

Military Metabolic Monitoring

Total Energy Expenditure Estimated Using Foot–Ground Contact Pedometry

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ABSTRACT

Routine walking and running, by increasing daily total energy expenditure (TEE), can play a significant role in reducing the likelihood of obesity. The objective of this field study was to compare TEE estimated using foot–ground contact time (Tc)-pedometry (TEE_{PEDO}) with that measured by the criterion doubly labeled water (DLW) method. Eight male U.S. Marine test volunteers [27 ± 4 years of age (mean $\pm$ SD); weight = 83.2 ± 10.7 kg; height = 182.2 ± 4.5 cm; body fat = $17.0 \pm 2.9\%$] engaged in a field training exercise were studied over 2 days. TEE_{PEDO} was defined as (calculated resting energy expenditure + estimated thermic effect of food + metabolic cost of physical activity), where physical activity was estimated by Tc-pedometry. Tc-pedometry was used to differentiate inactivity, activity other than exercise (i.e., non-exercise activity thermogenesis, or NEAT), and the metabolic cost of locomotion (M_{LOCO}), where M_{LOCO} was derived from total weight (body weight + load weight) and accelerometric measurements of Tc. TEE_{PEDO} data were compared with TEEs measured by the DLW ($^2\text{H}_2^{18}\text{O}$) method (TEE_{DLW}): TEE_{DLW} = 15.27 ± 1.65 MJ/day and TEE_{PEDO} = 15.29 ± 0.83 MJ/day. Mean bias (i.e., TEE_{PEDO} – TEE_{DLW}) was 0.02 MJ, and mean error (SD of individual differences between TEE_{PEDO} and TEE_{DLW}) was 1.83 MJ. The Tc-pedometry method provided a valid estimate of the average TEE of a small group of physically active subjects where walking was the dominant activity.

INTRODUCTION

ROUTINE AEROBIC EXERCISE, such as walking and running, can increase total energy expenditure (TEE), improve physical fitness, and reduce the likelihood of obesity, Type 2 diabetes, and other chronic disorders.^{1–3} However,

the association of physical activity, metabolic energy expenditure, and health is not fully understood. For example, exercise does not always have a clear impact on the management of obesity.⁴

Ambulatory monitoring of free-living individuals is one way to improve our quantitative

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understanding of the role of physical activity and energy expenditure in health management.⁵⁻⁷ New wearable monitors are needed that can unobtrusively and reliably gather data on the type, duration, frequency, intensity, and metabolic cost of physical activity.

A number of field methodologies exist to assess TEE. Standard field methods of assessing the metabolic cost of locomotion (M_{LOCO}) include ambulatory indirect calorimetry,⁷ and doubly labeled water (DLW).^{8,9} Direct observation is valid,¹⁰ but labor-intensive and difficult to scale to large groups of subjects. Ambulatory indirect calorimetry can measure minute-to-minute energy expenditure, but is obtrusive and requires the use of a mouthpiece or mask.⁷ The DLW ($^2\text{H}_2^{18}\text{O}$) method of measuring daily TEE is valid and unobtrusive, but expensive and typically only used over intervals of 2 or more days.¹¹

Field methods of estimating the metabolic cost of physical activity include direct observation (factorial method),⁸ heart rate (HR) monitoring,¹² accelerometry,^{5,13,14} and pedometry.¹⁵⁻¹⁷ The HR method is not valid for light physical activity and requires individual calibration to account for individual variation in HR-to- VO_2 relationship.¹² The output of waist-mounted accelerometers is correlated with the M_{LOCO} over level terrain, but not well correlated to the metabolic cost of non-locomotion activities.^{13,14} Standard pedometry is objective, inexpensive, unobtrusive, and relatively reliable.¹⁶ However, most pedometers only record total step count, do not provide data on the pattern or intensity of locomotion, and, as with accelerometry, provide only indirect estimates of M_{LOCO} .

The present study focuses on a unique type of pedometry that estimates M_{LOCO} from foot-ground contact time (Tc) measurements and total subject weight (body weight + load).¹⁷ The rate of metabolic energy expenditure during walking or running is primarily determined by the cost of supporting body weight and rate at which this force is generated.¹⁸ The rate of force generation can be estimated as total body weight divided by the time that a single foot contacts the ground during each stride.¹⁷⁻¹⁹ Under controlled laboratory conditions, this approach can provide accurate estimates of the M_{LOCO} .¹⁹

The objective of this study was to compare TEE estimated using Tc-pedometry with that measured by the criterion DLW method. The test volunteers were U.S. Marines participating in a physically demanding dismounted infantry field training exercise where movement by foot was the dominant form of structured physical activity.

MATERIALS AND METHODS

Test subjects

The U.S. Marine Corps (USMC) test volunteers who participated in this study gave their free and informed written consent in accordance with relevant U.S. Army regulations regarding the use of volunteers in research. The investigators adhered to the policies for protection of human subjects as prescribed in Army Regulation 70-25, and the research was conducted in adherence with the provisions of 45 CFR Part 46. Eight male Marines [27 ± 4 years of age (mean $\pm$ SD); weight = 83.2 ± 10.7 kg; height = 182.2 ± 4.5 cm; body fat = $17.0 \pm 2.9\%$] were studied during the first 2 days of a 7-day USMC Infantry Officer Course field exercise. Five additional Marine test volunteer cohorts, who received tap water rather than DLW, provided urine samples that were used to monitor for any changes in baseline isotopic enrichment that might affect the precision of the DLW measurements.

Data presented here are from a 50-h period from day 1 (0500 h) to day 3 (0700 h) of a 7-day field exercise. The field exercise, which is designed to test the student's physical and mental performance during simulated combat, is part of the 10-week-long USMC Infantry Officer Course. Students commonly operate on limited sleep, march for extended periods of time while carrying heavy loads (15–60 kg), and consume one or two Meal-Ready-to-Eat (MRE) field rations per day where each MRE ration provides about 5.65 MJ (1,350 kcal).

Meteorologic conditions were temperate: ambient temperature = $19\text{--}31^\circ\text{C}$ (range); black globe temperature = $20\text{--}44^\circ\text{C}$; relative humidity = 43–95%; wind speed = $0.2\text{--}3.8$ m s⁻¹.

Resting energy expenditure (REE)

REE was calculated for each Marine using the equation of Mifflin et al.²⁰:

$$\text{REE (kcal/day)} = [10 \cdot \text{weight (kg)} + 6.25 \cdot \text{height (cm)} - 5 \cdot \text{age (years)}] \quad (1)$$

Body weight, loaded weight, equipment, and clothing log

Seminude body weight was measured at the start of the study using a calibrated balance accurate to ± 0.05 kg (Model 770, Seca, Hamburg, Germany). This balance was also used for daily measurements of total weight, which included all clothing, equipment, weapons, food, and water. Body fat was estimated pre- and post-study from abdomen circumference using an equation developed with U.S. Marine subjects similar to those in the present study,²¹ that is, $\text{FFM} = (40.99 + 1.0435 \times \text{BM}) - (0.6734 \times \text{abdomen})$, where FFM = fat free mass in kg, BM = body mass in kg, and abdomen = waist circumference in cm measured at the level of the navel. Three sequential measurements of abdomen circumference were made on each test volunteer by the same investigator using a spring-loaded fiberglass anthropometric tape. Fat mass was calculated as body mass minus fat-free mass. Test volunteers kept a daily log of hour-to-hour changes in clothing and equipment. Hourly loaded weight was estimated for each subject by adjusting for changes in clothing and equipment noted in the equipment logs.

Food intake and estimated thermic effect of food (TEF)

Daily food intakes were calculated from individual collections of the various wrappers from ration items consumed on a given day, with the TEF estimated as 10% of total caloric intake. The food consumed consisted almost exclusively of MRE field rations. Metabolizable energy intake was calculated by factoring quantities of individual food items consumed against their caloric content (Nutritionist version 5; First DataBank, Inc., Hearst Corp., San Bruno, CA).

Accelerometric assessment of M_{LOCO}

Taylor and colleagues used high-speed cinematography and force platform methods to

show that the M_{LOCO} is primarily determined by the cost of supporting body weight and the rate at which this force is generated.^{18,19} The rate of force generation can be estimated as total body weight divided by the time during each stride that a single foot was in contact with the ground (T_c). At a given total body weight, increases in the speed of locomotion are associated with decreases in foot contact time, increases in the rate of force generation, and increases in the M_{LOCO} . Thus, a close approximation of M_{LOCO} may be obtained from measurements of total body weight and foot contact time.

The M_{LOCO} was calculated from total subject weight (including load carried), and time-series T_c measurements.¹⁷⁻¹⁹ T_c values were measured using a prototype pedometer that attached to the boot laces ($2.5 \text{ cm} \times 2.5 \text{ cm} \times 1.3 \text{ cm}$; 72 g) (Fitsense, Inc., Southboro, MA). This prototype device did not record raw accelerometric signals, but provided T_c and time of flight (loft time) during each stride by on-the-fly analysis of the rapid foot de-acceleration on heel strike, and the more subtle acceleration on toe-off. The reader is referred elsewhere for a more detailed description of the methodology, including an example of the accelerometer signal and validation of the accelerometrically determined T_c against T_c measured by force plate.²² Equations for the relationship between total weight, accelerometrically measured T_c , and M_{LOCO} were generated for walking and running using published data²² and unpublished data (personal communication) from P.G. Weyand and co-workers. The pedometers were worn continuously during the 50-h experiment.

Activity was classified into five categories: run, walk, slow walk, shuffle or "non-exercise activity thermogenesis" (NEAT), and no activity. Periods of running and walking were readily identified from T_c duration. Periods were classified as "slow walk" when heel strike was detected but not the more-subtle toe-off. The T_c for these slow walk periods was about 1,000 ms, and movement velocity was less than 0.894 m s^{-1} ($< 2 \text{ mph}$). NEAT periods were defined as time gaps greater than 1.5 min among bouts of running, walking, or slow walking when the pedometer could not discern a heel strike or toe-off, but was unable to classify the period as

“no activity” because accelerometric evidence of activity was present. Although no single definition exists, NEAT typically refers to energy expenditure for everything that is not sleeping, eating, or volitional exercise, to include sitting, standing, maintaining non-recumbent body posture, changing body posture, fidgeting, and spontaneous muscle contraction. In the present study, the NEAT movement category, the most undefined of the movement categories, included any activities in which foot motion was present. The metabolic cost of a NEAT period was calculated as the average of REE plus the metabolic cost of standing, where the metabolic cost of standing with a load was calculated using the non-movement portion of the Pandolf equation.²³ Finally, periods when no accelerometric signal was present were classified as “no activity” with energy costs equal to estimated REE.

T1 → The equations in Table 1 were used to calculate the M_{LOCO} for each of the five activity categories. Individual daily TEE was calculated for each individual as the sum of calculated REE, TEF, and M_{LOCO} derived from total subject weight and T_c values. No attempt was made to correct TEE for upper body exercise or the effects of terrain grade. The range in elevations over the 9-km² area in the northwest quadrant of the USMC Base Quantico where the Marines trained elevations was about 9 m (126–135 m above sea level).²⁴

Assessment of daily average TEE by DLW

The DLW method²⁵ is based on the assumption that after an initial oral dose of stable $^2\text{H}_2\text{O}$ (deuterium oxide) plus H_2^{18}O , the deuterium is eliminated from the body as water ($2\text{H}_2\text{O}$),

whereas H_2^{18}O leaves as both water (H_2^{18}O) and exhaled carbon dioxide (C^{18}O_2). The rate of CO_2 production (V_{CO_2}) is calculated from the difference in elimination rates of the two isotopes. Oxygen consumption and total metabolic energy expenditure are calculated from V_{CO_2} using a metabolic fuel quotient (FQ) (respiratory exchange ratio) calculated from food intake and body energy store combustion, and conventional calorimetric relationships.²⁶

In this study, TEE_{DLW} was measured using standard procedures.^{25,27–29} Briefly, on the morning of day 0, the volunteers, who had refrained from eating or drinking for at least 12 h, reported to the testing area with a baseline sample of their first morning-void urine. After body weight was recorded and baseline saliva samples were collected, the eight subjects drank 0.30 g/kg of body weight of H_2^{18}O (Isotec, Inc., Miamisburg, OH) and 0.09 g/kg of body weight of $^2\text{H}_2\text{O}$ (MSD Isotopes, St. Louis, MO), as well as the 100 mL of tap water used to rinse the dose container. Saliva samples used to determine total body water (TBW) were collected 3 and 4 h after the initial dose of DLW. The subjects were free to eat and drink only after the final saliva sample was collected. First morning-void urine samples were collected at the beginning and end (day 1 and day 3) of the study period. All urine and saliva samples were stored in 4.5-mL tubes with silicone O-ring seals (Nunc, Roskilde, Denmark).

Isotopic analyses were performed as previously described.³⁰ Briefly, the ^{18}O abundances were measured by equilibration of fluid with CO_2 . Measurements were done in duplicate with an SD of 3 ± 10^{-5} atom percent (0.15%). Deuterium abundances were measured by the

TABLE 1. METABOLIC COST OF LOCOMOTION EQUATIONS FOR EACH MOVEMENT CATEGORY

Movement category	Equation for estimating M_{LOCO} (W)
Run	$M_{\text{LOCO}} = 4.517(W_{\text{TOTAL}}/T_c) - 378.33$
Walk	$M_{\text{LOCO}} = 4.312(W_{\text{TOTAL}}/T_c) - 269.62$
Slow walk	$M_{\text{LOCO}} = 4.312(W_{\text{TOTAL}}/T_c) - 269.62$
	where $T_c = [\text{Mean walk } T_c + (3\text{SD})]$
Shuffle/NEAT	$M_{\text{NEAT}} = [(1.5 \cdot W_b + 2.0(W_b + L)(L/W_b)^2] - \text{REE}/2$
No activity	$M_{\text{LOCO}} = 0$

M_{LOCO} = metabolic cost of locomotion (in W), W_{TOTAL} = total weight (in kg), W_b = body weight (in kg), T_c = foot–ground contact time (in s), M_{NEAT} = metabolic cost of non-exercise activity thermogenesis, L = load (in kg), REE = resting energy expenditure (in W).

zinc reduction method. Measurements were performed in triplicate with an SD of 1.7 ± 10^{-5} atom percent (1.2%). Isotope enrichments were calculated by taking the arithmetic difference between the per mil enrichment of each sample and the respective pre-dose sample. The ratio of excess isotope was calculated and converted to atom percent excess.

Daily TEE was calculated using the linear regression method.²⁸ Baseline isotopic ^2H and ^{18}O abundances were monitored in five cohorts who received tap water instead of DLW. The rate of O_2 production was calculated from CO_2 production using a calculated FQ.²⁶ That is, a metabolic FQ was calculated from the macronutrient composition of the rations consumed and the magnitude of the estimated energy deficit ($\text{TEE} - \text{food intake}$), assuming the energy deficit was met from the body's glycogen stores (estimated as 300 g) and the body's fat stores, which were assumed to be composed of 90% fat and 10% protein. Standard factors were used to correct for isotope fractionation in respiratory and cutaneous water efflux.^{11,29} The use of placebo cohorts to monitor for any changes in background isotopic enrichment helped ensure the accuracy of the TEE_{DLW} measurements.²⁸ The benchmark DLW method used to measure TEE is known to be accurate.²⁵ Although the precision of the TEE_{DLW} measurements was reduced by the relatively short 2-day study period, Schoeller²⁷ suggested the precision of the DLW method, in a 25-year-old male with a 2-day study period at isotopic doses similar to those in the present study, should be <1 MJ/day.

Data analyses

The data were analyzed using Student's *t* test, linear correlation and regression, and an Altman-Bland plot,³¹ which shows the difference between individual measures by the two methods plotted against the mean of the two methods. The mean error was calculated as the SD of the difference between TEE_{PEDO} and TEE_{DLW} , while total error was calculated as $[\sum(\text{TEE}_{\text{PEDO}} - \text{TEE}_{\text{DLW}})^2 / (n - 1)]^{1/2}$.

RESULTS

The Marine test volunteers carried loads of 30.0 ± 6.9 kg (range = 17.1–39.9 kg). The esti-

mated average metabolic FQ was 0.804. Calculated REE was 7.71 ± 0.51 MJ/day (range = 6.84–8.56 MJ/day) and constituted $52 \pm 3.5\%$ of TEE_{DLW} . Baseline isotopic enrichments did not change significantly, and thus no baseline enrichment corrections were made to TEE_{DLW} calculations. In addition, TEE_{DLW} was not corrected for the estimated 2% change in TBW, given that the influence of changes in pool size on TEE_{DLW} will be less than 2% if the pool size changes less than 4%.²⁷

Logbook entries indicated the subjects engaged in a limited amount of upper body exercise: that is, 2 h of practice throwing hand grenades, 1 h of preparation of a hasty defense (a defense organized when time is limited and characterized by improvement of the natural defensive strength of the terrain by utilization of foxholes, emplacements, and obstacles), and loading a truck.

Food energy intake was 5.72 ± 1.14 MJ/day (range = 3.80–7.02 MJ/day).

TEE_{DLW} equalled 15.27 ± 1.65 MJ/day and ranged between 13.29 and 17.80 MJ/day, with the average $\text{TEE}_{\text{DLW}}/\text{REE}$ ratio being 1.99 ± 0.26 (range = 1.73–2.32). TEE_{PEDO} equalled 15.29 ± 0.83 MJ/day (range = 14.26–16.67 MJ/day). Mean bias ($\text{TEE}_{\text{PEDO}} - \text{TEE}_{\text{DLW}}$) was 0.02 MJ, and both mean error and total error were 1.83 MJ. The mean individual TEE_{DLW} and TEE_{PEDO} values over the 2-day experimental period are shown in Table 2.

Pedometry

The Tc frequency distribution is shown in Figure 1. The Marines averaged $6,672 \pm 987$ steps/day (range = 5,389–8,258). This suggests the Marines traveled about 5.3 ± 0.8 km/day (approximate range = 4.3–6.6 km/day), assuming the distance traveled during each step is about 0.8 m. The relatively limited number of steps per day was presumably largely due to the heavy loads carried by the Marines and the associated increase in the per-step cost of locomotion. Additionally, at slow rates of movement the Tc pedometer may have classified very slow steps as “shuffle/NEAT,” thereby decreasing the total step count. The distribution of time spent across the different

T2

F1

TABLE 2. DAILY TEE VALUES MEASURED USING THE DLW METHOD (TEE_{DLW}) AND THE FOOT-GROUND CONTACT PEDOMETRY METHOD (TEE_{PEDO}) (MJ/DAY) FOR EIGHT MALE MARINE TEST VOLUNTEERS DURING A 2-DAY FIELD TRAINING EXERCISE

Subject number	TEE_{PEDO}	TEE_{DLW}	Difference	Absolute difference
1	16.17	17.81	-1.64	1.64
2	14.26	16.67	-2.41	2.41
3	15.17	14.72	0.45	0.45
4	16.67	15.29	1.38	1.38
5	14.85	14.31	0.54	0.54
6	15.77	13.29	2.48	2.48
7	14.81	13.37	1.44	1.44
8	14.61	16.70	-2.09	2.09
Mean	15.27	15.29	0.02	1.55
SD	1.65	0.83	1.83	0.77

F2

movement types, expressed as a percentage of total time, is shown in Figure 2. Activities other than locomotion (i.e., shuffle / NEAT category), and walking (walk category), were the predominant physical activities. NEAT activities occupied about two-thirds of the subject's time, and accounted for $51 \pm 9\%$ of TEE [composed of a $15 \pm 6\%$ contribution from activity-related energy expenditure (AEE) and a $35 \pm 2\%$ contribution from REE]. Remarkably little time or metabolic energy was spent in inactivity (apparent sleep).

The group means for TEE_{DLW} and TEE_{PEDO} , compared using a paired Student's t test, did not differ significantly ($t = -0.03$, $df = 7$, $P = 0.98$) ($r = 0.17$, not significant). Although the correlation was weak, the Altman-Bland plot (Fig. 3), showing the difference between methods ($TEE_{PEDO} - TEE_{DLW}$) plotted against the mean of the two measures, illustrates the small bias between measures. Similarly, a comparison of M_{LOCO} with (AEE_{DLW}) ($AEE_{DLW} = TEE_{DLW} - TEF - REE$), showed a weak correlation of individual values but a close correspondence of

F3

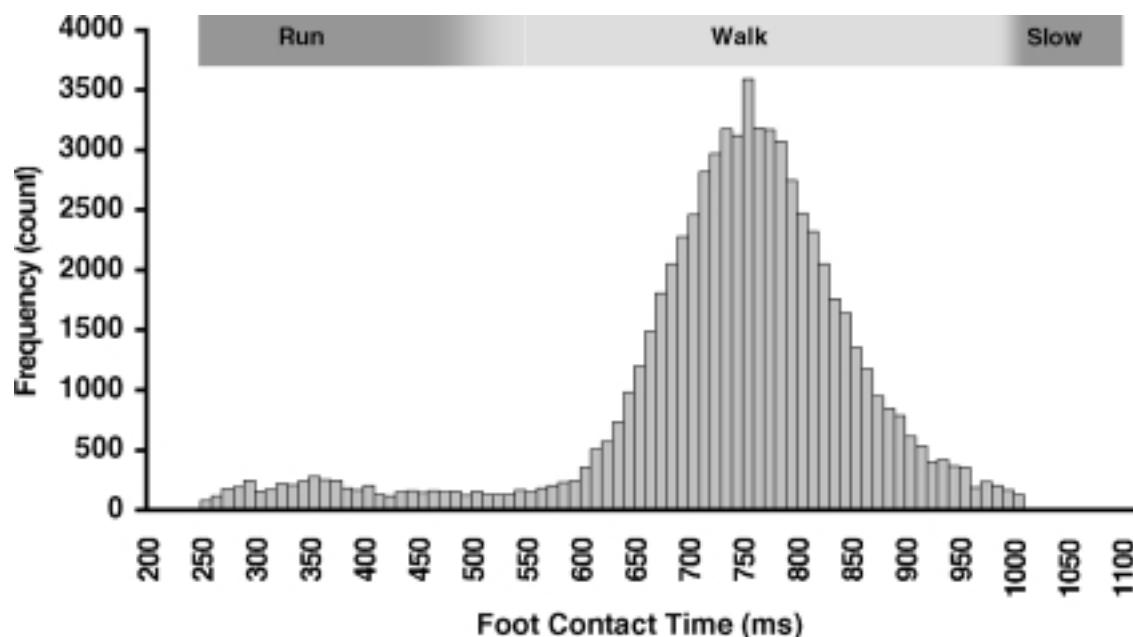


FIG. 1. Frequency distribution of accelerometrically measured Tc values measured over a 50-h experimental period in eight U.S. Marines participating in a field training exercise.

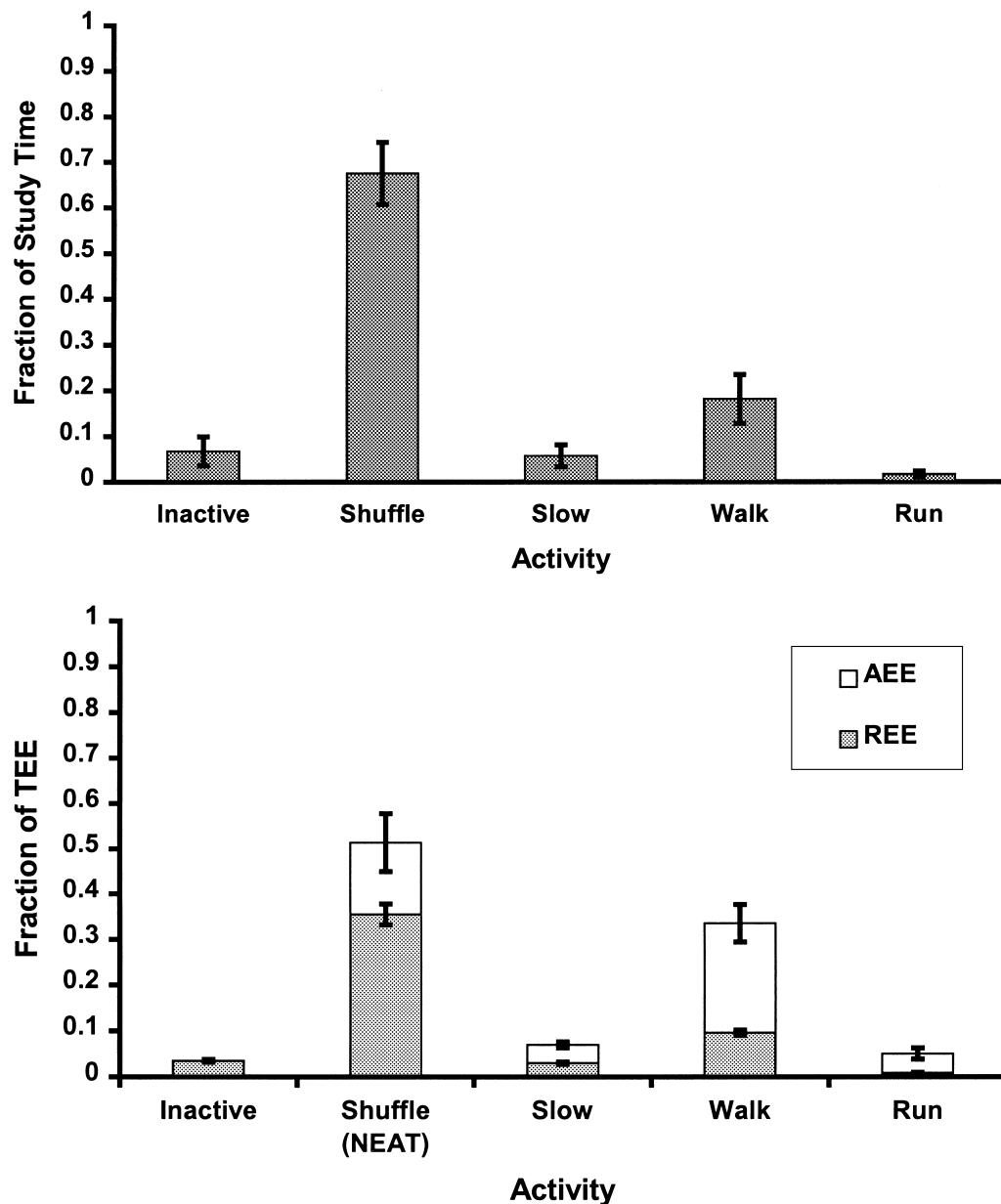


FIG. 2. Activity distribution, expressed as a fraction of study time or fraction of TEE for various categories of physical activity. The “shuffle” category represents NEAT. Data are from eight male Marine test volunteers over a 2-day (50-h) field training exercise. Mean values with SD are shown for fraction of study time, AEE, and REE.

group mean values ($AEE_{DLW} = 7.00 \pm 1.85$ MJ/day, $M_{LOCO} = 7.02 \pm 0.75$ MJ/day) (paired $t = 0.029$, $df = 7$, $P = 0.98$, not significant) ($M_{LOCO} = 0.0951 \times AEE_{DLW} + 6.35$; $r = 0.23$).

DISCUSSION

The present findings indicate that the Tc-pedometry method can provide valid estimates of

the average TEE of small groups of active subjects where walking is the dominant activity. We found that the overall difference between TEE_{PEDO} and TEE_{DLW} groups was insignificant and averaged less than 1%. Fogelholm et al.,⁴ in a study of 20 overweight women, compared TEE estimated by HR monitoring and by commercial accelerometer (Caltrac, Muscle Dynamics, Torrance, CA) with TEE measured by DLW. They reported greater inaccuracy in es-

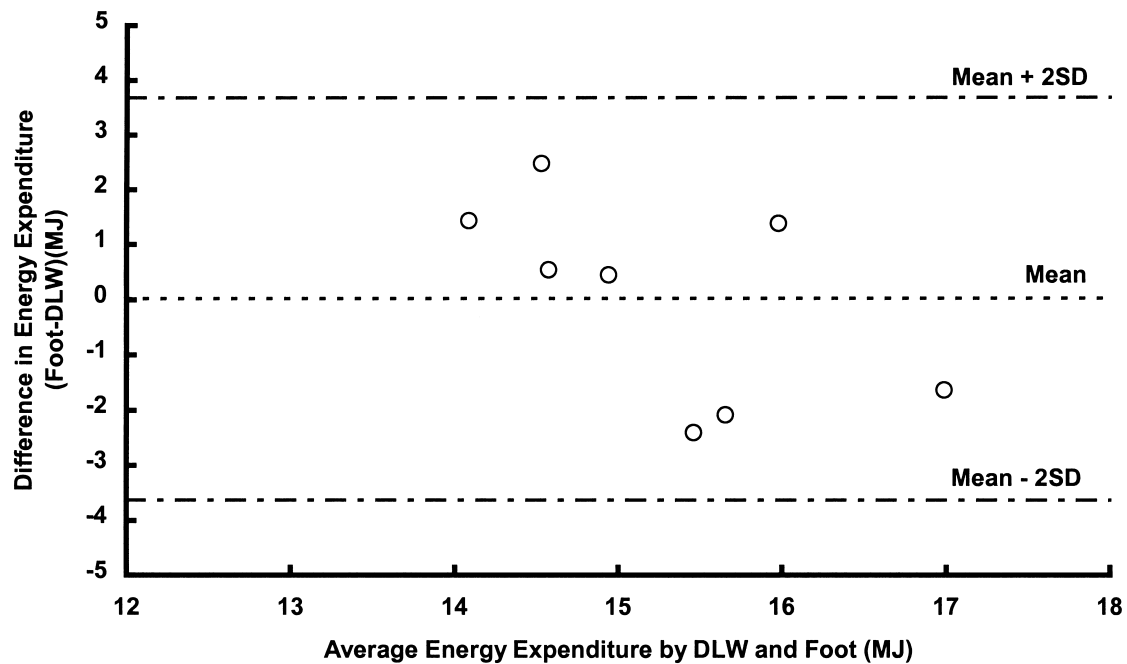


FIG. 3. Altman-Bland plot³¹ showing the difference in TEE between the pedometry and DLW methods ($TEE_{PEDO} - TEE_{DLW}$) plotted against the mean of the two measures. Eight male Marine test volunteers were studied over a 2-day field training exercise. Mean bias (i.e., $TEE_{PEDO} - TEE_{DLW}$) was 0.02 MJ, and the mean error (SD of individual differences between TEE_{PEDO} and TEE_{DLW}) was 1.83 MJ.

timating individual differences (~ 3.7 vs. 2.5 MJ/day) and a greater error as a percentage of TEE ($\sim 16\%$ vs. 12%) than in the present study. However, the error (SD of the difference between methods) and the bias (mean difference between the alternative methods and TEE_{DLW}) were similar for HR and commercial accelerometer methods,⁴ and for the accelerometer-based Tc-pedometry method used in the present study.

Attempts to estimate TEE using conventional pedometers, that is, simple devices that provide only the total number of steps per day rather than time series data, have generally been unsuccessful.^{4,32} This is presumably due to (a) the lack of a clear method of converting steps per day, a measure of physical activity, to metabolic energy expenditure, and (b) an inability to differentiate inactivity, activity other than locomotion, and locomotion.

The Tc-pedometer method has a number of advantages. Tc values are easily converted to M_{LOCO} values knowing total subject weight.¹⁹ In addition, the Tc-pedometry approach does

not require individual calibration, can be used to monitor relatively low-intensity locomotion, and uses simple algorithms to estimate TEE. In comparison, the HR method requires laborious generation of individual HR-to- VO_2 calibration curves to convert HR data to metabolic cost, and the method is not suited to monitoring the energy cost of low-intensity activities. Commercial devices that rely on accelerometers for data collection, such as the Caltrac, commonly use proprietary equations to estimate TEE.

Notably, the Tc-pedometry method, by combining pedometry and accelerometric activity monitoring, can be used to differentiate major categories of activity: locomotion, NEAT, and inactivity. A similar use of the locomotion-NEAT-inactivity categorization is used to present data collected using another recently developed research-grade accelerometric pedometer (AMP-331, see <http://www.dynastream.com>; DynaStream, Inc., Cochrane, AB, Canada). NEAT in the present study included energy expended in activities such as occupying defensive positions, planning missions, and reviewing mission

performance. Inevitably, NEAT includes difficult-to-characterize activities. To provide a more complete account of NEAT, investigators have used inclinometers to monitor body posture and to detect changes in body posture.³³ Similarly, by quantifying the time spent in various categories of locomotion, Tc-pedometry helps define NEAT more completely.

NEAT was an important part of the time and energy budget of our physically active, sleep-restricted Marines, accounting for about two-thirds of the time and half the TEE of the subjects. The observed variability and magnitude of NEAT among the Marines are consistent with the results of a classic whole-room respirometer study that found NEAT varies widely and can be a significant component of TEE.³⁴ Also, Levine et al.³⁵ found that NEAT appears to play an important role in mediating TEE and weight gain in response to overeating. NEAT may also play a role in preventing obesity.

The Tc-pedometer method can help meet the need to accurately estimate the energy cost of walking and running, major components of normal physical activity. However, there are limits. The complex nature of physical activity prevents any single instrument from being suitable for all conditions. For example, Tc-pedometry would be modestly relevant among individuals primarily engaged in activities other than walking and running. The Marine test volunteers are clearly distinct from generally older, less-fit, less-physically active, obese and diabetic populations. Nevertheless, the present results seem instructive, and the methods presented here can be readily applied to estimating TEE in other populations if estimates of dietary intake and total weight can be obtained.

It is reasonable to argue that the amount of volitional exercise and the magnitude of NEAT are related to the likelihood of obesity and Type 2 diabetes. Can innovative ambulatory monitors, such as Tc-pedometers, activity monitors, and inclinometers, be used to explore these relationships? Aerobic fitness, which reflects the amount, duration, and intensity of antecedent physical activity, can be assessed using Tc-pedometry without the

need for expensive and cumbersome equipment to measure gas exchange (indirect calorimetry).²² Ambulatory monitors can also be used to assess TEE and the distribution of locomotion-NEAT-inactivity across patient populations. Ambulatory monitors could also be used to reward increased activity, or perhaps even increased NEAT. Finally, knowing the intensity and duration of activity may make it possible to estimate individual metabolic fuel utilization, allowing a patient's diet to be liberalized or constrained as a function of physical activity.

In conclusion, our findings indicate that Tc-pedometry can provide valid estimates of the mean TEE of small groups of physically active subjects where walking is the dominant activity. This scalable new approach to assessing physical activity patterns, quantifying the M_{LOCO} , and quantifying daily TEE, deserves further study.

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