Comparison of Accelerometry and Oxymetry for Measuring Daily Physical Activity

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To assess the validity of accelerometry in measuring daily physical activity, the energy consumption calculated by accelerometry, with respiratory gas analysis as a reference, was evaluated in 45 non-athletes during various exercise tests. Subjects were required to (1) walk on a treadmill ergometer at various speeds, (2) walk on a treadmill ergometer at a fixed speed and with a stride of 20% more or 20% less than that when walking freely, (3) walk on a treadmill ergometer at a fixed speed wearing either sneakers or leather-soled shoes, and (4) cycle on a bicycle ergometer. There were strong linear relationships between the measurements during the progressively graded treadmill test, with an overall Pearson correlation coefficient of 0.97. The mean estimated difference ranged from –0.77 to 0.27 kcal/min and the coefficients of variation from 13.2% to 22.2%. However, the difference between the methods was not negligible for individual subjects. Accelerometry overestimated energy expenditure during short-step walking, and underestimated it during long-step walking. No significant difference in energy expenditure was found according to the type of shoes worn. Cycling activity was not recorded by accelerometry. Accelerometry is a reasonably accurate and feasible method for evaluating the physical activities of non-athletes, and could be a common tool for epidemiological research and health promotion despite its limitations. (Circ J 2002; 66: 751–754)

Key Words: Accelerometry; Epidemiology; Health promotion; Oxymetry; Physical activity

Adequate physical activity with good dietary and relaxation habits has been claimed to maintain a person’s health by preventing age-related chronic diseases.1 Regular moderate physical activity is known to reduce obesity2 and increase both serum high-density lipoproteins concentration,3,4 and insulin sensitivity5 and reduce blood pressure6 leading to a reduction in the risk of developing coronary artery disease.7 Exercise also helps the elderly to participate in social activities through positive adaptation of bone and skeletal muscles.8 Moreover, exercise activates immune function,9 which might suppress cancer occurrence. As well as disease prevention, stepped physical training improves respiratory function in rehabilitation after acute myocardial infarction and coronary arterial bypass surgery.10,11 On the other hand, heavy physical exertion can trigger acute myocardial infarction.12,13

It is therefore necessary to determine the amount of physical activity that can safely and effectively be prescribed, and various methods, such as direct or indirect calorimetry, job classification, diary or recall survey, doubly labeled water method, heart rate monitoring, and the use of pedometers, are available to assess either the amount of physical activity or energy expenditure.14,15 Each method has its limitations in accuracy or convenience for the general population.

We assessed the validity of a newly developed, low-priced accelerometer and its implication for public health.16

Methods

Subjects
A total of 39 non-athletic healthy university students and 6 white-collar workers, all living in Nagoya City, Japan and its vicinity were recruited for the study between April 1998 and February 1999. The ages of the 25 male and 14 female students ranged from 20 to 24 years and that of the 6 male workers from 39 to 44 years. Information on the purpose and procedures of the study was given to each subject, and oral consent was obtained before participation.

Protocol
Before the test, all subjects were questioned regarding medical history and physical activity status. Height, weight, and proportion of body fat impedance were simultaneously measured with an electronic scale (TBR-202, Tanita Co Ltd, Japan), as well as resting heart rate and blood pressure in the sitting position. Subjects wore a face mask connected to an expiratory gas analyzer (Oxycon Sigma, Erich Jaeger, B.V. (Mijnhardt), The Netherlands). Under electrocardiographic monitoring, oxygen consumption and the respiratory quotient were measured breath by breath and automatically averaged every 30 s. We used the mean value for the 2 min after reaching a steady state in the respective activities. Energy expenditure was calculated from the mean measurements of oxygen consumption per minute multiplied by the equivalent obtained from the Lusk table17 and by the mean value of the respiratory quotient. The influence of...
diet on the respiratory quotient was not included because of its insignificance in repeated measurements for the same subject.

Subjects also wore an accelerometer (Calorie Counter Select 2, Suzuken Co Ltd, Japan) on the right side of the waist, attached to a belt, during the study, and the signals were continuously sent to the analyzer through a cable. The accelerometer measures the maximal amplitude of acceleration of the vertical waist movement in 10 grades every 4 s. Total energy expenditure is estimated by the summation of the vertical waist movement in 10 grades every 4 s. Total energy expenditure is estimated by the summation of the vertical acceleration, basal metabolism, and weak wavering movement (measured at 4 s intervals in the absence of acceleration).

\[ E = 1.11 \times (BM + K \times BW) + \sum \]

where E is total energy expenditure, BM is basal metabolism, K is a constant for each of 10 grades of acceleration, BW is body weight, \( \sum \) is energy consumed by weak movement, and 0.11 in 1.11 is the addition of the specific dynamic action of the foot.

Using a motorized treadmill ergometer (MAT-2600 and Stress Test System ML4500, Fukuda Denshi Co Ltd, Japan) or a cycle ergometer (Ergometer Computronic 232CXL, Combi Corporation, Japan), subjects were requested to perform 4 types of stress test.

**Test 1** Walking on the treadmill ergometer at various speeds. Eighteen male and 11 female students, and 6 male workers walked or jogged on the treadmill apparatus with a gradient of 0% and at speeds of 3, 6, and 9 km/h, sequentially for 5 min each, after resting while standing for 5 min. Shoe type and stride were arbitrary.

**Test 2** Walking on the treadmill ergometer at a fixed speed with variable stride. Seven male and 3 female students walked at 20% more (long-step) and 20% less (short-step) than their respective free strides on a 0% gradient at a speed of 4 km/h for 5 min at a time. The sequence of strides was randomly allocated. A metronome was used as a pace-maker.

**Test 3** Walking on the treadmill ergometer at a fixed speed wearing 2 types of shoe. The same subjects as in Test 2 walked on a 0% gradient at a speed of 4 km/h wearing sneakers and leather-soled shoes alternately for 5 min each. The sequence in which the shoes were worn was randomly allocated.

**Test 4** Cycling on the bicycle ergometer with varied loads. Six male and 2 female students randomly drawn from Test 1 cycled on the bicycle ergometer at loads of 50 and 100 W sequentially for 5 min each after sitting still for 5 min.

All experiments were carried out in the same room and conditions (temperature, 25–26°C).

**Statistical Analysis**

Data are expressed as mean ± standard deviation. To assess the relationship between the estimated energy expenditure by accelerometry and oxymetry during the progressively graded stress tests, simple regression lines were drawn using the least square method for each subject, and means and standard deviations of both regression coefficient and Y-intercept were calculated. Differences in regression coefficient and Y-intercept by sex and age group, obesity and sporting activity were studied with Student’s t-test or analysis of variance. For additional information, the overall Pearson correlation coefficient between the 2 methods was calculated including all data from the progressively graded stress tests. Agreement between the measures was evaluated using mean values and the coefficient of variance of the estimated difference. Effects of strides and shoes on the estimation were verified with the paired t-test. A p value less than 0.05 was considered statistically significant.

**Results**

The mean height, weight, and proportion of body fat of the 35 subjects in Test 1 were 168.3±5.9 cm, 59.7±7.8 kg, and 17.8±3.8%, respectively. Scatter plots of energy expenditure measured by accelerometry and oxymetry throughout the progressively graded treadmill test are shown in Fig 1. The mean value of the regression coefficient of the regression lines drawn for each subject was 0.93±0.28 and that of the Y-intercept 0.23±0.94 kcal/min. The mean regression coefficients of males and females in their twenties, and males in their fortes were 0.92, 0.99, and 0.86, respectively, and the mean Y-intercepts were 0.21, 0.32, and 0.14 kcal/min. There were no significant differences among the 3 groups. The mean regression coefficients of overweight (body fat ≥20%) and lean (<20%) subjects were 0.98 and 0.89 (NS), and the mean Y-intercepts were –0.05 and 0.24 kcal/min (NS), respectively. The mean regression coefficients of regular exercisers and non-regular exercisers were 0.92 and 0.91 (NS), and the mean Y-intercepts were 0.21
and 0.29 kcal/min (NS), respectively.

The overall Pearson correlation coefficient between accelerometry and oxymetry throughout the progressively graded treadmill test for 35 subjects was 0.97 (p<0.0001), and the regression equation was y = 0.89x + 0.41. The correlation coefficients and regression equations were 0.96 (y = 0.98x + 0.94) for males in their twenties, 0.98 (y = 0.98x + 0.40) for females in their twenties, and 0.97 (y = 0.85x + 0.16) for males in their forties (p<0.0001 for each). Mean differences (and coefficients of the variance) between the methods for each treadmill speed were 0.27 kcal/min (16.5%) at 0 km/h, -0.48 kcal/min (22.2%) at 3 km/h, 0.20 kcal/min (16.1%) at 6 km/h, and -0.77 kcal/min (13.2%) at 9 km/h.

The mean height, weight, and body fat of the 10 study subjects of Tests 2 and 3 were 169.8±8.3 cm, 61.3±9.0 kg, and 20.4±4.8%, respectively. The average pace of free walking was 107 steps/min, and that of short- and long-step walking was 116 and 87 steps/min, respectively. Accelerometry estimated energy expenditure to be higher than oxymetry by 0.92±1.21 kcal/min in short-step walking, but lower by 1.22±0.73 kcal/min in long-step walking (p<0.0001) (Fig 2). The mean difference in the estimation between accelerometry and oxymetry was 0.54±0.87 kcal/min when the subjects walked in sneakers and 0.46±0.55 kcal/min when walking in leather-soled shoes (p=0.67) (Fig 3).

The mean height, weight, and body fat for the 8 subjects of Test 4 were 167.7±6.9 cm, 60.8±7.5 kg, and 19.5±3.1%, respectively. Scatter plots of the energy expenditure estimated from accelerometry and oxymetry during the progressively graded cycling tests are shown in Fig 4. Accelerometry hardly detected any energy expenditure: the regression coefficient was a low 0.11±0.02, with a Y-intercept of 1.15±0.09 kcal/min.

**Discussion**

Walking and jogging are the most common and easy exercises in daily life and many sports include one or the other or both. Thus, accurate measurement of walking is deemed essential to understanding a person's physical activity. We examined the validity of accelerometry as a method of measuring physical activity in non-athletic healthy Japanese. Our study compared various modes of exercise such as golf or housework. A wrist and ankle accelerometer (or actometer) would help estimate whole-body movement of the waist. Expiratory gas analysis was used as a reference for estimating energy expenditure because its error is only 2–3% compared with direct calorimetry.

A strong correlation between accelerometry and oxymetry was found, with an overall coefficient of correlation of 0.97, and it was not significantly influenced by sex, age, body fat or daily physical activity. However, it should be noted that the difference in estimated energy expenditure between the methods was not negligible for an individual subject. The accelerometer we used overestimated energy consumption in short-step walking and underestimated the effect of long strides. The type of shoes worn did not affect the estimation of energy expenditure. In cycling, accelerometry detected hardly any energy expenditure.

Previous studies have shown the lack of validity of the simple classical pedometer; the number of steps is underestimated when walking at low speed, and overestimated during high-speed walking or jogging. The classical pedometer simply detects accelerations beyond a certain level and sums them, so weak movements of the waist are not measured. It is important that the grade of acceleration is taken into account in estimating energy expenditure, but we found that even after controlling for the degree of acceleration, the present accelerometer produced similar directions of error as a pedometer. Thus, further correction with respect to the character of each acceleration is needed.

Although we suspected that the elasticity of the shoes' sole would change the nature of acceleration, there have not been any studies examining the buffering effects of shoes. We compared walking with 2 types of shoes, but we found that the type of shoe did not affect the estimation of energy expenditure by the accelerometer. To fully assess the attenuation of impact by shoes, we need more studies of walking in extreme conditions such as bare feet, in high-heeled shoes or wooden clogs, on a sandy road or wooden floor, or tatami floor, which is popular in Japanese houses.

The accelerometer recorded almost no energy expenditure during cycling. Needless to say, arm exercise and weight loading are not measured with this device and it is these weak points of the accelerometer that explain the underestimation of energy expenditure during moderate exercise such as golf or housework. A wrist and ankle accelerometer (or actometer) would help estimate whole-body energy expenditure.
body motion.

Our multiphase physiological evaluation indicated that measurements with this new device were highly valid on the laboratory basis. Suzuki et al compared the accuracy of the same type of accelerometer with records of physical activity in daily life, and found a good agreement. This alternative technique will promote its wider use.

The advantage of accelerometry is its convenience (just a 32 g device on the waist) and objectivity. Furthermore, it can accumulate data on daily energy expenditure for 7 days, which increases reliability through attenuation of day-to-day variation. The cost (=6,000 yen) is expected to decrease as it becomes more commonly used, and the combination of price reduction and physicians’ knowledge of this technique will promote its wider use.

Study Limitations

First, the test was performed with young and middle-aged adults who were generally in good physical condition. It might be important to examine the validity of this measure in growing, aged, and unhealthy people. Second, the results were obtained at a particular temperature. It is uncertain whether the relationships between the measures will remain constant throughout the 4 seasons. To elucidate these points, further investigation is warranted.

We conclude that accelerometry is a useful tool for individuals to measure their physical activity and it has great potential for use in the general population for health promotion and for epidemiological research in communities.

References