Daily physical activity assessment: what is the importance of upper limb movements vs whole body movements?

H Kumahara¹, H Tanaka² and Y Schutz¹*

¹Department of Physiology, Faculty of Biology and Medicine, University of Lausanne, Lausanne, Switzerland; and ²Laboratory of Exercise Physiology, Faculty of Sports and Health Science, Fukuoka University, Fukuoka, Japan

OBJECTIVE: The movement of the upper limbs (e.g., fidgeting-like activities) is a meaningful component of nonexercise activity thermogenesis (NEAT). This study examined the relationship between upper limb movements and whole body trunk movements, by simultaneously measuring energy expenditure during the course of the day.

DESIGN: A cross-sectional study consisting of 88 subjects with a wide range in body mass index (17.3–32.5 kg/m²). The energy expenditure over a 24-h period was measured in a large respiratory chamber. The body movements were assessed by two uniaxial accelerometers during daytime, one on the waist and the other on the dominant arm. The accelerometry scores from level 0 (=immobile) up to level 9 (=maximal intensity) were recorded. The activities of subjects were classified into eight categories: walking at two speeds on a horizontal treadmill (A & B), ambling (C), self-care tasks (D), desk work (E), meals (F), reading (G), watching TV (H).

RESULTS: There was a significant relationship between the accelerometry scores from the waist (ACwaist) and that from the wrist (ACwrist) over the daytime period ($R^2 = 0.64; P < 0.001$). The ACwrist was systematically higher than the ACwaist during sedentary activities, whereas it was the reverse for walking activities. ACwrist to ACwaist ratio of activities E–H were above 1.0 and for walking activities (A–C) were below 1.0. A multiple regression analysis for predicting daytime energy expenditure revealed that the explained variance improved by 2% only when the ACwrist was added as a second predictor in addition to the ACwaist. This indicates that the effect of the ACwrist for predicting energy expenditure was of limited importance in our conditions of measurement.

CONCLUSIONS: The acceleration of the upper limbs which includes fidgeting is more elevated than that of the whole body for sitting/lying down activities. However, their contribution to energy expenditure is lower than whole body trunk movements, thus indicating that the weight-bearing locomotion activities may be a key component of NEAT. However, its contribution may depend on the total duration of the upper limb movements during the course of the day.


Keywords: NEAT (nonexercise activity thermogenesis); indirect calorimetry; accelerometer; walking exercise; upper limb movement; lower limb movement

Introduction
Energy expenditure allocated for physical activity is a variable component of the total daily energy expenditure, which may play an important role in the management of obesity and its related diseases. The physical activity of daily living is composed of structured activities (purposeful walking and running) as well as such nonstructured activities as fidgeting-like activities, maintenance and transition of posture, moving around and other minor physical activities of daily life.

Since an overfeeding investigation by the group of Levine et al. was reported showing that fat gain was inversely related to nonexercise activity thermogenesis (NEAT), the energy expended due to nonstructured activities is now considered to be an important component of the physical activity.

Accelerometer devices are often used to evaluate physical activity²,³ and a simple waist-worn device could potentially assess the energy expenditure related to the voluntary activities involving displacement of the body. However, certain movements (such as transitions from lying down to
sitting or to standing as well as upper body movements, that is, fidgeting-like activities) are unlikely to be assessed adequately. Sedentary activities involving fidgeting-like activities have been recognized to occupy (in time and duration) a substantial part of the total physical activity of daily living. Therefore, such activities should be taken into account when calculating the total energy expenditure.

Zhang et al recently reported that accelerometry using sensors on the thighs and chest (trunk) could be used to assess the duration of gross physical activities such as mobility-related activities (postures and lower limb movements, walking, running, ascending/descending stairs). But it would fail to measure upper limb movements even if the movements were of meaningful activities (such as fidgeting).

On the other hand, in the field of psychophysiology and rehabilitation medicine, some accelerometry sensors attached to the thighs, trunk and upper limb have been used to classify the different type of gross physical activity, especially for the purpose of assessing the activity restriction of patients with upper limbs disorders. These devices enable us to detect the duration of the displacement as well as upper limb movements in free-living conditions for long periods of time. However, these studies have not tracked the energy expenditure related to those activities. When the management of obesity and other diseases are considered, it is essential to describe the full and/or part of body movements and its contribution to energy expenditure.

The purpose of this study was to investigate the relationship between the upper limb body movements measured by a wrist-worn accelerometer vs whole body (trunk) movements measured by a waist-worn accelerometer, and their relative importance during the course of the day.

Methods

Subjects

In all, 88 subjects (33 males and 55 females) of 74 healthy Japanese and 14 Caucasian subjects participated in this study. The subjects of these two ethnic groups could be pooled since there was no difference in the energy expenditure during 24 h in a respiratory chamber among them when they were strictly matched for gender, age, height and weight. After the experiment was explained, each subject signed an informed consent statement approved by the ethical committee of the University of Lausanne. The subjects ranged in age from 18 to 64 y and showed a wide range of body mass index, $22.2 \pm 3.2$ kg/m². The physical characteristics of the subjects are detailed in Table 1. Part of the subjects were participating in a large study of total energy expenditure in confined and free-living conditions to examine the potential of the accelerometric technique to predict total energy expenditure.

Study design

The subjects stayed for 24 h in a large respiratory chamber, with a floor surface area of $13 \text{ m}^2$ and a volume of $31 \text{ m}^3$. The oxygen consumption and carbon dioxide production were continuously measured, from which energy expenditure was then calculated. The details of the configuration of the chamber and the method of gas analysis were described previously. During the test, the subjects were permitted to lead a nonrestrained life, excluding the following walking activities and a controlled sleeping period (for 8 h). Two moderate walking sessions on a horizontal motor driven treadmill (3.9 and 5.1 km/h, 30 min each) were scheduled. Free walking around (ambling: self-paced, the total duration of 45 min) on the floor was also required. They ingested three standard experimental meals (breakfast, lunch and dinner) according to the estimated energy needs. The energy intake was not significantly different from the 24-h energy expenditure measured by the chamber.

During the daytime (16 h), two uniaxial accelerometers were rigidly fixed on the waist and on the wrist of the dominant arm. Dominancy was based on writing. The waist-worn device was placed on the diagonal site of the right lumbar using a belt. It measured the acceleration parallel to the body segment in the vertical direction. The wrist unit was attached on the forearm proximally from the wrist joint using a wrist-supporter band. The sensitive direction paralleled the length of the arm.

In addition, the subjects filled their activities during the daytime in a time-table sheet using a 1 min scale.

Accelerometer feature

A small ($6.2 \times 4.6 \times 2.6 \text{ cm}, 40 \text{ g}$) activity monitor with uniaxial piezoelectricity accelerometer sensor (LifeRocker, Suzuken Co. Ltd., Japan) was employed. The characteristics and details of this device have been described elsewhere.

Table 1 Physical characteristics of the subjects

<table>
<thead>
<tr>
<th></th>
<th>Males (n = 33)</th>
<th>Females (n = 55)</th>
<th>Total (N = 88)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age (y)</strong></td>
<td>37.1 ± 13.8</td>
<td>38.1 ± 11.7</td>
<td>37.8 ± 12.4</td>
</tr>
<tr>
<td><strong>Height (cm)</strong></td>
<td>172.4 ± 6.9</td>
<td>163.3–193.6</td>
<td>164.0 ± 8.9</td>
</tr>
<tr>
<td><strong>Weight (kg)</strong></td>
<td>68.6 ± 9.7</td>
<td>54.8 ± 9.4</td>
<td>60.0 ± 11.6</td>
</tr>
<tr>
<td><strong>BMI (kg/m²)</strong></td>
<td>23.1 ± 2.8</td>
<td>21.6 ± 3.3</td>
<td>22.2 ± 3.2</td>
</tr>
</tbody>
</table>

International Journal of Obesity
In short, it samples the acceleration at 32 Hz and assesses it in the range from 0.06 to 1.94 G (one G is equal to earth gravity acceleration). The accelerometer is designed to estimate the total daily energy expenditure from the subject’s anthropometric data and accelerometer signals resulting from the subject’s movements. Furthermore, the device provides an index of physical activity intensity (accelerometry score) based on the accelerometric signals. A maximum pulse over 4 s is taken as the acceleration value, and the activities are categorized into 11 scores (zero, i.e., below 0.06 G, 0.5 and 1–9) based on the pattern (amplitude and frequency) of the accelerometric signal. The accelerometry score showed a significant correlation with the metabolic equivalent (METs) during treadmill walking as well as daily activities over a longer time period.9,12

Using the accelerometry score to assess body movements

We employed the accelerometry score (11 scores) provided by the accelerometer to evaluate movements of trunk (device put on the waist) and that of upper limb (device put on the wrist of dominant arm). The data of the accelerometry score were calculated from the median value obtained over a 2 min period by the accelerometer algorithm and stored for subsequent analyses. All data were then averaged over 15 min to be in phase with the chamber energy expenditure value.

To investigate the difference among the major activities, the daily physical activities were categorized into the following eight categories based on the activity diary:

A: Treadmill walking; speed = 3.9 km/h
B: Treadmill walking; speed = 5.1 km/h
C: Ambling around in the chamber
D: Self-care tasks; cleaning, arrangements, washing, brushing
E: Desk work; studying, writing, computer-working and any handcraft like activities in sitting posture
F: Meals; during breakfast, lunch dinner in sitting posture
G: Reading; posture was mixed sitting/lying on the bed
H: Watching TV; posture was mixed sitting/lying on the bed

For the above classification, we analyzed only the data of the period for which the time-table sheet was filled up properly. Overall more than 90% of the measurements during the daytime could be categorized into the above eight groups.

Statistical analyses

The data were expressed as the average and standard deviation (s.d.). A statistical analysis was performed with the StatView software (version 5.0.1, SAS Institute, Cary, NC, USA). P < 0.05 was considered to be statistically significant, unless otherwise noted.

Correlation and linear regression lines between the accelerometry scores and the energy expenditure (kJ/min) were calculated for all individuals during daytime. Moreover, a multiple regression analysis was performed to explore the effect of the addition of the accelerometry score of the wrist to that of the waist to predict the energy expenditure. A linear regression between the accelerometry scores from the waist-worn device and that from the wrist was made.

Due to bias distribution of the data of the accelerometry scores, Mann–Whitney U-test (nonparametric analysis) was performed to investigate the difference between the scores of the waist and that of the wrist in each category.

Kruskal–Wallis analysis was made to investigate the differences of indices among types of activities (eight groups). When the analysis showed significant differences among the groups, the Mann–Whitney U-test was employed to determine the presence of any significant differences. In addition, Bonferroni’s correction was applied for multiple comparisons.

The ratio of the accelerometry scores from the wrist to that from the waist was calculated, except when a denominator and/or a numerator were zero (0).

Results

The individual relationships between the measured total energy expenditure (kJ/min) and the accelerometry scores from waist-worn device were highly significant (r ranging from 0.678 to 0.954; P < 0.001). The accelerometry scores from upper limb also correlated significantly with the total

Figure 1 Relationship between the accelerometry scores from the waist and that from the wrist over the daytime period in the pooled subjects (N = 88). There was a significant correlation between both values (r = 0.798; P < 0.001, s.e.e. = 0.57, y = 1.18x – 0.48). The regression equations were also calculated separately for the two situations: first during treadmill walking periods only (bold line: y = 0.54x + 2.34, s.e.e. = 0.89, r = 0.509, P < 0.001) and second during non-structured activities (thin line: y = 0.64x – 0.09, s.e.e. = 0.32, r = 0.642, P < 0.001). Note that the slope and the intercept between the two lines were statistically different (P < 0.001). The dotted line represents the line of identity.
energy expenditure \((r\) ranging from 0.449 to 0.939; \(P<0.001\)). When a multiple regression analysis was used to explore the effect of the addition of the accelerometry scores of the wrist to that of the waist to estimate the measured energy expenditure, the total variance improved only by \(1.5 \pm 1.8\%\) (range, 0–7.3%).

Figure 1 shows that the relationship between the accelerometry scores from the waist and that from the wrist in the pooled subjects \((N = 88)\). A significant correlation \((r = 0.798; P<0.001)\) was found: the slope of regression equation approximated unity. However, it had a large scatter. The accelerometry score of the waist was significantly higher than that of the wrist during treadmill walking periods (ie gross and structured displacement); in contrast, it was significantly lower in nonstructured activities. When we considered the treadmill walking session separately from the nonstructured activities, we found that the correlation remained significant \((P<0.001)\) (Figure 1).

The measured energy expenditure adjusted for body weight (kJ/kg/h) is presented in Figure 2 together with the accelerometry scores of the waist and that of the wrist in each categorized activities (eight groups). The average rate of energy expenditure in the different categories were:

- A: 13.4 \(\pm 2.2\) kJ/kg/h (3.2 \(\pm 0.5\) kcal/kg/h);
- B: 17.1 \(\pm 2.2\) (4.1 \(\pm 0.5\));
- C: 8.7 \(\pm 2.0\) (2.1 \(\pm 0.5\));
- D: 7.9 \(\pm 2.1\) (1.9 \(\pm 0.5\));
- E: 6.2 \(\pm 1.7\) (1.5 \(\pm 0.4\));
- F: 6.4 \(\pm 1.5\) (1.5 \(\pm 0.4\));
- G: 5.9 \(\pm 1.8\) (1.4 \(\pm 0.4\)) and H: 5.7 \(\pm 1.4\) (1.4 \(\pm 0.3\)), respectively. Significant differences for the indices (accelerometry scores and energy expenditure) among the eight types of activities were found \((P<0.001)\). Thereafter, the Mann–Whitney U-test along with Bonferroni’s correction also demonstrated the presence of significant differences (significance was \(P<0.00625)\): the energy expenditure of each category was significantly different except between the categories E (Desk works) and F (Meals) \((P=0.0066)\). Regarding the waist accelerometry score, there were significant differences among the categories except for categories E, G (Reading) and H (Watching TV) \((P=0.0388, 0.0098 and 0.7586)\). In contrast, significant differences were observed among the categories except for between categories C (Walk around) and D (Self-care tasks) \((P=0.6142)\) in the wrist accelerometry score.

The accelerometry score of the waist was significantly higher than that of the wrist during treadmill walking (A & B; \(P<0.001)\), and no significant difference was observed during ambling (C; \(P=0.335)\). During self-care tasks (D) and sedentary (sitting) like activities (E, F, G & H), the waist accelerometry score was always significantly lower than that of the wrist one \((P<0.001)\). The ratio of the wrist/waist score is presented in Figure 2; the ratios were higher than 1.0 for sedentary activities and were lower than 1.0 for walking activities.

**Discussion**

**Upper limb and whole body movement assessed by acceleration**

Our accelerometric data revealed that the upper limb movements such as fidgeting-like activities while in sitting position (category E–H) were more intense and had larger variations than the whole body (trunk) movements. During tasks from sitting to standing activities (category D), the upper body movements still had a higher intensity than the whole body movements. However, this was reversed for walking activities (Figure 2). The ratio of walking activities (A–C) were mostly below one (average = 0.8, range from 0.7

---

**Figure 2** Average of the waist-accelerometry scores, wrist-accelerometry scores and the ratio of wrist to waist scores in each categorized activity (eight categories, see text). The rate of energy expenditure is also shown. The data are expressed as the mean and standard deviation.
to 1.1), whereas the ratio of activities E–H were systematically above one (average = 2.9, range from 2.6 to 3.1). Even while watching TV, which would be expected to involve few segmental movements, upper body movements were still detected. Tamura et al.\(^{13}\) reported that wrist accelerations were observed when the subject was in sitting position, with the waist acceleration close to zero. Our study also confirmed their results. Moreover, they also indicated that the wrist acceleration occurred more often and had larger variations during daily living in comparison to waist acceleration.

The upper limb spontaneous movements can be considered to be important either for biomechanic balance (swinging arm during walking) or prehension and task accomplishment. A previous study\(^{14}\) showed that arm movements during sitting-like activities (reading, watching TV, eating, desk work etc) had larger interindividual variability than locomotion activities such as during domestic work tasks as well as during walking and jogging.

### Body movements and their effect on energy expenditure

Previous studies\(^{6–8}\) in the area of psychophysiology and rehabilitation medicine, have attempted to classify and quantify the different types of activities for the purpose of examining the physical activity limitation of patients with certain medical disorders and to evaluate its outcome. These studies indicated that accelerometer with the sensors located on the thighs, chest (trunk) and upper limb could be used to assess the duration of gross physical activities such as mobility-related activities (standing, sitting, lying, walking, running, ascending/descending stairs) as well as upper limb movements (fidgeting, washing, cleaning) in comparison to a certain reference value (videotape recording method). However, these studies were not designed to assess the energy expenditure related to those activities.

Our results indicated that the upper limb movements during sedentary activities may involve a lower metabolic output than locomotion activities. This is not surprising since weight-bearing activities (locomotion) involve, for the same acceleration, a greater force (acceleration \(\times\) weight) and power than isolated limb activities without support for the body. Note that the energy expended due to sitting activities might consist of upper limb movements as well as posture maintenance. Our results also showed that purposeful walking tripled and quadrupled resting level in energy expenditure (3–4 METs), depending upon the speed of displacement. Ambling and self-care tasks approximately doubled the resting level since these activities were accompanied by trunk movements. Levine et al.\(^{15}\) reported that even very slow walking (<2 km/h) can increase energy expenditure almost twofold compared to resting level. In contrast, mixed sedentary activities (category E–H) with little gross body movements involved increasing energy expenditure above resting by less than 50% on average. The energy expended during meals (category F) was similar to that for desk work (category E), considering that eating requires mastication which increases the energy expenditure,\(^{16}\) in addition to spontaneous arms movements and prehension. Previous studies\(^{4,15,17,18}\) indicated that fidgeting and sedentary activities (writing and clerical work) while remaining seated, can moderately increase energy expenditure above resting level (ie below 50%). However these activities may frequently occur.

Acceleration signal-based parameters are often used in the long-term measurement of activity-related energy expenditure. A body acceleration signal from the center of mass (by the sensor attached to the waist or trunk) appeared to have a close relationship with the oxygen uptake during level walking,\(^{2,19}\) so that it provides a reasonable estimation of the energy expenditure. However, on the other hand, it seems impossible to pick up energy expenditure due to static work and isometric exercise of the upper limbs (ie carrying load and grasping) by accelerometer alone. The upper limb movements have a noncyclic somehow random character and many degrees of freedoms.\(^{8}\) Patterson et al.\(^{20}\) reported that a wrist-worn accelerometer has shown a different level of acceleration when reading is compared to typing activities, although the energy cost of the task was not significantly different.

Our results showed that the explained variance of energy expenditure was improved only by 1.5% on average (range 0–7.3%), when the wrist accelerometer data were added as a second predictor to the waist accelerometer data. Swartz et al.\(^{21}\) have also found that addition of a wrist to a waist accelerometer could significantly improve the prediction of metabolic equivalents (METs) of daily-life activities (yardwork, housework, walking, recreation etc), but it resulted in only a minor improvement in prediction (2.6% of the variance). Thus, it suggests that the effect of the wrist accelerometer for predicting energy expenditure would be of limited importance.

### Instrument and study limitations

Whether a multidirectional accelerometer (eg triaxial accelerometer) provides a more accurate measure of upper body movements than a uniaxial one depends on the types of movements involved: for instance, swinging arms during structured walking would not involve much error since the direction of movement (vector) changes constantly. Previous studies\(^{9,22}\) suggested that in most situations, the recordings obtained with an uniaxial accelerometer closely approximate the recordings from a triaxial accelerometer. Uniaxial accelerometer has some advantages by (1) providing reliable measurements of simple arm movements involved in daily living activities and (2) by displaying high sensitivity to movements parallel to the length of the arm. Furthermore, we have tested our device in comparison with a three-dimensional accelerometer put simultaneously on the same side of the forearm during free-living conditions.\(^{23}\) The
uniaxial accelerometer could explain such a large variance (70%) of three-dimensional acceleration, the latter calculated as the square-root of the sum of the squared accelerations for the three directions. We believe that single-axis acceleration could well reflect accelerations in the two other axes in the case of heterogeneous movements.24,25

In conclusion, the movements of the upper limb, such as fidgeting while sitting/lying down positions, are more important in terms of acceleration than whole body movements. However, such fidgeting movements induce a smaller energy expenditure than locomotion activities, thus indicating that the latter constitutes a key component of NEAT.

Acknowledgements
This work was in part supported by the Medical Frontier Strategy Research Grants H13-211th-31 from Japanese Ministry of Health Labor and Welfare.

We are grateful to the participants for their cooperation. We thank the Japanese associations/groups in Switzerland, particularly The Japan Club of Geneva, The Swiss–Japanese Journal Grüez and The Swiss Happy Net (http://www.swippy.ch), and the people who helped in the recruiting process of the subjects. We are grateful to Assistant Professor Takuya Yahiro and the staff at the Laboratory of Exercise Physiology, Faculty of Sports and Health Science, Fukuoka University for their valuable assistance in making the preparations for this study. We would also like to acknowledge the contribution of Professor Munehiro Shindo at the Fukuoka University; Professor Yutaka Yoshitake, PhD, at the National Institute of Fitness and Sports in Kanoya; Mayumi Yoshioka, PhD, at the Laval University Medical Center and Laval University and thank them for their support.

A part of this study was presented at 12th European Congress on Obesity in Helsinki, Finland (ECO2003).23

References