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# Evaluation of a portable device to measure daily energy expenditure in free-living adults[1–3]

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## ABSTRACT

**Background:** Increasing daily energy expenditure (EE) plays an important role in the prevention or treatment of several lifestyle-related diseases; however, its measurement remains problematic.

**Objective:** The objective was to evaluate a portable armband device for measuring daily and physical activity EE compared with doubly labeled water (DLW) in free-living individuals.

**Design:** Daily EE and physical activity EE were measured in 45 subjects over a 10-d period simultaneously with 2 techniques: a portable armband and DLW. Resting metabolic rate was measured by indirect calorimetry, and the thermic effect of a meal was estimated (10% of daily EE). Physical activity EE was obtained by subtracting the values for resting metabolic rate and thermic effect of a meal measured with DLW from those measured with the armband. Body composition was measured with dual-energy X-ray absorptiometry. Concordance between measures was evaluated by intraclass correlation, SEE, regression analysis, and Bland-Altman plots.

**Results:** Mean estimated daily EE measured with the armband was 117 kcal/d lower (2375 ± 366 kcal/d) than that measured with DLW (2492 ± 444 kcal/d; $P < 0.01$). Despite this group difference, individual comparisons between the armband and DLW were close, as evidenced by an intraclass correlation of 0.81 ($P < 0.01$).

**Conclusions:** The portable armband shows reasonable concordance with DLW for measuring daily EE in free-living adults. The armband may therefore be useful to estimate daily EE. *Am J Clin Nutr* 2007;85:742–9.


**KEY WORDS** Energy expenditure, physical activity, doubly labeled water, portable armband

## INTRODUCTION

Increasing daily energy expenditure (EE) plays an important role in the regulation of body weight and in the prevention or treatment of several lifestyle-related diseases, including mortality (1–7). Despite the critical importance of the appropriate level of daily EE and its central role in some theories of aging (8), in understanding the course of certain illnesses (9), and in the regulation of energy balance, its accurate measurement in free-living individuals remains difficult (5, 10, 11). There is a need to develop and validate instruments that could be useful in the monitoring of individual levels of total and physical activity EE. Furthermore, the self-monitoring of daily EE may increase awareness regarding the levels of EE needed to reduce health problems associated with physical inactivity (eg, obesity and type 2 diabetes) and serve as a useful element to promote lifestyle change (3, 4, 12).

Investigators have not consistently used a criterion method to validate instruments to measure daily EE. This is not a trivial point, because noncriterion methods are frequently compared against other noncriterion methods. This type of approach may suffer from a circularity in that the 2 methods compared (eg, 2 forms of self-report) may have correlated errors, which makes it difficult to arrive at a consensus regarding the accuracy of a given instrument. For example, questionnaires intended to evaluate physical activity EE have recently been shown to either over- or underestimate actual EE up to 60% (13). The development of the doubly labeled water (DLW) method has provided one valid and unobtrusive method for measuring free-living EE, from which the accuracy of field instruments can be determined (10). Unfortunately, its relatively high price, the need for mass spectrometry instrumentation, and the required technical expertise have limited its widespread application in research. Thus, the objective of this study was to examine the accuracy of a portable armband device and its associated software as a system to assess daily and physical activity EE in free-living adults in comparison with the DLW method.

## SUBJECTS AND METHODS

### Subjects

The physical characteristics of the men and women in the study sample are shown in **Table 1**. All subjects participated in a medical history and physical examination. To be eligible to participate, the subjects had to be ≥18 and ≤85 y of age, have no major illness or disease other than diabetes (type 1 or type 2), have a body mass index (BMI; in kg/m$^2$) ≥18 and ≤35, be nonsmokers, and be low-to-moderate alcohol consumers (≤2drinks/d). We sought to include both persons in good health and a subset of diabetic persons. Fifty persons were recruited and

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**TABLE 1**
Subject characteristics[1]

| Variable | Value ($n$ = 13 M, 32 F) |
|---|---|
| Age (y) | 35.1 ± 14.0 (20.1–78.2) |
| Height (m) | 1.69 ± 0.07 (1.58–1.88) |
| Weight (kg) | 68.2 ± 14.1 (52.0–107.1) |
| BMI (kg/m$^2$) | 23.9 ± 4.0 (17.9–34.3) |
| Fat-free mass (kg) | 47.3 ± 8.6 (36.5–70.8) |
| Fat mass (kg) | 18.4 ± 9.5 (2.8–43.3) |
| Daily EE by DLW (kcal/d) | 2492 ± 444 (1606–3415) |
| Physical activity EE by DLW (kcal/d) | 857 ± 326 (66–1514) |
| Resting metabolic rate (kcal/min) | 0.96 ± 0.17 (0.72–1.49) |
| Physical activity level | 1.6 ± 0.3 (1.03–2.4) |

[1] All values are $\bar{x}$ ± SD; range in parentheses. EE, energy expenditure; DLW, doubly labeled water.

tested, but only 45 were included in the data analysis. To be included in the final data analysis, "on-body" time of the armband needed to be >95%. Five persons did not meet the criterion of >95% on-body time. The reasons for unacceptable time are not readily apparent, with the notable exception of one person, who had placed the armband on the arm in such a way that no contact with the skin was possible and thus no data were recorded. Of the 45 subjects included in data analysis, 13 were men (2 diabetic) and 32 were women (4 diabetic).

### Overview of protocol

The study was approved by the University of Montreal Ethics Committee. All subjects were recruited on a voluntary basis and signed a consent form. A medical appointment was scheduled at the metabolic unit facility on day 0. DLW was administered on day 0, and urine samples were collected on days 0 and 1. The DLW measurement period was completed with urine samples collected on day 10. On day 1, the armband was strapped onto the right arm before the measurement of resting metabolic rate (RMR). EE was simultaneously measured by the DLW and armband methods for the 10-d period. RMR was measured in a controlled environment for 40 min with the ventilated-hood technique. After completion, the subjects were instructed on how to use the armband and how to complete a daily diary. The diary was used to record any problems with the armband and to document when the armband was removed (eg, for showering). The subjects were asked to make a third visit to the metabolic unit on day 4 so that the study personnel could download the armband data, replace the battery, and make sure that the diary was properly completed for the first 3 d. The subjects made their final visit on day 10 to measure body composition with dual-energy X-ray absorptiometry (DXA) and to return the diary and the armband for the final download of data.

### Portable armband

The portable armband (HealthWear Bodymedia, Pittsburgh, PA) uses a 2-axis accelerometer, a heat flux sensor, a galvanic skin response sensor, a skin temperature sensor, and a near-body ambient temperature sensor to capture data. These data as well as body weight, height, handedness, and smoking status (smoker or nonsmoker) are used to calculate EE. The armband was placed on the upper right arm (on the triceps and at midhumerus point) of each volunteer. All subjects were instructed to remove the armband only for bathing purposes or any water activity. When downloading the data, the software (INNERVIEW version 4.02; Bodymedia, Pittsburgh, PA) provided percentages of on-body time. A threshold of 95% on body time was used to include an individual in the data analysis.

### Resting metabolic rate

RMR was measured by indirect calorimetry after the subjects fasted for 12 h. Concentrations of carbon dioxide and oxygen were measured with a SensorMedics Delta Track II (Datex-Ohmeda, Helsinki, Finland) with the ventilated-hood technique. Measurement of gas concentrations were then used to determine 24-h RMR with the Weir equation (14). The subjects were instructed to *1*) fast and drink only water for 12 h before testing, *2*) consume no alcohol, *3*) restrain from physical activity for 24 h before testing, and *4*) keep physical activity to a minimum on the morning of the test. Measurements were performed while subjects were lying in a supine position, without speaking or sleeping and with minimum movements. Measurements were performed over a 40-min period. The first 10 min were considered an acclimatization period, and data from the last 30 min were used for the analyses. The temperature of the room was maintained at an average of 22 °C. The calorimeter gas analyzers were calibrated before every measurement for pressure and gas concentrations. In our laboratory, the intraclass correlation coefficient (ICC; 2-factor random effect) for RMR determined by using a test-retest condition in 19 different subjects is 0.92 ($P < 0.01$). RMR was also calculated according to the World Health Organization (WHO) equations (15).

### Thermic effect of a meal

The thermic effect of a meal (TEM) was estimated as 10% of daily EE and was calculated as daily EE × 0.10 (16). The calculation was specifically made for each daily EE measurement (by DLW or armband).

### Body composition and anthropometric measurements

Body weight (kg) was measured to the nearest 20 g with an electronic scale (Balance Industrielles Montréal Inc, Montreal, Canada), and standing height was measured to the nearest 0.1 cm with a wall stadiometer (Perspective Enterprises, Portage, MI). Both measurements were performed following standard techniques while the subjects were shoeless. BMI was calculated as body weight (kg)/height$^2$ (m). Fat-free mass and fat mass were measured by DXA with a LUNAR Prodigy system (software version 6.10.019; General Electric Lunar Corporation, Madison, WI). The DXA equipment was calibrated daily by using a known calibration standard. In test-retest analyses, the ICC (2-factor, random effect) in 18 different subjects was 0.99 ($P < 0.01$) for fat mass and 0.99 ($P < 0.01$) for fat-free mass.

### Doubly labeled water

Daily EE was determined from DLW over a 10-d period. The DLW method uses the differential loss of the $^2$H and $^{18}$O isotopes of water to integrate carbon dioxide production over time in free-living subjects. After a dose of deuterated water is administered, the $^2$H is lost from the body water at an exponential rate. When $^{18}$O-water is administered, the $^{18}$O is also lost with body water turnover (as per the $^2$H isotope) and with each molecule of

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**TABLE 2**
Paired *t* test comparison of daily energy expenditure (EE)[1]

| Daily EE measurements or estimates | $\bar{x} \pm$ SD | Mean difference (variable − DLW) | Range |
|---|---|---|---|
| | | *kcal/d* | |
| Armband | 2375 ± 366 | −117[2] | 1640–3248 |
| Vinken et al (19) | 2852 ± 390 | 361[2] | 2177–4093 |
| WHO RMR × 1.4 | 2135 ± 358 | −357[2] | 1765–3245 |
| WHO RMR × 1.6 | 2440 ± 409 | −52[2] | 2017–3708 |
| WHO RMR × 2.0 | 3050 ± 511 | 558[2] | 2521–4635 |

[1] $n = 45$. DLW, doubly labeled water; WHO RMR, resting metabolic rate estimated with World Health Organization equations.
[2] Significantly different from DLW, $P < 0.01$.

carbon dioxide produced because carbonic anhydrase in the body rapidly facilitates the equilibrium exchange of water and carbon dioxide/carbonic acid oxygen (17, 18). The difference between the rates of disappearance of $^2H$ and $^{18}O$ corresponds to the total carbon dioxide production over that period. These rates are determined from urine samples taken at the start and at the end of the measurement period. A fixed respiratory quotient of 0.88 was used to establish oxygen consumption and obtain a value for daily EE. The energy spent by each subject in physical activity per day can be estimated by subtracting other measured or estimated components (RMR and TEM) from daily EE (10).

The DLW experiments generated 5 urine samples per subject: a predose sample, 2 samples obtained after the $^2H_2{}^{18}O$ dose has initially equilibrated in the body (postdose samples 1 and 2), and 2 at the end of the collection period (postdose samples 3 and 4). Postdose samples 1 and 2 were collected on day 1, 16–24 h after the dose of DLW on day 0. There was a minimum of 30 min and a maximum of 4 h between postdose samples 1 and 2 as well as between postdose samples 3 and 4. All samples were measured in triplicate for $^{18}O$-water and in triplicate for $^2H$-water. An Isoprime Stable Isotope Ratio Mass Spectrometer connected to a Multiflow-Bio module for Isoprime and a Gilson 222XL Autosampler (GV Instruments, Manchester, United Kingdom) were used for daily EE measurements. Data processing was performed with MassLynx 3.6 software (Waters Corp, Milford, MA). Stability tests were performed each day before testing, which yielded an SD of 0.026% for deuterium and 0.004% for $^{18}O$. Known reference materials—Vienna-Standard Mean Ocean Water (V-SMOW), Greenland Ice Sheet Program (GISP), Standard Light Antarctic Precipitation (SLAP), and International Atomic Energy Agency standards (IAEA-304A and IAEA-304B)—were used for calibration and data normalization. Isotope ratio analysis results were reported as delta (δ) relative to a reference gas. Daily EE was also determined with a prediction equation based on field variables (age, sex, and weight) (19).

## Statistics

Statistical analyses were performed with SPSS software (version 13.0; SPSS Inc, Chicago, IL). Sample size calculations showed that 40 subjects (DLW versus the armband) would give 80% power at a 0.05 level test to reject the null hypothesis that the ICC is ≤0.60 when the true underlying value is 0.80 and 2 measurements are performed in each subject. Thus, 50 subjects were enrolled in this study to plan for a 20% dropout rate due to subject noncompliance or other unanticipated problems. The ICCs are a class of statistics suitable for evaluating the extent of agreement between ≥2 measures of the same construct (20). We used ICC (one-factor random effect). The ICC may be conceptualized as the ratio of between-subject variance to total variance. The closer the correlation is to 1.0, the greater the concordance between measures. To examine whether the differences between DLW and armband estimates are a function of true values, Bland and Altman analyses were used (21). Specifically, individual comparisons between DLW and the armband were completed by examining a plot of the differences in total and physical activity EE by DLW and the armband versus mean total and physical activity EE determined by both methods. From these data, limits of agreement between DLW and the armband were calculated, ie, mean difference between DLW and the armband ± 2 SD of the difference (daily EE: ±454 kcal/d; physical activity EE: ±480 kcal/d). A more stringent predefined value of ± 300 kcal/d was set based on the fact that within-subject measures of daily EE (by DLW) can vary by 8% (or ≈200 kcal/d) when accounting for analytic and biologic variation (22). Because we compared 2 methods (DLW versus armband) and not within-subject measures of DLW, we added an additional 100 kcal/d (200 + 100 kcal = 300 kcal/d) to estimate the number of outliers between methods.

A regression analysis was conducted between daily EE and physical activity EE between the armband and DLW. To evaluate the presence of a systematic bias, we also plotted the residual values against the reference method. Paired *t* tests were performed to determine differences between the mean values obtained with the armband and DLW.

## RESULTS

The physical characteristics and EE results from DLW for the 45 subjects ($n = 13$ men and 32 women) included in data analysis are shown in Table 1. The physical characteristics represent a relatively broad range of healthy and diabetic adult men and

**TABLE 3**
Level of agreement between measures of daily energy expenditure[1]

| Comparison | Regression analysis ($r^2$) | SEE | ICC ($r$) | ICC (95% CI) | Cronbach's α |
|---|---|---|---|---|---|
| DLW vs armband | 0.74[2] | ±189 | 0.81[2] | 0.68, 0.89 | 0.92 |
| DLW vs Vinken et al (19) | 0.45[2] | ±292 | 0.41[2] | 0.14, 0.62 | 0.80 |
| DLW vs RMR × 1.4 | 0.42[2] | ±276 | 0.37[2] | 0.09, 0.60 | 0.77 |
| DLW vs RMR × 1.6 | 0.42[2] | ±316 | 0.64[2] | 0.44, 0.79 | 0.78 |
| DLW vs RMR × 2.0 | 0.42[2] | ±395 | 0.23 | −0.07, 0.49 | 0.78 |

[1] $n = 45$. ICC, intraclass correlation coefficient; DLW, doubly labeled water; RMR, resting metabolic rate.
[2] $P < 0.01$.

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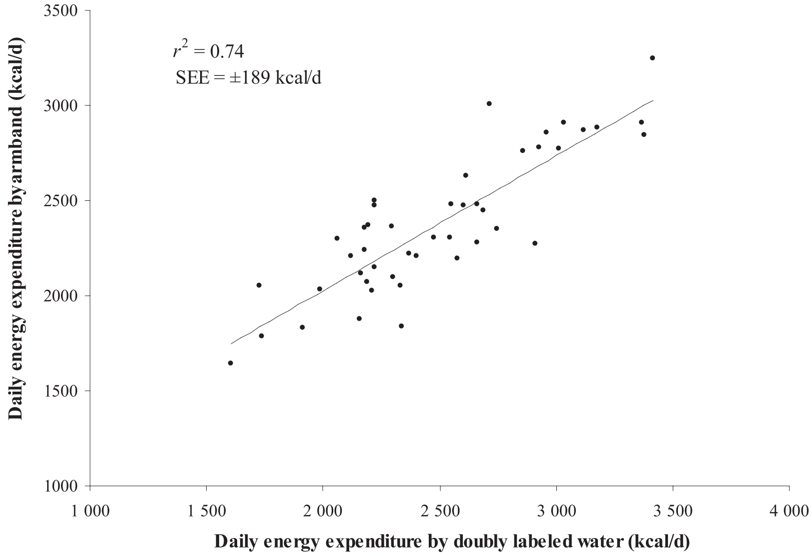


**FIGURE 1.** Regression analysis between the armband and doubly labeled water methods for measuring daily energy expenditure ($n$ = 45; $P < 0.01$).

women. Physical activity EE results showed that most subjects were lightly active, ie, had a mean physical activity level (PAL) of 1.6. The PAL was calculated as daily EE minus TEM divided by RMR. Because sex did not affect the results, all results are reported for the entire cohort.

The portable armband significantly underestimated (−117 kcal/d; $P < 0.01$) daily EE (2375 ± 366 kcal/d) versus DLW (2492 ± 444 kcal/d) over a 10-d period (**Table 2**). We then compared DLW values with values obtained with widely used equations. The equation of Vinken et al (19) significantly overestimated daily EE (361 kcal/d; $P < 0.01$), and the WHO equations (15) ranged from underestimating daily EE by 357 kcal/d to overestimating it by 558 kcal/d with the sedentary (1.4) and heavy (2.0) activity factors, respectively. The smallest mean difference was observed between DLW and the WHO equation multiplied by an activity factor of 1.6 (−52 kcal/d; $P$ = 0.34). This result can easily be explained by the actual average PAL of 1.6 of our population.

Although there was a significant group mean difference between the values obtained with the armband and DLW methods, individual values were relatively similar, as evidenced by the ICC of 0.81 (95% CI: 0.68, 0.89) in **Table 3**. This result indicates that 81% of the variance was explained by differences between individuals, whereas 19% of the variation was due to variation between methods. The individual agreement was not as high for the WHO value multiplied by an activity factor of 1.6 (ICC $r$ = 0.64, $P < 0.01$) or for the Vinken et al (19) equation (ICC $r$ = 0.41, $P < 0.01$). The magnitude of the potential discrepancy between the armband and DLW methods is shown by the SEE (±189 kcal/d). The scatterplot between the armband and DLW methods for total daily EE is presented in **Figure 1**. It must be noted that 2 measures can have a large difference in mean or variance and still have a perfect correlation. The regression analysis showed a moderate level of agreement between the DLW and armband measurements of daily EE ($r^2$ = 0.74, $P < 0.01$). No apparent outliers were noted.

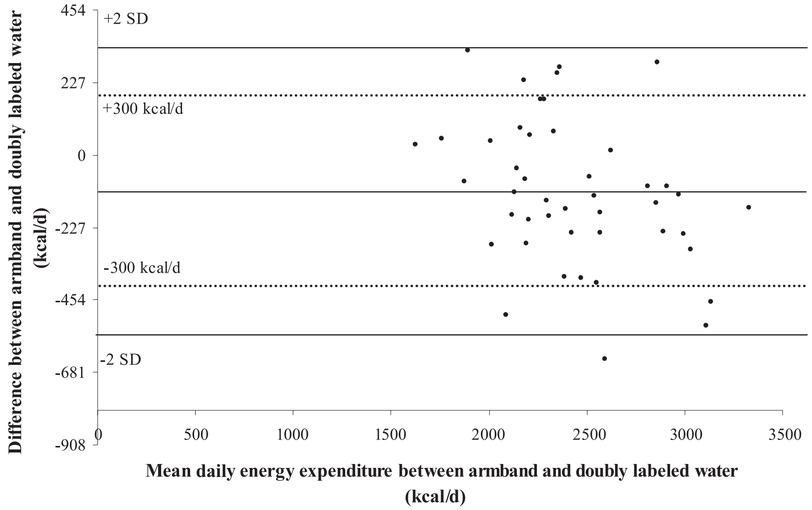


**FIGURE 2.** Bland-Altman plot between the armband and doubly labeled water methods for measuring daily energy expenditure ($n$ = 45). The unbroken horizontal lines represent the limits of agreement corresponding to ±2 SD. The horizontal broken lines represent the ±300-kcal limits of agreement.

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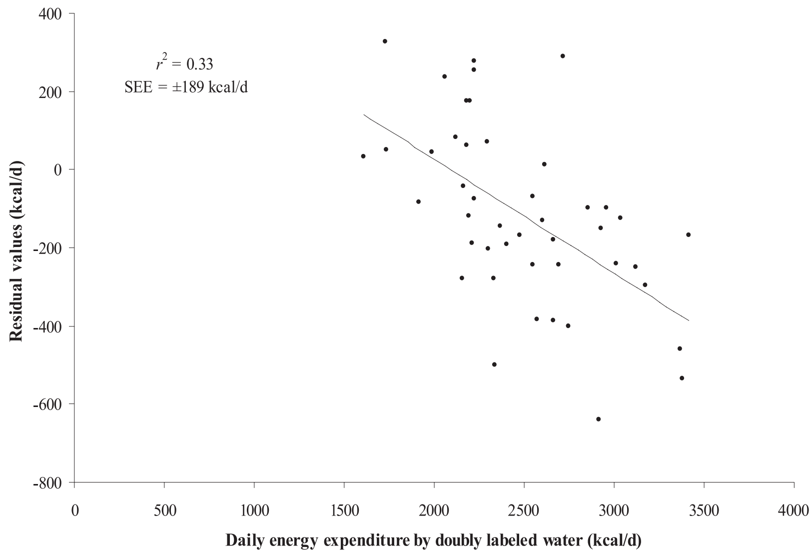


**FIGURE 3.** Residual values for daily energy expenditure (EE) plotted against the reference method for measuring daily EE ($n = 45$). The regression line between the residuals values and the reference values identifies a slight overestimation for subjects with lower daily EEs and an underestimation for subjects with higher daily EEs.

The Bland-Altman plot for total daily EE is shown in **Figure 2**. This plot examines comparisons between the armband and DLW by plotting differences in total daily EE between DLW and the armband versus mean daily EE determined between DLW and the armband. We noted that 80% of the values ($n = 36$ of 45) were within the predefined level of agreement between methods (±300 kcal/d) and 98% ($n = 44$ of 45) were within 2 SD (±454 kcal/d) of the difference between methods. Results of the regression analysis for residual values for TEE plotted against the values obtained from the DLW measurements are shown in **Figure 3**. The plot identifies an overestimation for the lower EE results and an underestimation of the higher EE values ($r^2 = 0.33$, $P < 0.01$).

A significant mean difference was observed between physical activity EE measured with the armband versus DLW (**Table 4**; mean difference of −225 kcal/d; $P < 0.01$; $n = 41$). The ICC between these 2 measures was $r = 0.46$ (95% CI: 0.19, 0.67; $P < 0.01$), which suggests that 46% of the variance was explained by differences between individuals and 54% of the variation was due to variation between methods. The SEE was ±179 kcal/d. Similar comparisons were made for the physical activity EE calculated with the equation of Vinken et al (19) and the WHO equations multiplied by an activity factor (daily EE from equations minus indirect calorimetry measurements for RMR and calculated TEM). Individual agreement was better with the armband measurements (ICC $r = 0.46$, $P < 0.01$) than with any other method. The smallest mean difference was observed for the WHO equations multiplied by 1.6 (−40 kcal/d; $P = 0.44$). The regression analysis between the armband and DLW methods for physical activity EE was significant ($r^2 = 0.49$, $P < 0.01$; $n = 41$), as shown in **Figure 4**. The concordance between the armband and DLW methods for measuring physical activity EE, with the use of Bland-Altman plots, is shown in **Figure 5**. We noted that 83% ($n = 34$ of 41) of the subjects were within 2 SD of physical activity EE. The armband was either placed improperly or malfunctioned during the measurement of RMR for 4 of the 45 subjects included in the data analysis. Thus, these 4 subjects did not have values available for this analysis and were excluded.

**TABLE 4**
Paired *t* test comparison of physical activity energy expenditure (EE)[1]

| Physical activity EE measurements | $\bar{x}$ ± SD | Mean difference (variable − DLW) | Range |
|---|---|---|---|
| | | *kcal/d* | |
| Armband | 639 ± 248 | −225[2] | 163–1165 |
| Vinken et al (19) | 1190 ± 190 | 327[2] | 728–1587 |
| WHO RMR × 1.4[3] | 547 ± 151 | −316[2] | 293–933 |
| WHO RMR × 1.6[3] | 824 ± 186 | −40 | 540–1279 |
| WHO RMR × 2.0[3] | 1378 ± 267 | −739[2] | 1035–2032 |

[1] $n = 41$. To calculate physical activity EE, WHO RMR and the thermic effect of a meal (10% of daily EE) were subtracted from daily EE. DLW, doubly labeled water; WHO RMR, resting metabolic rate estimated with World Health Organization equations.
[2] Significantly different from DLW, $P < 0.01$.
[3] WHO RMR was multiplied by activity factors of 1.4, 1.6, or 2.0 to obtain values for daily EE.

Although it was not the major purpose of this study, we reported a concordance between measures of indirect calorimetry and the armband measurement (data not shown in tabular form). The armband provided higher values for RMR (1.05 ± 0.17 kcal/min) than did indirect calorimetry (0.96 ± 0.17 kcal/min; $P < 0.05$), which suggests a possible overestimation with the armband. The ICC between these 2 measures was 0.77, which suggested that 77% of the variance was explained by differences between individuals, whereas 23% of the variation was due to variation between methods. The regression analysis between the armband and indirect calorimetry was $r^2 = 0.77$ (SEE = ±0.08 kcal/min; $P < 0.01$). Similar results were obtained when the WHO equations were used to predict RMR ($r^2 = 0.79$, SEE = ±0.08 kcal/min; $P < 0.01$).

## DISCUSSION

We evaluated the accuracy of the portable armband compared with that of the DLW method for measuring both total daily and

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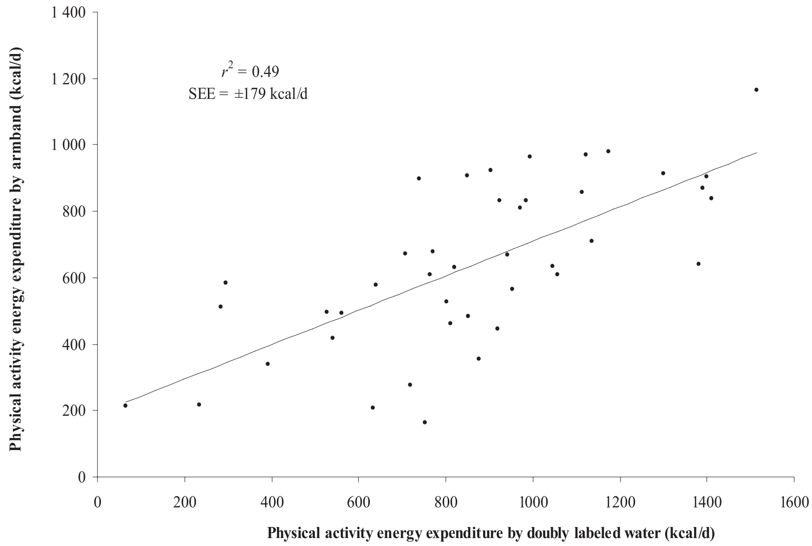


**FIGURE 4.** Regression analysis between the armband and doubly labeled water methods for measuring physical activity energy expenditure ($n = 41$; $P < 0.01$).

physical activity EE in free-living adults. Our findings suggest reasonable concordance between the methods on the basis of ICCs and the Bland-Altman plots.

### Total energy expenditure

Despite an average significant underestimation of daily EE by the armband (−117 kcal/d) compared with the DLW method, the methods provided relatively similar results. This statement is based on the magnitude of the ICC, which showed that 81% of the variance in daily EE was explained by interindividual differences (Table 3) and a high correlation coefficient between methods (Figure 1). Daily EE values for 9 of the 45 subjects were outside the hypothesized ±300 kcal/d range. We compared the physical characteristics of these 9 subjects with those of the 36 subjects who had values within the acceptable range of prediction and found no differences in any of the physical characteristic between these groups. Thus, we cannot explain why these 9 subjects were "outliers," although one may suspect that sources of discrepancies include the armband's ability to accurately record different types of physical activity. However, the residual values (Figure 3) showed that the armband yielded an overestimation of daily EE for the subjects with low EE values and an underestimation of daily EE for the subjects with high EE values. These findings suggest that the device is more accurate for usual daily EE than for extreme levels (eg, athletes).

Nonetheless, despite a tendency to underestimate mean values, the armband provided better results than did common field methods for measuring daily EE (15, 19). Thus, the device may be a useful clinical instrument to estimate or monitor daily EE. For example, if threshold levels of daily EE could be estimated and prescribed to individuals on the basis of a person's age or diagnosis (eg, obesity or type 2 diabetes), the armband could provide useful feedback for a person seeking to increase and maintain a higher threshold level of daily EE. Accurate

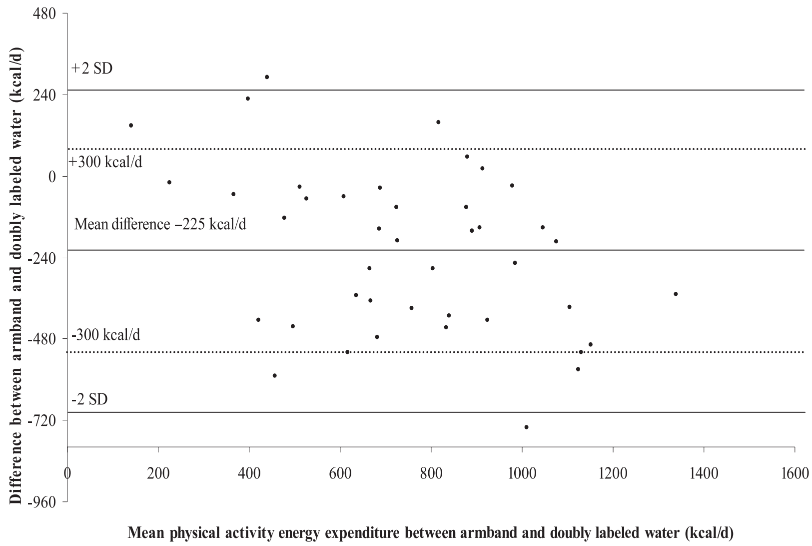


**FIGURE 5.** Bland-Altman plot between the armband and doubly labeled water methods for measuring physical activity energy expenditure ($n = 41$). The unbroken horizontal lines represent the limits of agreement corresponding to ±2 SD. The broken horizontal lines represent the ±300-kcal limits of agreement.

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**TABLE 5**
Level of agreement between measures of physical activity energy expenditure[1]

| Comparison | Regression analysis ($r^2$) | SEE | ICC ($r$) | ICC (95% CI) | Cronbach's $\alpha$ |
|---|---|---|---|---|---|
| DLW vs armband | 0.49[2] | ±179 | 0.46[2] | 0.19–0.67 | 0.80 |
| DLW vs Vinken et al (19) | 0.15[2] | ±186 | −0.003 | −0.29–0.29 | 0.52 |
| DLW vs RMR × 1.4 | 0.11[3] | ±148 | −0.10 | −0.38–0.20 | 0.40 |
| DLW vs RMR × 1.6 | 0.09[3] | ±183 | 0.26[3] | −0.03–0.51 | 0.41 |
| DLW vs RMR × 2.0 | 0.06 | ±263 | −0.27 | −0.52–0.03 | 0.40 |

[1] $n$ = 41. ICC, intraclass correlation coefficient; DLW, doubly labeled water; RMR, resting metabolic rate.
[2] $P < 0.01$.
[3] $P < 0.05$.

self-monitoring in the free-living environment may provide helpful feedback that increases self awareness—an important element for positive decision making and positive lifestyle changes (3, 4, 12). These types of studies, however, need to be performed in larger and more diverse sample populations (eg, children, older adults, obese persons, and athletes) to determine whether the armband is accurate in various population subgroups and assists in increasing subject compliance. In addition, we cannot provide information on whether the armband accurately measures EE over a single day. Although this instrument does provide this type of information, DLW does not. A limitation of the DLW approach is that it provides an integrated assessment of daily EE and not a day-to-day assessment of EE. In this respect, the armband might give timely additional information to assist the subject in regulating energy balance.

## Physical activity energy expenditure

The measurement of physical activity EE with the armband was somewhat less precise than was the measurement of total daily EE. On the basis of the ICC, we noted that 46% (compared with 81% for daily EE) of the variation was explained by interindividual differences and 54% (compared with 19% for daily EE) by differences between the 2 methods (Table 3 and **Table 5**). The regression analysis between methods was moderate ($r^2$ = 0.49, $P < 0.01$). Inspection of the Bland-Altman plots showed that 17% ($n$ = 7 of 41) of the values obtained for physical activity EE were outside the hypothesized limit of agreement of ±300 kcal/d. We maintained the same level of hypothesized agreement as total daily EE because the variation (SD) in physical activity EE accounts for a larger percentage of the mean value than does the daily EE. A significant difference ($P < 0.01$) was noted between the means of physical activity EE as measured by DLW (857 ± 326 kcal/d) and the armband (639 ± 248 kcal/d). The lower accuracy of the armband than of the DLW method for measuring physical activity EE was expected. Physical activity EE, as measured by DLW, is a derived value; thus, the potential exists that the propagation of error associated with the addition and subtraction of the other components (RMR and TEM) may introduce imprecision between methods. Thus, we cannot state whether the lower accuracy in measuring physical activity EE was due to the armband or to the imprecision of the derived values from DLW.

## Resting components of total daily energy expenditure

The ICC was $r$ = 0.77 ($P < 0.01$) for RMR, which suggests that >77% of the individual differences were due to interindividual differences. However, a similar level of concordance was obtained when WHO equations were used to predict RMR (ICC $r$ = 0.75, $P < 0.01$). These similar results were probably due to the fact that the variables used (sex, weight, and age) were similar between both the WHO equations and the armband.

It should be noted that no important safety issue was reported regarding the use of the armband. Four subjects mentioned only minor discomfort during sleep or small skin irritations toward the end of the 10-d wearing period. No lesions were apparent on medical inspection.

In conclusion, the results of the present study support a reasonable level of concordance between the portable armband and DLW methods, especially for measuring total daily EE and, to a lesser degree, physical activity EE. This portable device might be useful in helping individuals to increase their level of daily EE to regulate energy balance and energy needs and to offset chronic diseases associated with physical inactivity (1, 23).

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MS-O collected and analyzed the data and wrote the draft of the manuscript. DM analyzed the DLW data and revised the manuscript. DBA conducted the statistical analysis and revised the manuscript. RR-L supervised the study, wrote the draft of and revised the manuscript. RR-L and DBA received honorarium from the sponsor Roche Diagnostics. MS-O was involved with a private company that used the armband founded after the completion of the study. DM declared no conflict of interest.

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