercise. We then explored whether ethnicity or other clinical covariates influenced the relationship between Measured and Actual energy expenditure (using linear regression).

Results

Characteristics of participants

Baseline characteristics of participants are presented in **Table 1**. South Asians had lower height, but higher waist circumference and waist-hip ratio, compared to Europeans. Weight and body mass index were similar in the two populations. Prevalence of T2D, hypertension and coronary heart disease (CHD) was higher in South Asians and average time spent on the treadmill was higher in Europeans compared to South Asians.

Comparison of devices

The agreement between Measured and Actual energy expenditure was evaluated using Bland-Altman plots. All devices underestimated energy expenditure in the active stages (stages 1–4) of treadmill ($P < 0.001$, **Figures 1** and **2**). The difference between Measured and Actual energy expenditure increased with each stage of the treadmill test (**Figure 1**). The mean difference between Measured and Actual energy expenditure

Table 1: Clinical characteristics of participants. Results are presented as mean (SD) for continuous variables or as percentage for categorical variables. P values are for the difference between south Asians and Europeans, calculated by regression analysis with adjustment for age and gender.

	Europeans	South Asians	p
Age (years)	52.0 (13.7)	50.1 (12.6)	0.2
Male %	55.5%	60.5%	0.3
Type 2 Diabetes (%)	5.7%	12.8%	0.01
Hypertension (%)	23.2.0%	39.9%	0.001
CHD (%)	6.7%	15.8%	0.006
Smoking (%)	42.1%	24.1%	<0.001
Height (cm)	168.7 (10.8)	164.7 (8.6)	0.002
Weight (cm)	75.4 (17.0)	75.2 (12.0)	0.9
Body mass index (kg/m^2)	27.0 (5.9)	27.7 (3.9)	0.5
Waist circumference (cm)	90.4 (13.9)	94.4 (11.0)	0.003
Hip circumference (cm)	103.7 (10.7)	104.0 (8.4)	0.8
Waist hip ratio	0.87 (0.07)	0.91 (0.09)	<0.001
Time on treadmill (minutes)	9.3	8.0	0.01

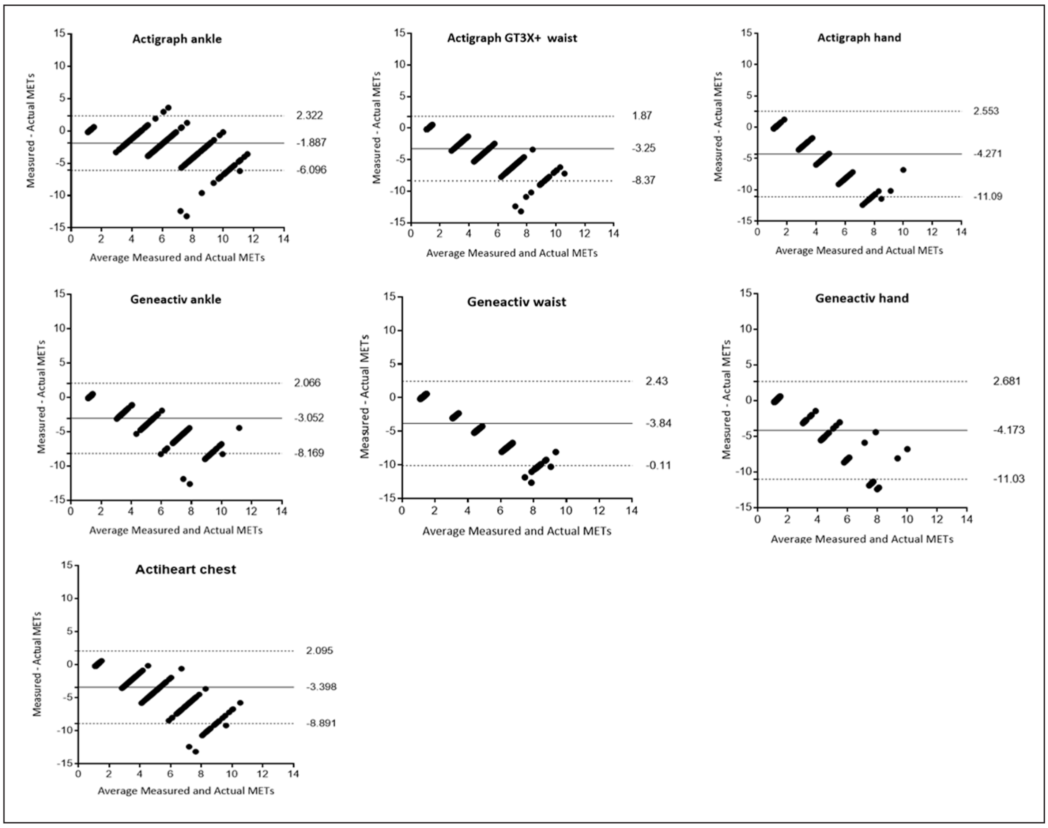

Figure 1: Bland-Altman plot for comparing the agreement between physical activity energy expenditure (METs) calculated by accelerometers (Measured) and the ETT (Actual). The difference of estimate of moderate physical activity from the Measured and the Actual (y-axis) are depicted in relation to the mean of estimates of physical activity from the Measured and the Actual (x-axis).

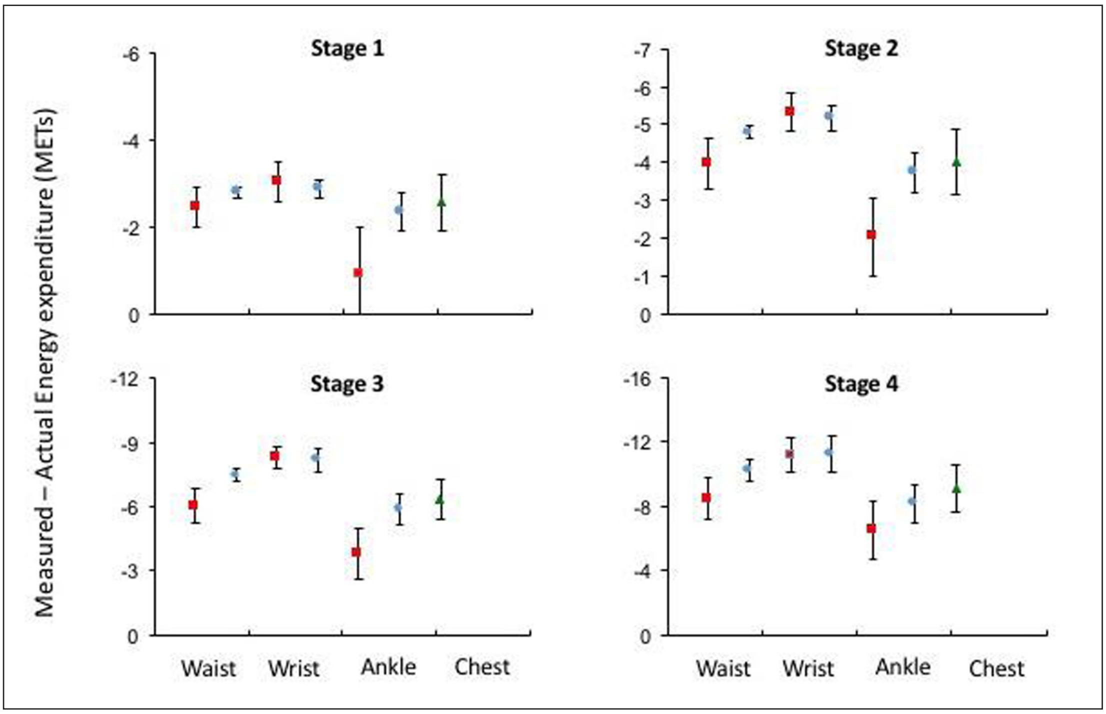

Figure 2: Mean difference between Measured (from the accelerometery device) and Actual (from the ETT) energy expenditure during rest and active stages of graded exercise test. (Red square: Actigraph GT3X+; Blue circle: Geneactiv; green triangle; Actiheart).

was lower for Actigraph GT3X+ in all the three positions compared to Geneactiv (P < 0.05, **Table 2**). The difference between Measured and Actual was also lower for Actigraph GT3X+ in the ankle and waist positions, compared to Actiheart (P < 0.05, **Table 2** and **Figure 2**).

Comparison of positions

Amongst the four different body positions evaluated, devices worn on the ankle showed least difference between Measured and Actual energy expenditure followed by devices worn on the waist and chest (**Figure 2** and **Table 2**). Wrist-worn devices consistently showed highest difference between Measured and Actual energy expenditure. The differences were most evident at peak exercise (Measured – Actual for Actigraph GT3X+ on ankle: –6.52 (1.77); waist: –8.46 (1.29); wrist –11.17 (1.03); Geneactiv on ankle: –8.17 (1.19); waist –10.24 (0.64); wrist: –11.21 (1.10); Actiheart on chest: –9.09 (1.43), P < 0.001) (**Table 2**).

Impact of ethnicity and anthropometric measurements on accelerometer output

There was little evidence for heterogeneity in the relationship between Measured and Actual energy expenditure between the two populations for any of the devices or positions tested ($P_{het} > 0.05$, **Table 2**). In both the populations the difference between Measured and Actual was smallest for the Actigraph GT3X+ in the ankle position followed by the waist position while the wrist-worn devices showed a poor relationship between Measured and Actual (P < 0.05 from analysis of variance).

Next, we evaluated whether the relationship between Measured and Actual energy expenditure is influenced by age, gender, ethnicity, anthropometric or other clinical measures (**Table 3**). Linear regression was used to quantify the relationship between Measured (predictor) and Actual (outcome) energy expenditure. This was followed by adding physical and clinical covariates to the model and assessing the change in beta coefficient and 95% confidence interval before and after adding the covariates. The change in beta coefficient was considered insignificant if the 95% CI overlapped before and after adding clinical variables to the model. For all three devices, there was little evidence these clinical variables impacted on the relationship between Measured and Actual Energy expenditure during the complete treadmill test (same beta coefficient and 95% CI before and after adding clinical variables to the model, **Table 3**).

Discussion

We show that the Actigraph GT3X+ worn on the ankle or waist measures energy expenditure during a treadmill test more accurately than both the Geneactiv device, in similar positions, and the chest-worn Actiheart device. Although all the three devices evaluated consistently underestimate actual energy expenditure, device performance is similar between South Asians and Europeans. The Actigraph GT3X+,

Table 2: Mean difference between Measured (from the accelerometery device) and Actual (from the treadmill test) energy expenditure (METs) during graded exercise test. P-values are for the difference between Measured and Actual (paired samples t-test).

Device	Stage 1 (4.6 Mets)	Stage 2 (7.0 Mets)	Stage 3 (10.1 Mets)	Stage 4 (13.4 Mets)	P_{het*}
Actigraph-GT3X+					
Ankle	–0.91 (1.08)	–2.03 (1.03)	–3.81 (1.19)	–6.52 (1.77)	0.8
Waist	–2.45 (0.44)	–3.95 (0.66)	–6.02 (0.81)	–8.46 (1.29)	0.7
Hand	–3.03 (0.46)	–5.33 (0.49)	–8.29 (0.52)	–11.17 (1.03)	0.9
Geneactiv					
Ankle	–2.34 (0.43)	–3.73 (0.54)	–5.87 (0.75)	–8.17 (1.19)	0.7
Waist	–2.78 (0.14)	–4.80 (0.18)	–7.45 (0.29)	–10.24 (0.64)	0.7
Hand	–2.86 (0.19)	–5.18 (0.34)	–8.19 (0.56)	–11.21 (1.10)	0.8
Actiheart					
Chest	–2.55 (0.66)	–4.03 (0.86)	–6.35 (0.89)	–9.09 (1.43)	0.7

All P-values for difference between Measured and Actual MET.minutes: P < 0.001.
* P_{het} represents p-value for comparison of differences between South Asians and Europeans.

Table 3: Impact of age, gender, ethnicity and anthropometric measurements on the relationship between Measured (from the accelerometer) and Actual (from the treadmill test) energy expenditure. Results are presented as **Beta (95% CI)**. Beta coefficients represent the relationship between Measured and Actual energy expenditure, before and after adjusting for the respective clinical variable. P values are calculated by regression analysis with adjustment for age, gender and ethnicity. Statistical significance inferred at P < 0.001 (i.e. P < 0.05 after conservative Bonferroni correction for multiple testing).

	Waist		Wrist		Ankle		Chest
	Actigraph	**Geneactiv**	**Actigraph**	**Geneactiv**	**Actigraph**	**Geneactiv**	**Actiheart**
Accelerometer	2.38 (2.25_2.51)	5.58 (5.29_5.87)	3.00 (2.44_3.57)	3.65 (3.01_4.30)	1.43 (1.34_1.51)	2.51 (2.38_2.64)	2.28 (2.11_2.46)
Age	2.40 (2.27_2.54)	5.57 (5.28_5.86)	3.02 (2.43_3.60)	3.61 (2.95_4.26)	1.43 (1.35_1.52)	2.50 (2.37_2.63)	2.27 (2.10_2.45)
Sex	2.40 (2.27_2.54)	5.57 (5.28_5.86)	3.01 (2.42_3.59)	3.65 (3.00_4.31)	1.44 (1.35_1.52)	2.50 (2.37_2.63)	2.27 (2.10_2.45)
Ethnicity	2.40 (2.27_2.54)	5.57 (5.28_5.86)	3.01 (2.42_3.59)	3.65 (3.00_4.31)	1.44 (1.35_1.52)	2.50 (2.37_2.63)	2.27 (2.10_2.45)
Height	2.40 (2.27_2.54)	5.59 (5.31_5.88)	3.00 (2.42_3.59)	3.66 (3.01_4.32)	1.44 (1.35_1.53)	2.50 (2.37_2.63)	2.28 (2.11_2.45)
Weight	2.40 (2.27_2.54)	5.57 (5.28_5.87)	3.01 (2.43_3.60)	3.63 (2.98_4.29)	1.43 (1.35_1.52)	2.50 (2.37_2.63)	2.31 (2.14_2.48)
Body mass index	2.40 (2.27_2.54)	5.57 (5.28_5.87)	3.01 (2.43_3.60)	3.63 (2.98_4.29)	1.43 (1.35_1.52)	2.50 (2.37_2.63)	2.31 (2.14_2.48)
Waist	2.40 (2.26_2.53)	5.56 (5.27_5.85)	3.02 (2.43_3.60)	3.61 (2.96_4.27)	1.43 (1.34_1.52)	2.50 (2.37_2.63)	2.34 (2.17_2.51)
Hip	2.41 (2.27_2.54)	5.58 (5.29_5.87)	3.04 (2.46_3.62)	3.64 (2.98_4.29)	1.44 (1.35_1.52)	2.51 (2.38_2.64)	2.33 (2.16_2.50)
Waist hip ratio	2.40 (2.26_2.53)	5.55 (5.27_5.84)	2.99 (2.40_3.57)	3.63 (2.98_4.29)	1.43 (1.35_1.52)	2.49 (2.37_2.62)	2.28 (2.10_2.45)
Smoking	2.40 (2.27_2.54)	5.57 (5.28_5.86)	3.04 (2.45_3.62)	3.70 (3.04_4.35)	1.44 (1.35_1.53)	2.50 (2.37_2.63)	2.27 (2.10_2.45)
Functional status	2.41 (2.27_2.54)	5.57 (5.28_5.86)	3.06 (2.47_3.65)	3.73 (3.08_4.38)	1.44 (1.35_1.53)	2.50 (2.37_2.63)	2.28 (2.10_2.46)
Angina	2.40 (2.26_2.53)	5.56 (5.27_5.85)	3.02 (2.43_3.60)	3.64 (2.98_4.29)	1.44 (1.35_1.53)	2.50 (2.37_2.63)	2.27 (2.09_2.44)
Myocardial Infarction	2.41 (2.27_2.54)	5.59 (5.30_5.88)	3.05 (2.46_3.63)	3.65 (3.00_4.31)	1.44 (1.35_1.53)	2.50 (2.37_2.63)	2.27 (2.10_2.45)
CABG/PCI	2.40 (2.27_2.54)	5.57 (5.28_5.86)	3.04 (2.45_3.63)	3.66 (3.00_4.31)	1.44 (1.35_1.53)	2.50 (2.37_2.63)	2.27 (2.10_2.45)
Type 2 Diabetes	2.40 (2.27_2.54)	5.56 (5.28_5.85)	3.00 (2.42_3.59)	3.64 (2.99_4.30)	1.44 (1.35_1.52)	2.50 (2.37_2.63)	2.27 (2.10_2.45)
Hypertension	2.40 (2.26_2.53)	5.56 (5.27_5.85)	3.00 (2.42_3.59)	3.65 (3.00_4.30)	1.44 (1.35_1.53)	2.53 (2.40_2.66)	2.27 (2.09_2.44)

Results are presented as Beta (95%CI). Beta coefficient represents the change in Actual METs per unit change in Measured METs.

Geneactiv and Actiheart devices are not influenced by differences in anthropometric measures. Our results suggest that the Actigraph GT3X+ worn on the ankle or waist is a suitable device for objective measurement of energy expenditure during physical activity amongst South Asians, and for comparison of energy expenditure between South Asian and European populations.

We evaluated the performance of three commercially available accelerometers, for measurement of energy expenditure. Actiheart includes heart rate monitoring in addition to accelerometry, and incorporates this information into estimation of energy expenditure. The Actigraph GT3X+, Geneactiv and Actiheart devices have been validated against actual energy expenditure determined by doubly-labeled water and calorimetry in Europeans in both laboratory and free-living settings (Brage et al., 2005, Esliger et al., 2011, Hendelman et al., 2000, Leenders et al., 2001). However, measurement of energy expenditure during physical activity accelerometers is closely influenced by both technical factors such as device positioning (Atallah et al., 2010), as well as biological factors such as height, weight, waist-hip ratio and fat mass (Westerterp, 2013). These observations suggest that accuracy of accelerometers may vary between South Asians and Europeans as a result of the anthropometric differences between the two populations.

We show that Measured energy expenditure from all three accelerometers is lower than the Actual energy expenditure, during all stages of the treadmill test. The Actigraph GT3X+ captured energy expenditure more accurately that the Geneactiv device in all positions evaluated. Ankle and waist worn Actigraph GT3X+ devices also performed superiorly to the Actiheart device. This is consistent with previous studies which support the validity of the Actigraph device under both laboratory (Santos-Lozano et al., 2012) as well as free-living conditions (Hendelman et al., 2000, Leenders et al., 2001). In contrast, wrist-worn accelerometers showed poor relationship and captured minimal energy expenditure, likely reflecting the relative lack of contribution of hand movement to physical activity during walking (Tudor-Locke et al., 2015).

The relationship between Measured and Actual energy expenditure was similar amongst South Asians and Europeans for all devices and positions. These results support the validity of the accelerometers evaluated for comparisons of physical activity and energy expenditure between populations.

Strengths and limitations of the study

Although we show for the first time the validity of physical activity accelerometers amongst South Asians, our study has some limitations. We compared measured with actual energy expenditure estimated based on speed and incline of the exercise treadmill, rather than directly measured energy expenditure from double labeled water or calorimetry. However, published studies show that estimates of energy expenditure based on speed and incline correlate closely with direct measurements from doubly-labeled water and calorimetry (Maeder et al., 2008). Secondly, we studied people in a hospital setting, with a limited sample size, and limited the assessment of physical activity to energy expenditure during walking. Future work should include assessment of device performance under a wider range of activities in free-living conditions.

Conclusion

In summary, we show that the Actigraph GT3X+ is more accurate than the Geneactiv and Actiheart devices for measurement of physical activity during walking, and that energy expenditure during walking is best measured by devices worn on the ankle and waist. The performance of the Actigraph GT3X+ is similar in South Asians and Europeans and does not appear to be materially influenced by anthropometric parameters. Our results support the view that the Actigraph GT3X+ is a suitable device for measurement of energy expenditure during physical activity in trans-ethnic epidemiological studies.

Data Accessibility Statement

Data underlying the results contain potentially identifying and sensitive patient information, hence there are ethical and legal restrictions on sharing the data. Data requests may be sent to Ninha Silva (ninha.silva@imperial.ac.uk), School of public health, Faculty of Medicine, Imperial college London, UK.

Additional File

The additional file for this article can be found as follows:

- **Supplementary Material.** Exercise treadmill test and Accelerometers. DOI: https://doi.org/10.5334/paah.46.s1

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Competing Interests

The authors have no competing interests to declare.

Author Contribution

SA and JC conceived and designed the study. SA, ML, JS and JC interpreted the data, revised the manuscript and approved the final draft.

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