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ABSTRACT

PURPOSE: The purpose of the study is to develop algorithms to predict energy expenditure (EE) and to evaluate their utility compared to existing accelerometer technology. **METHODS:** Twenty-one healthy males (n=21) and twenty-three healthy females (n=23) wore an ActiGraph (AG) (GT3X+) monitor on a waist belt and placed the Samsung Galaxy S2 SP in a front trouser pocket, while completing a routines of 13 physical activities over a 69 min period. Oxygen consumption was simultaneously measured by indirect calorimetry using an Oxycon Mobile metabolic analyzer. Accelerometer data from the SP were downloaded after each trial along with raw AG counts (100Hz). EE prediction equations for the SP were developed from the walking and running activities using standard regression methods. The vector magnitude of standard deviation of horizontal and vertical (i.e., 5s-counts) and BMI were employed to develop the prediction equation. This equation was then cross-validated on a separate holdout sample (n=22) using equivalence testing to evaluate accuracy. **RESULTS:** The overall mean absolute percentage errors were large for both the SP algorithm (42.4%) and the Freedson's AG algorithm (38.2%). However, the estimated METs from the SP was statistically equivalent to the measured METs for the two activities used in calibration: walking (90% CI: 2.85, 3.50 kcal/min) and running (90% CI: 7.64, 8.25 kcal/min). Other activities were not accurately assessed with the SG but none of the estimates from the AG met the statistical criteria for equivalency. **CONCLUSION:** The study demonstrates that data from SP can be easily calibrated to estimate energy expenditure and that accuracy is comparable to the common research-grade monitors.

INTRODUCTION

- The popularity of smartphone (SP) technology provides new opportunities for free-living physical activity monitoring.
- Surprisingly, the feasibility and utility of using the built-in accelerometer sensor in SPs have not been systematically examined.

PURPOSE

The purpose of the present study was utilizing those sensor technologies to develop the EE estimate prediction equation from the detected activities based on mobile phone data and then to perform a cross validation to compare the accuracy

METHODS

Participants

	Development Group				Cross-validation Group			
Variable	Female (N=13)	Range	Male (N=10)	Range	Female (N=10)	Range	Male (N=11)	Range
Age (yrs)	23.2 ± 2.4	20 - 27	26.9 ± 4.3	22.0 – 36.0	23.8 ± 3.7	20 - 31	28.6 ± 8.1	18.0 – 43.0
Height (cm)	169.4 ± 7.8	162.4 - 187.0	174.7 ± 6.3	166.4 - 187.0	163.9 ± 7.0	154.2 - 177.8	175.9 ± 3.5	170.4 - 182.3
Weight (kg)	65.4 ± 9.9	55.2 - 85.4	73.0 ± 10.6	56.3 - 90.7	56.4 ± 7.2	47.6. - 70.6	74.6 ± 8.3	62.4 - 87.7
Body Fat (%)	20.5 ± 6.4	12.4 -34.3	16.7 ± 6.7	5.7 - 31.7	19.2 ± 5.0	8.3 -27.6	19.1 ± 5.4	12.3 - 26.1
BMI (kg•m^{-2})	22.8 ± 3.6	18.1 - 31.2	23.9 ± 2.9	19.9 - 27.7	20.1 ± 1.48	18.1 - 23.0	24.1 ± 2.5	20. - 27.9

- Initially, sixty healthy men (n=30) and women (n=30) volunteered to participate in the study, but a total of forty-four participants, twenty-one males (n=21) and twenty-three females (n=23), were used in the final data analysis.

METHODS (Cont.)

Instruments

- The Oxycon Mobile portable metabolic analyzer *(Viasys Healthcare Inc, Yorba Linda, CA)* was used to measure oxygen consumption.
- The Samsung Galaxy S2 uses Google's Android mobile operating system equipped with a built-in accelerometer and gyroscope.
- Actigraph GT3X+ is the most commonly used accelerometer to assess physical activity under free-living conditions
- Accmeter Application is a customized smartphone application (developed by the Department of Biomedical Engineering, Yonsei University, South Korea) that records acceleration and gyroscope data using an external SD card inserted into the smartphone. All data store in the file are recorded with an indicator of the system's current time, plus X, Y, and Z values for each sensor in comma separated values file.

Procedures

- Fort the first visit, each subject's weight, height, and RMR were measured.
- For the second visit, participants wore ActiGraph (AG) (GT3X+) monitor on a waist belt and placed the Samsung Galaxy S2 SP in a front trouser pocket, while completing a routines of 13 physical activities over a 69 min period.
- Oxygen consumption was simultaneously measured by indirect calorimetry using an Oxycon Mobile metabolic analyzer.

Data Analyses

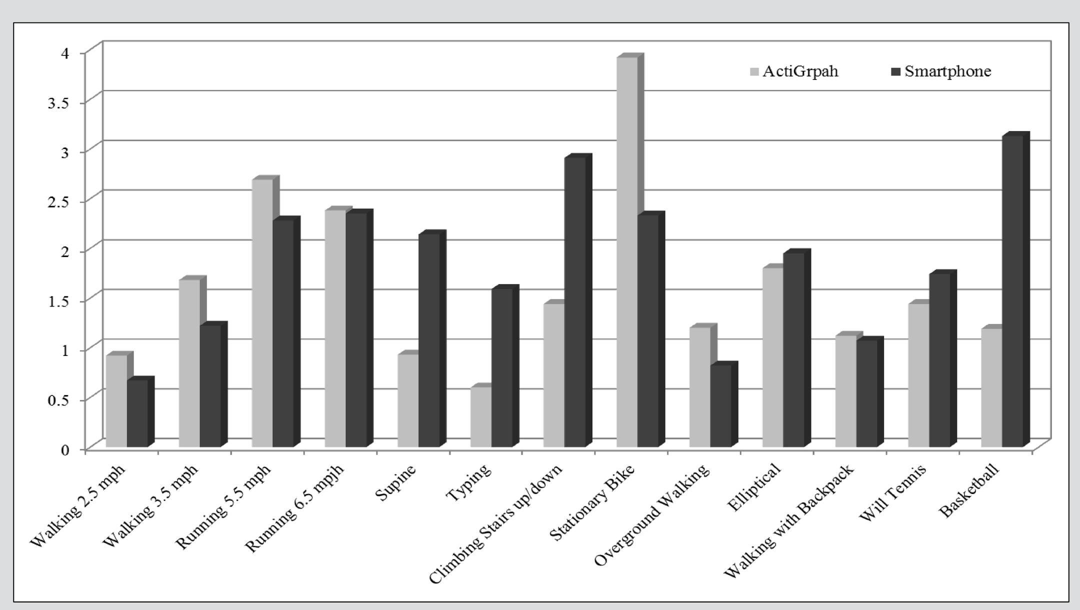
- Accelerometer data from the SP were downloaded after each trial along with raw AG counts (100Hz).
- EE prediction equations for the SP were developed from the walking and running activities using standard regression methods.

Developed Equation = 1.856 + (0.803 × VM: Standard Deviation of horizontal and vertical) + (-0.091 × BMI)

- The vector magnitude of standard deviation of horizontal and vertical (i.e., 5s-counts) and BMI were employed to develop the prediction equation.
- This equation was then cross-validated on a separate holdout sample (n=22) using equivalence testing to evaluate accuracy.

RESULTS

Figure 1. Root mean square error comparison between ActiGraph and Smartphone.



RESULTS (Cont.)

Table 2. Measurement agreement between measured MET and predicted MET

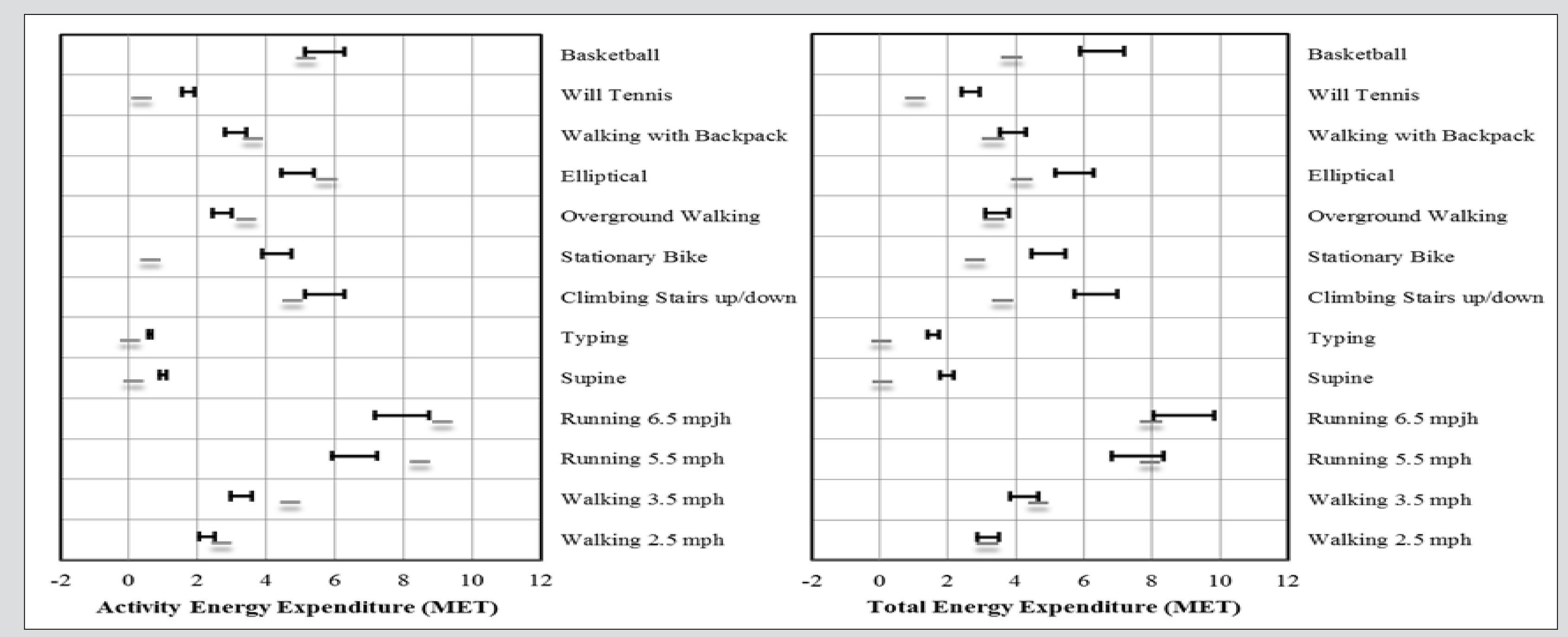
ActiGraph predicted MET			90% CI of predicted MET		Equivalence zone of measured MET		Oxycon Mobile measured MET		RMSE
Activity	Mean	SE	Lower bound	Upper bound	Lower bound	Upper bound	Mean	SE	Mean
Walking 2.5 mph	2.70	0.11	2.40	3.00	2.05	2.51	2.27	0.13	0.92
Walking 3.5 mph	4.70	0.18	4.41	5.01	2.95	3.60	3.27	0.11	1.68
Running 5.5 mph	8.46	0.13	8.17	8.76	5.91	7.23	6.57	0.21	2.69
Running 6.5 mph	9.14	0.21	8.84	9.44	7.15	8.74	7.94	0.19	2.38
Supine	0.11	0.18	-0.18	0.41	0.90	1.10	1.00	0.11	0.93
Typing	0.04	0.17	-0.25	0.34	0.55	0.68	0.61	0.18	0.60
Climbing Stairs up/down	4.75	0.14	4.46	5.05	5.01	6.13	5.70	0.14	1.44
Stationary Bike	0.61	0.15	0.31	0.91	3.88	4.75	4.31	0.23	3.92
Overground Walking	3.42	0.18	3.13	3.72	2.45	2.99	2.71	0.19	1.20
Elliptical	5.76	0.21	5.47	6.06	4.42	5.40	4.91	0.11	1.80
Walking with Backpack	3.61	0.18	3.32	3.91	2.80	3.43	3.11	0.12	1.12
Will Tennis	0.36	0.19	0.07	0.66	1.56	1.90	1.73	0.13	1.44
Basketball	5.16	0.18	4.87	5.46	5.13	6.27	5.70	0.12	1.19

*Significant equivalence.
*RMSE: root mean square error; MET: Metabolic Equivalents; SE: Standard Error; CI; Confidence Interval

Smartphone predicted MET			90% CI of predicted MET		Equivalence zone of measured MET		OM Mobile measured MET		RMSE
Activity	Mean	SE	Lower bound	Upper bound	Lower bound	Upper bound	Mean	SE	Mean
Walking 2.5 mph*	3.16	0.13	2.85	3.50	2.87	3.51	3.19	0.12	0.67
Walking 3.5 mph	4.65	0.11	4.35	4.96	3.82	4.62	4.24	0.14	1.22
Running 5.5 mph*	7.95	0.21	7.64	8.25	6.82	8.34	7.57	0.15	2.28
Running 6.5 mph	8.31	0.19	7.64	8.25	8.04	9.82	8.93	0.17	2.35
Supine	0.08	0.18	-0.22	0.38	1.80	2.20	1.99	0.19	2.14
Typing	0.05	0.17	-0.25	0.36	1.43	1.75	1.58	0.14	1.59
Climbing Stairs up/down	3.61	0.18	3.31	3.92	5.72	6.99	6.35	0.17	2.91
Stationary Bike	2.79	0.17	2.49	3.10	4.46	5.45	4.95	0.14	2.33
Overground Walking	3.34	0.18	3.03	3.65	3.12	3.82	3.46	0.15	0.82
Elliptical	4.17	0.17	3.86	4.48	5.20	6.36	5.71	0.19	1.95
Walking with Backpack	3.33	0.19	3.01	3.65	3.53	4.32	3.91	0.18	1.07
Wii Tennis	1.06	0.21	0.74	1.36	2.42	2.96	2.68	0.18	1.74
Basketball	3.87	0.24	3.55	4.19	5.87	7.18	6.52	0.18	3.13

*Significant equivalence.
*RMSE: root mean square error; MET: Metabolic Equivalents; SE: Standard Error; CI; Confidence Interval

Figure 3. Results from 95% equivalence testing for agreement in total MET between Smartphone and OM (left), and in AEE (MET) between Actigraph and OM (right). *Black solid bar: Equivalence zone of measured MET, Grey solid line: 90% CI of predicted MET



- None of the estimated MET estimates from the Actigraph (using Freedson equation, 2011) were significantly equivalent to the OM for the group-level comparisons.
- The estimated METs from the smartphone for walking 2.5 mph and running 5.5 mph (illustrated in Table 3) were significantly equivalent to the measured EE from the OM.
- The overall MAPEs were large for both the SP algorithm (42.4%) and the Freedson's AG algorithm (38.2%).
- Bland-Altman plots indicated that there were some degree of significant proportional bias for both estimates.

DISCUSSION

- The present study demonstrated the accelerometer-enabled smartphone can be a competitive and objective tool in estimating EE for adults.
- The estimates of MET from the developed equation model provide valid estimates for quantifying physical activity patterns.
- The new technology, for instance, using built-in technology in the smartphone can open up unlimited opportunities in the field of PA assessment