MOTION SENSOR OUTPUTS OF CHILDREN AND ADOLESCENTS WALKING AND RUNNING TO THREE TREADMILL SPEEDS

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Abstract
The study examined the motion sensor outputs of Singaporean children and adolescents of both sexes to walking and running on a motorized treadmill (Quinton Series 90) under controlled laboratory conditions. 58 youths of normal body mass (N=58, age: 13.2±3.0 y; height: 1.53±0.02 m; body mass: 45.5±14.2 kg; BMI: 18.8± 3.0 kg/m^2; Tanner rating: 2.5±1.3) were recruited for the study. Accelerometer (ActiGraph GT 1 M) activity (ActiCounts in counts/min) and step rate (ActiSteps in steps/min) and pedometer (Omron HJ 005-E) step rate (PedoSteps in steps/min), oxygen uptake (in ml/kg/min) and heart rate (in bpm) were obtained from 5-minutes stages of 0 % gradient of treadmill walking at 4 km/hr and running at 6 km/hr and 8 km/hr. Walking at 4 km/hr was estimated at 4.0-6.0 METs, whilst running at 6 km/hr and 8 km/hr was estimated at 6.3-8.6 and 10.0-11.4 METs, respectively. Motion sensor outputs increased significantly with treadmill speeds (76-101 % for ActiCounts; 22-24 % for ActiSteps and18-25 % for PedoSteps, all p<0.01) as did oxygen uptake (48-55 %) and heart rate (27-28 %) but there was no sex difference in activity or step rate or physiological responses (p>0.01). No meaningful relationships were obtained between accelerometer activity rate and oxygen uptake or heart rate. There was acceptable agreement between accelerometer and pedometer step rate for the walking and running on the treadmill but the difference between accelerometer and pedometer step rate was smallest at a treadmill running speed of 6 km/hr. These results show that accelerometer and pedometer step rates are useful and suitable measurements of physical activity involving walking and running among Singaporean children and adolescents of normal body mass. Further investigations are necessary to fully exploit the use of accelerometer data in physical activity research among young people.

Key words: *Motion sensor output, children and adolescents, treadmill walking and running*

Introduction

Regular and adequate amounts of physical activity (PA) are associated with desirable health outcomes among children and adolescents while inadequate and irregular amounts of PA are associated with poor levels of physical fitness, increased likelihood of obesity and deleterious health ailments in childhood and adulthood.

Biddle et al (2004) stressed the importance of a better understanding between PA and health in youth, while Strong et al (2005) presented persuasive evidence of the links between PA and short and long term health and behavioural outcomes in youth. Therefore when PA is the target of assessment, either as an intervention or as an outcome variable of choice for research, an accurate and reliable assessment of PA is paramount. Advances in technology make electromechanical motion body sensors, in particular accelerometers and pedometers, popular among researchers when assessing PA among youths. Both are lightweight and are unobstructive and are usually worn at the hip or waist. Their use as PA assessment tools and data interpretation in young people are reviewed elsewhere (Rowlands et al, 2007; Rowlands 2007; Kavanagh & Menz 2008). One disadvantage of both the pedometer and the accelerometer is that they do not provide any information about the type of physical activity or the context or social setting that the physical activity occurred (Ward et al 2005). Another disadvantage of pedometers is that the step count accumulated provides no information about the intensity of the physical activity aggregated. Despite these limitations, the amount of research generated by accelerometer and pedometer devices continues to multiply (Tudor-Locke et al 2002; Rowlands, 2007). The time-sampling and data storage capability of most accelerometers are useful for documenting movement characteristics over researcher-determined time periods. The periods of varying intensity- low, moderate and vigorous can be categorised based on the rate of activity counts accumulated. The latest version of the uniaxial ActiGraph (GT1M) accelerometer has a memory size of 1 Mb and can collect data at 1 s epochs for nearly six days.

It has the capacity to use epochs ranging from 1 to 15s to objectively assess the temporal pattern of children's activity over days at a time. The accelerometer monitors human motion (frequency and intensity over a user-specified time epoch duration. The acceleration signal is digitised, and the magnitude is summed over the epoch duration. At the end of each epoch, the summed value or activity count is stored in memory, and the integrator is reset. The relatively high cost of each unit (about S$ 450) additional software and hardware for calibration, distillation and analysis of data limit its use to smaller-scale studies. The relatively lower cost of pedometers (about S$ 25) coupled with the ease of its use and increasing volume of pedometer-derived reported PA data in the research literature, make pedometers an attractive and objective alternative to accelerometers, for garnering PA data in youths, especially in large-scale population based studies.

It is prudent to heed the view of Tudor-Locke et al (2002) that as pedometers are consumer items, they are likely to evolve, and regardless of the brand preferred, it is important that researchers report the validity of the pedometer chosen. The Omron Model HJ-005 pedometer is reasonably-priced and is commercially available. The validity and reliability of Omron HJ-005-E were previously established in a group of 34 boys and girls aged 8 and 10 years. Inter-class correlation coefficients R between pedometer step counts and the GT1M ActiGraph accelerometer counts were 0.850, 0.829 and 0.685 (all $P<0.05$), respectively, under 4km/h, 6km/h and 8km/h controlled-speed conditions, in the field. Intra-class correlation coefficients between two units of the Omron HJ-005-E pedometer worn on the left and right hip under the same speed-controlled conditions were 0.918, 0.812, and 0.876, respectively (Wang Ye, 2008). Researchers, in an attempt to put biological meaning to accelerometer counts related accelerometer-derived activity counts with energy expenditure at various intensities from sedentary to vigorous (e.g. Trost et al 2002; Rowlands 2004) and the publication of numerous count thresholds from different models of accelerometers, highlights the lack of agreement about the interpretation of accelerometer outputs and the many published thresholds have compounded the issue and make across studies comparisons of data problematic (Rowlands 2007). The advice provided by Tudor-Locke et al (2002) that accelerometer-derived activity counts should not be equated to energy expenditure since the two are conceptually dissimilar, provides encouragement for researchers to focus on relating accelerometer outputs to other physiological parameters (e.g. heart-rate, or oxygen uptake) and mechanical outputs (e.g. step counts).

These data are useful for the comparison of physical activity when using the ActiGraph GM 1 M accelerometer and the Omron HJ-005-E electronic pedometer, as they are conducted in standardized controlled laboratory environment. There are limited data from accelerometer and pedometer in relation to physiological parameters in children and adolescent of both sexes in response to different treadmill speeds in the same study. These data are important as they provide a biological basis of understanding accelerometer and pedometer-derived data from different exercise intensities under laboratory conditions in a sample of Asian children and adolescent participants. Moreover, there are scant data on Asian young people in this regard and as greater research attention is focused on young people in Asia, ethnic and race relevant data are useful for comparison. In apparently the only published study on an Asian sample, Louie et al (1999) examined the validity of heart rate, pedometry (Digiwalker DW-200, Yamax) and accelerometry (WAM Model 7164 and TriTrac 3D Model T303) for estimating the energy cost of physical activity (treadmill walking at 4 and 6 km/hr; treadmill running at 8 and 10 km/hr; playing catch, playing catch, and sitting and crayoning) in a sample of 21 Hong Kong Chinese boys aged 8-10 years. Their results showed that the WAM accelerometer and the hip pedometer accounted for similar variances in submaximal allometrically scaled (ml/kg $BM^{0.75}$/min) oxygen uptake (73.8% for the WAM versus 73.4% for the Digiwalker). Limitations of the cited study are that no data on Chinese girls are available, the age span of the boys was rather narrow and the models of accelerometer and pedometer are different and no longer commercially available. Hence the purpose of the present study is to examine the outputs of motion sensors and physiological responses to three treadmill speeds in a larger cohort Singaporean children and adolescents of both sexes and in commercially available accelerometer and pedometer.

Methods and Procedures

Participants

A convenience sample of 58 healthy male and female children and adolescents, segregated into three cohorts, Cohort 1: aged 11 years (N=20), Cohort 2: aged 14 years (N=20) and Cohort 3: 17 years (N=18) participated in the study. The sample size of the present study is substantially larger and consisted participants of both sexes than previously published research of similar but not identical nature on motion sensors that involved young people (e.g. Louie et al 1999). The research procedures were reviewed and approved by the Institutional Review Board for Ethical Clearance at Nanyang Technological University, Singapore.

Written informed consent and assent forms were obtained from the parents and participants. As step counts in children are affected by body mass index (Duncan et al 2006), all participants recruited for study were of normal body mass index. Participants wore comfortable exercise attire- shorts, a T-shirt and sports shoes for the laboratory-based test. All participants were habituated to the laboratory test environment, the motion sensors and were familiarized to walking (at 4 km/hr) and running (6 km/hr and 8 km/hr) on the motorized treadmill. The characteristics of the participants are presented in Table 1.

Instruments

Uniaxial ActiGraph accelerometer

The ActiGraph accelerometer (GT1M, Fort Walton Beach, FL, USA) was used in the present study. The ActiGraph is sensitive to movement along the vertical axis and can be programmed to record data in epochs of between 1 s and 5 minute or, when in raw data mode, at a rate of 30 Hz. The ActiGraph was checked for calibration using the manufacturer-recommended hardware and software, and calibrated if necessary. The pedometer function of the ActiGraph that allows for the simultaneous collection of step counts per minute (ActiSteps) was also used. The sampling period or epoch of the ActiGraph in the present study was set at 5s and the accelerometer output expressed as activity counts per 1 min (ActiCounts). The accelerometer was also synchronized to the investigator's timing device. Rowlands (2007) recommends that when assessing physical activity in children, epoch durations of less than 10 seconds are recommended.

Uniaxial pedometer

The Omron Step Counter HJ-005-E (Omron Healthcare Co., Ltd., Japan) was also used in the present study and registers the number of steps taken during physical activity over a period of time. Omron pedometer products use glass-enclosed magnetic reed proximity switch for their function. The step counter has a 5-digit LCD display (up to 99 999). The pedometers were checked using a shake (Vincent et al 2002) and brief walking test (Tudor-Locke and Myers 2001). If the step count error exceeded ±5 % in either the shake or walking test, the pedometer was not used in the study. All pedometers passed the shake and walking test in the present study. Reliability research by Crouter et al (2003), albeit with adults using the Omron HJ-105-E at 54, 67, 80, 94, and 107 m/min treadmill speeds for 5-minute stages showed that the Omron HJ-105 displayed a high degree of reliability between devices attached at the right and left sides (ICC > 0.83, p<0.05 for a treadmill speed of 80m/min).

In the laboratory, correlations between pedometer step counts and oxygen uptake during treadmill exercise ranged from r= 0.62 to 0.93 (P<0.05) (Eston et al 1998; Louie et al, 1999). In the present study, the pedometer readings were reset to zero for each testing phase. The total number of steps was recorded at the end of each 5-minute treadmill stage. Pictures of the Actigraph GT 1 M and the Omron Step Counter are depicted in Figure 1 (a & b).

Figure 1a: Motion sensors: ActiGraph GT 1 M accelerometer

Figure 1b: Motion sensors: Omron HJ 005-E pedometer

Procedure

Anthropometric measurements

Stature and body mass of participants were measured. Standing height was measured to the nearest 0.1 centimetre using a rigid stadiometer and body mass was measured to the nearest 0.1 kg using a balance scale. Body mass index (BMI) was calculated as body mass in kilograms divided by height in meters squared (kg/m^2). Exercise testing on the treadmill was conducted in a controlled laboratory environment (ambient temperature 22 ± 2º C) and relative humidity 60±5 %). A qualified female nurse examined the sexual maturity status of the participants using the pubic hair criteria of Tanner (1962).

Motion sensor placements
Prior to testing, the ActiGraph and Omron motion sensors were worn concurrently (clipped onto the waistband of the shorts) on the right and left hips, respectively, adhering to the manufacturers' recommendations (e.g. for best results, keep the unit aligned to the crease line of the trousers). Research informs that accelerometer placements at the right or left side of the hip did not significantly affect the data (i.e. total activity counts/min and time spent at different intensity levels) obtained from 16, seven-year-old boys and girls, worn over 4 days, and monitored over the waking hours (Nilsson et al 2002). Similarly, studies show that left or right placements of pedometers generated step counts that were not significantly different from each other (Basset et al 1996; Crouter et al 2003). Additionally, Vincent and Pangrazi (2002) reported that wearing motion sensors like the pedometer among young people aged between 8 and 12 years, who were well-habituated to the pedometers (i.e. after allowing for 10 minutes of uninhibited exploration of the device), produced no significant reactivity. Reactivity is explained as a significant reaction to wearing the device compared to not wearing the device. The present group of participants was well-habituated to wearing both the accelerometer and the pedometer.

Treadmill speed
Before the start of the exercise testing, the activity monitors were reset and synchronized to an external time piece. Following a 2- to 3-minute familiarization period with the motor-driven treadmill (Quinton Series 90, Quinton Instrument Company, USA) at a steady pace equivalent to a 2.5km/hr walking pace, participants performed three continuous 5-minute exercise bouts which consisted of (a) walking at 4km/hr, (b) jogging or running at 6km/hr, and (c) running at 8km/hr. A similar but not identical protocol of 4-minute stages at five different treadmill speeds (walk at 4 and 6 km/hr; run at 8 and 10 km/hr was successfully completed by 8 to 10-year-old Chinese boys (Louie et al 1999). These exercise bouts were performed at 0 % gradient since previous studies show that vertical axis accelerometers to be generally non-responsive to gradient changes (Haskell et al 1993; Melanson & Freedson 1995). Verbal encouragement was given to the participants through the tests to maintain a steady walking or running pace for each of the five minute stages.

Indirect calorimetry and heart rate monitoring
The Cosmed $K4b_2$ (Cosmed, Italy), a widely used portable telemetry device, was used to measure the rates of oxygen uptake ($\dot{V}O_2$), carbon dioxide production (CO_2) and pulmonary ventilation ($\dot{V}_E$). The validity and reliability of the Cosmed $K4b_2$ system were previously established (Pinnington et al 2001; Duffield et al 2004). Prior to each test session, the Cosmed transmitter was turned on and warmed-up for at least 30 minutes. Calibration of the Cosmed system was conducted in accordance to the recommended procedures set by the manufacturer. The portable unit was fixed onto the subject by an anatomic harness and powered by a rechargeable battery that also was attached to the same harness. Expired gas was collected via an attached face mask that covered both the nose and mouth. The face mask was secured by a mesh headcap with adjustable straps.

Subjects breathed through the facemask whilst seated for approximately 3 to 5 minutes to allow the stabilisation of respiratory variables, HR and familiarisation with the Cosmed equipment. The heart rate (HR) telemetry device of the Cosmed $K4b_2$ system was used for the recording of baseline and exercise HR. The telemetry device comprised a double electrode transmitter chest belt (Sports Tester PE 3000) and a HR receiver probe connected to the portable unit of the Cosmed $K4b_2$ system. The transmitter was positioned on the chest, anterior to the xiphisternal joint, and strapped to the subject via an elastic belt. Heart rate signals were picked up by the receiver probe that was attached on the left side of the thorax approximately 5 cm superior to the left nipple and a Polar wrist monitor. The Polar wrist monitor was secured on the treadmill in close proximity to the subject to ensure transmission of heart rate signals.

Physiological measurements
Baseline physiological measurements (HR and $\dot{V}O_2$) were obtained 1 minute prior to the start of each test, and throughout the three, 5-minute treadmill tests at 4-, 6- and 8 km/hr. All analysis of cardio-respiratory variables (HR and $\dot{V}O_2$)were performed on the steady state variables obtained during the last two minutes of each 5-minute exercise stage at 4 km/hr, 6 km/hr and 8 km/hr, respectively. Both accelerometer and pedometer were immediately removed at the end of the test session and the data in the ActiGraph GT 1 M accelerometer (ActiCounts/min and ActiSteps/min) were downloaded using manufacturer recommended hardware and software, and together with the Omron HJ-005-E pedometer (PedoSteps/min) were entered into a personal computer for statistical analysis.

Statistical analysis
All data were analysed using SPSS (Statistical Package for the Social Sciences for Windows Version 16.0). Descriptive statistics (means ± sd) were calculated for all output measures.

Sex differences in accelerometer and pedometer data sets and physiological responses to the treadmill speeds were explored using one-way analysis of variance (OW-ANOVA). Paired-sample t-tests were used to analyse motion sensor outputs (step rate) and physiological responses in response to the three treadmill speeds. Pearson product-moment correlations were computed between ActiCounts, ActiSteps, PedoSteps and treadmill speeds, physiological variables (HR, $\dot{V}O_2$) to determine significant relationships among the variables. Agreement between ActiSteps and PedoSteps were examined using the method described by Bland and Altman (1986) and the difference between ActiSteps and PedoSteps was tested by a paired-sample t-test. An alpha level of 0.05 was used for all statistical tests, however where stated, the alpha level was reduced to 0.01 to account for multiple tests of significance.

Results

The descriptive characteristics, motion sensor responses and physiological responses of the 58 youths to walking and running at three treadmill speeds are summarized in Table 1. OW-ANOVA on accelerometer, pedometer and physiological responses to the three treadmill speeds revealed no sex differences ($p>0.01$). Hence the male and female data in each cohort were pooled. All participants were within the normal weight-for-height range according to charts furnished by the School Health Services of the Ministry of Health (2002), and within the normal healthy range for BMI ($17<BMI<24.9$) based on international classifications (Cole et al 2000).

Preliminary data analyses of accelerometer (ActiCounts/min; ActiSteps/min) pedometer (PedoSteps/min) data and key physiological variables (i.e. oxygen uptake and HR) showed that for all cases, that was homogeneity of variance (Levene statistic > 0.01).

Paired-sample t-tests, with corrections for multiple comparisons (adjusted alpha= 0.01) revealed that for all 3 cohorts, accelerometer counts (ActiCounts/min), accelerometer steps (ActiSteps/min) increased significantly (all $p<0.01$) from treadmill speed from 4 to 6 km/hr and from 6 to 8 km/hr.

Table 2 shows the correlation matrix between motion sensor output (ActiCounts/min, ActiSteps/min and PedoSteps/min) and oxygen uptake in ml/kg/min at 4, 6 and 8 km/hr for all 58 participants. The highest shared variance (51.8%) was between PedoStep rate at 4 km/hr and $\dot{V}O_2$ (ml/kg/min) at 4 km/hr.

Table 1: Physical characteristics, accelerometer, pedometer outputs and physiological responses in relation to the three treadmill speeds

Cohort 1 (Pooled data of male and female participants) (N=19; age: 9.7±0.7 y; height:1.34±0.07m; body mass: 30.7±7.1 kg; BMI:16.9±2.5 kg/m²)				
Treadmill speed	0 km/hr	4 km/hr	6 km/hr	8 km/hr
ActiCounts (Counts/min)	-	2055±500	3557±967 [a]	5628±994 [b]
ActiSteps (Steps/min)	-	123±11	146±10 [a]	177±10 [b]
PedoSteps (Steps/min)	-	128±9	150±12 [a]	182±14 [b]
Oxygen uptake (ml/kg/min)	13±2	21±3	30±5 [a]	40±4 [b]
Heart rate (bpm)	102±12	114±12	149±15 [a]	178±31 [b]
Cohort 2 (Pooled data of male and female participants) (N=20; age:13.4±0.3 y; height:1.61±0.08m; body mass: 49.9±9.7 kg; BMI:19.2±3.1 kg/m²)				
ActiCounts (Counts/min)	-	1916±548	4203±828 [a]	7410±1023 [b]
ActiSteps (Steps/min)	-	104±15	135±10 [a]	163±7 [b]
PedoSteps (Steps/min)	-	111±10	135±14 [a]	165±8 [b]
Oxygen uptake (ml/kg/min)	10±2	15±2	24±4 [a]	35±4 [b]
Heart rate (bpm)	99±11	106±12	131±15 [a]	158±37 [b]
Cohort 3 (Pooled data of male and female participants) (N=18; age: 16.8±1.0 y; height:1.66±0.09m; body mass: 57.0±9.8 kg; BMI:20.5±2.5 kg/m²)				
ActiCounts (Counts/min)	-	2049±548	4167±840 [a]	7278±1222 [b]
ActiSteps (Steps/min)	-	103±14	127±5 [a]	160±9 [b]
PedoSteps (Steps/min)	-	110±8	127±7 [a]	161±9 [b]
Oxygen uptake (ml/kg/min)	9±2	14±2	22±3 [a]	35±3 [b]
Heart rate (bpm)	93±11	101±23	120±16 [a]	160±14 [b]

[a] Significantly different from 4 km/hr ($p<0.01$)
[b] Significantly different from 6 km/hr ($p<0.01$)

Table 2: Correlation matrix of motion sensor output rates (ActiCounts/min, ActiSteps/min, PedoSteps/min) and oxygen uptake in ml/kg/min walking and running at three different treadmill speeds (N=58, age: 13.2±3.0 y; height: 1.53±0.02 m; body mass: 45.5±14.2 kg; BMI: 18.8± 3.0 kg/m²; Tanner rating: 2.5±1.3)

Motion sensor output	$\dot{V}O_2$ (ml/kg/min) at 4 km/hr	$\dot{V}O_2$ (ml/kg/min) at 6 km/hr	$\dot{V}O_2$ (ml/kg/min) at 8 km/hr
ActiCounts (counts/min)	-0.03	-0.28	-0.18
ActiSteps (steps/min)	*0.65	*0.69	*0.36
PedoSteps (steps/min)	*0.72	*0.65	*0.38

*$P<0.01$

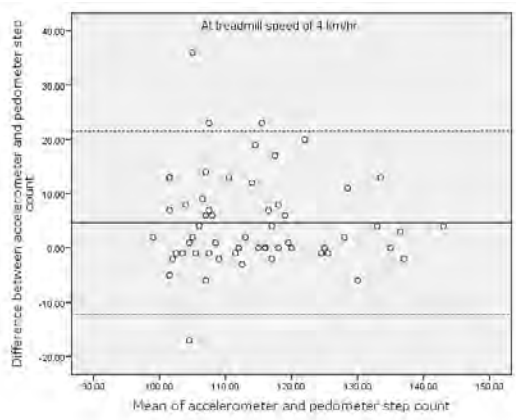

Figure 2a
Bland-Altman plot depicting error scores (ActiStep rate minus PedoStep rate) against the mean step rate of the two motion sensors (ActiSteps+PedoSteps/2) at a treadmill speed of 4 km/hr. The solid line represents the mean error while the dashed lines represent the 95 % limits of agreement. For the treadmill speed of 4 km/hr, the mean difference is 4.6±8.7 steps/min.

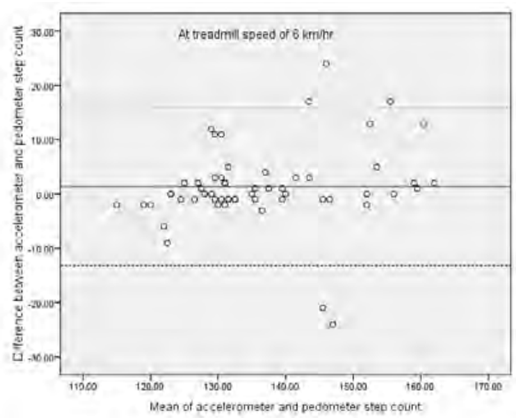

Figure 2b
Bland-Altman plot depicting error scores (ActiStep rate minus PedoStep rate) against the mean step rate of the two motion sensors (ActiSteps+PedoSteps/2) at a treadmill speed of 6 km/hr. The solid line represents the mean error while the dashed lines represent the 95 % limits of agreement. For a treadmill speed of 6 km/hr, the mean difference is 1.3±7.4 steps/min.

Figure 2 shows the mean error and the 95 % limits of agreement for the motion sensors in relation to the three treadmill speeds. The differences in step count rate between the ActiGraph GT 1 M accelerometer and the Omron HJ 005-E pedometer was lowest at a treadmill speed of 6 km/hr than at 4 km/hr or at 8 km/hr. However, results of paired sample t-tests revealed that for the three treadmill speeds, the step rate at each speed, recorded by the Omron HJ-005-E pedometer was significantly greater than that recorded by the ActiGraph GT 1 M accelerometer (t-ratios= -4.08 (4 km/hr); -20.62 (6 km/hr) and -3.42 (8 km/hr), all $p<0.01$).

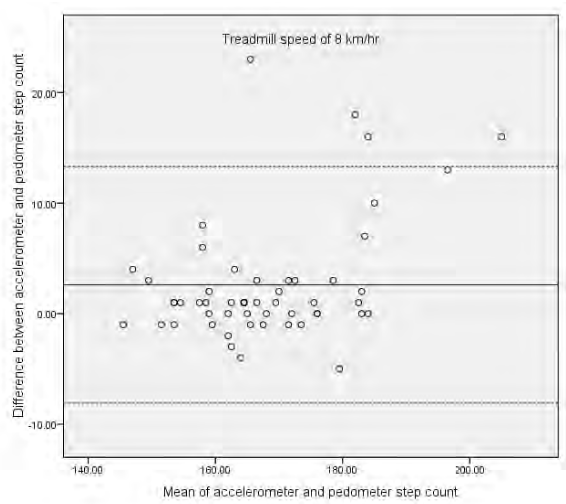

Figure 2c
Bland-Altman plot depicting error scores (ActiStep rate minus PedoStep rate) against the mean step rate of the two motion sensors (ActiSteps+PedoSteps/2) at a treadmill speed of 8 km/hr. The solid line represents the mean error while the dashed lines represent the 95 % limits of agreement. For a treadmill speed of 8 km/hr, the mean difference is 2.6±5.5 steps/min.

Discussion

Relevance and importance of the present study

An objective use of body motion sensors to examine physical activity among young people is important as concerns about the prevalence of young people in the Far East who are overweight and overfat gathers momentum.

Though research on accelerometer and pedometer use in the last decade has increased significantly (Tudor Locke et al, 2002; Rowlands et al, 2007), improvements in motion sensor technology mean that research on physical activity among youth must keep pace as new electronic models of motion sensors such as the Actigraph GT 1 M and Omron HJ 005-E become commercially available while older versions of accelerometers and pedometers become obsolete or are discontinued. To the authors' knowledge, there are apparently no information on the ActiGraph GT 1 M accelerometer and Omron HJ 005-E pedometer output data and physiological responses of male and female Asian samples of normal body mass to walking and running on a motorized treadmill under laboratory conditions.

These data are useful as more research become focused on the nexus between physical activity and health (Biddle et al, 2004; Strong et al, 2005) among Singaporean and East Asian youths.

Motion sensor outputs in relation to physiological responses

Preliminary analysis revealed no sex difference in motion sensor outputs and oxygen uptake and heart-rate response (all p>0.01) to walking and running on the treadmill at 4 km/hr and 6 and 8 km/hr. No equivalent study is available for comparison and the present result provides evidence of no sex difference in accelerometer count rate, step rates garnered by the ActiGraph GT 1 M and Omron HJ 005-E, body mass-accounted oxygen uptake and heart-rate in response to walking (4 km/hr) and running (6 and 8km/hr) on a motorized treadmill in large cohort of normal-weight children and adolescents. In terms of physiological responses to walking and running on the treadmill, this translated to, for subject cohort 1 (6.0, 8.6 and 11.4 METs), for subject cohort 2 (4.3, 6.9 and 10 METs) and for subject cohort 3 (4.0, 6.3 and 10 METs), respectively, assuming that 3.5 ml/kg/min equals 1 MET in young people (Armstrong & Welsman, 1997). Data from Table 1 show that motion sensor rates (ActiCounts/min, ActiSteps/min, PedoSteps/min) increased significantly from 4 km/hr to 6 km/hr and to 8 km/hr, as did, oxygen uptake (ml/kg/min) and heart rate (bpm). However, the percentage increase for each of the variables, with treadmill speed was not identical. For example, from 4 km/hr (walking) to 6 to 8 km/hr (running) the increases in ActiCounts/min were 101 and 76 %, respectively. This compared to changes in ActiStep and PedoStep rates of 22 and 24 %, and 18 and 25 %, accordingly. For the same treadmill speed change, the respective changes in oxygen uptake (ml/kg/min) and heart rate (bpm) were 55 and 48 %, and 27 and 28%, respectively.

In comparison, a study on 21 Chinese boys aged 8-10 years, using different accelerometers (TriTrac R3D and WAM 7164) and a different pedometer (Yamax Digiwalker DW 200) than the present study, deductions from the tabular data provided by Louie et al (1999) showed that TriTrac activity rate (counts/min) increased 73 and 12 % ; WAM activity rate (counts/min) increased 80 and 100%; and Yamx step count (steps/min) increased 19 and 26 % for a change in treadmill speed from 4 to 6 km/hr and from 6 to 8 km/hr. For the same treadmill speed change, the corresponding physiological change in oxygen uptake (ml/kg$^{0.75}$/min) was an increase of 50 and 48 %, and for heart rate (bpm), it was an increase of 16 and 25 %. These results demonstrate that whilst the physiological responses to changes in treadmill speed among children are somewhat similar in magnitude, the resultant motion sensor changes are markedly dissimilar. This, coupled with dissimilar subject cohorts, make comparisons across studies difficult. Hence researchers must be cautious in applying results of other studies to their own without first verifying that the cited data are applicable and valid to the existing study. A unique feature of the present study is that it is apparently the first to compare accelerometer-derived step count with that derived from an electronic pedometer under controlled laboratory conditions in the same cohort of subjects. Data in Table 1 showed that for treadmill speeds of 4, 6 and 8 km/hr, the step rate derived from the electronic pedometer was significantly greater (all p<0.01) than the step rate derived from the accelerometer (positive bias in pedometer step rate). However, Figure 2 shows that difference in step rate between the accelerometer and the pedometer was smallest at a treadmill jogging speed of 6 km/hr. As motion sensors (step count or step rate) are used to detect physical activity that are commonly associated with walking, jogging and running, the present result affirmed the assertions of some researchers that motion sensors are more sensitive at different speeds and accelerations of motion in children (Brage et al 2003). An unexpected result of the present study was the lack of significant associations (r= -0.3 to -0.02, p >0.01) between the accelerometer activity counts and oxygen uptake at the three treadmill speeds (see Table 2).

This contrasted with results reported by Louie et al (1999) where correlations between TriTrac and WAM accelerometer counts/min and heart rate ranged between 0.79 and 0.93 (p<0.01). The reason for this lack of correlation is not readily apparent but the use of a different accelerometer model and the frequency-filtering of the accelerometer that captures movements of a certain frequency range (Rowlands et al, 2007) cannot be ruled out. According to them, signals from the accelerometer are weighted according to the frequency of movement, with frequencies higher or lower than 0.75 Hertz subjected to decreasing weighting. However, the frequency of walking and running of the subjects in the present study was not determined. This represents an area for further research in subsequent studies. However, the correlations between step rates derived from the motion sensors to the three treadmill speeds are in general agreement with those reported by Louie et al (1999). For example the cited authors reported a significant correlation of 0.77 between scaled oxygen uptake and step rate assessed by the Yamax Digiwalker pedometer. This compares with significant correlations of 0.56 and 0.60 (p<0.05) between oxygen uptake (ml/kg/min) and ActiGraph GT 1 M accelerometer step rate and the Omron HJ 005-E pedometer. These results suggest that step rate is a useful means of assessing physical activity among children and adolescents, especially during walking and running between the speeds of 4 and 8 km/hr.

Conclusions

Data from the present study are from a sizeable subject cohort of children and adolescents of both sexes and provide much needed reference information derived from controlled laboratory conditions as physical activity research attention among Singaporean children and adolescents gathers momentum. Walking at 4 km/hr elicited between 4 and 6.0 METs whilst running at 6 km/hr and 8 km/hr elicited 6.3-8.6 and 10.0-11.4 METs, respectively.

Motion sensor outputs of children and adolescents increase with treadmill speeds, as did heart rate and oxygen uptake, albeit the magnitude of change among the variables were not identical.

Step rate assessed by the Omron HJ 005-E pedometer was significantly higher whilst walking at 4 km/hr, and running at 6 and 8 km/hr. Agreement in step rate was highest for the ActiGraph GT 1 M and the Omron HJ 005-E at a treadmill speed of 6 km/hr for Singaporean children and adolescents. These results suggest that step rate assessed by the ActiGraph GT 1 M and Omron HJ 005-E pedometer are useful and suitable measurements of physical activity involving walking and running among Singaporean children and adolescents of normal body mass. Further investigations including data reduction procedures and post-processing of accelerometer counts are necessary make biological sense of the resultant data and to exploit these devices for physical activity research among young people.

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ODZIV SENZORA GIBANJA KOD DJECE I ADOLESCENATA ZA VRIJEME HODANJA I TRČANJA NA TRI BRZINE PO POKRETNOM SAGU

Sažetak

Ovo istraživanje bavilo se izlazom senzora za gibanje u Singapuru, djece i adolescenata oba spola za vrijeme hodanja i trčanja na motoriziranom pokretnom sagu (Quinton Series 90) u kontroliranim laboratorijskim uvjetima. Ukupno 58 mladih normalne mase tijela (N=58, uzrast: 13.2±3.0 g.; visina: 1.53±0.02 m; masa tijela: 45.5±14.2 kg; BMI: 18.8± 3.0 kg/m^2; Tanner ocjena: 2.5±1.3) bilo je obuhvaćeno istraživanjem. Akcelerometarske (ActiGraph GT 1 M) aktivnosti (ActiCounts u broj/min) i step ritam (ActiSteps u step/min) i pedometer (Omron HJ 005-E) step ritam (PedoSteps in step/min), primitak kisika (u ml/kg/min) i srčani ritam (u otkuca u min) su praćeni od 5-minutnog stanja od 0 % gradijenta hodanja na pokretnom sagu brzinom od 4 km/h, tei trčanja od 6 km/h i 8 km/h. Hodanje od 4 km/h je procijenjeno na 4.0-6.0 METs, dok je trčanje od 6 km/h i km/h procijenjeno na 6.3-8.6 i 10.0-11.4 METs, respektivno. Izlaz senzora gibanja značajno se povećao s brzinom pokretnog saga (76-101 % za ActiCounts; 22-24 % za ActiSteps i 18-25 % za PedoSteps, sve uz p<0.01) baš kao I primitak kisika (48-55 %) i otkucaji srca (27-28 %) ali nije bilo razlika po spolu u aktivnosti step ritma ili fiziološkog odgovora (p>0.01). Neznačajne relacije su dobivene između akcelerometarske aktivnosti ritma i primitka kisika ili srčanog ritma. Prihvatljivo je slaganje između akcelerometarskog i pedometarskog step ritma kod hodanja ili trčanja na pokretnom sagu, ali razlike između accelerometarskog i pedometarskog step ritma su malene kod brzine saga od 6 km/h. Ovi rezultati pokazuju da je akcelerometarski i pedometarski step ritam korisna i primjenjiva mjera tjelesne aktivnosti koja uključuje hodanje i trčanje među djecom i adolescentima Singapura normalne tjelesne mase. Potrebna su daljnja istraživanje za potpuno korištenje podataka akcelerometra u istraživanju tjelesne aktivnosti mladih.

Ključne riječi: *izlaz senzora gibanja, djeca i adolescenti, hodanje i trčanje po pokretnom sagu*

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