Energy Expenditure of Walking and Running: Comparison with Prediction Equations

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ABSTRACT

HALL, C., A. FIGUEROA, B. FERNHALL, and J. A. KANALEY. Energy Expenditure of Walking and Running: Comparison with Prediction Equations. *Med. Sci. Sports Exerc.*, Vol. 36, No. 12, pp. 2128–2134, 2004. **Purpose:** This study established the published prediction equations for the energy expenditure of walking and running compared with the measured values. To make this comparison we first determined whether differences exist in energy expenditure for 1600 m of walking versus running, and whether energy expenditure differences occur due to being on the track or treadmill. **Methods:** Energy was measured via indirect calorimetry in 24 subjects while walking (1.41 $m \cdot s^{-1}$) and running (2.82 $m \cdot s^{-1}$) 1600 m on the treadmill. A subgroup also performed the 1600-m run/walk on the track. The measured energy expenditures were compared with published prediction equations. **Results**: Running required more energy ($P < 0.01$) for 1600 m than walking (treadmill: running 481 ± 20.0 kJ, walking 340 ± 14 kJ; track: running 480 ± 23 kJ, walking 334 ± 14 kJ) on both the track and treadmill. Predictions using the ACSM or Léger equations for running, and the Pandolf equation for walking, were similar to the actual energy expenditures for running and walking (total error: ACSM: −20 and 14.4 kJ, respectively; Légers walking: −10.1 kJ; Pandolf walking: −10.0 kJ). An overestimation ($P < 0.01$) for 1600 m was found with the McArdle's table for walking and running energy expenditure and with van der Walt's prediction for walking energy expenditure, whereas the Epstein equation underestimated running energy expenditure ($P < 0.01$). **Conclusion**: Running has a greater energy cost than walking on both the track and treadmill. For running, the Léger equation and ACSM prediction model appear to be the most suitable for the prediction of running energy expenditure. The ACSM and Pandolf prediction equation also closely predict walking energy expenditure, whereas the McArdle's table or the equations by Epstein and van der Walt were not as strong predictors of energy expenditure. **Key Words:** CALORIC COST, PREDICTED ENERGY COST, MODE OF EXERCISE, PREDICTION TABLES

According to the principles of physics, to move a specific mass a specific distance requires a given amount of energy (3,32); thus theoretically it should require the same amount of energy to walk or run a given distance. Previous work in quadrupeds has found that the amount of energy used to run a mile is nearly the same whether it is run at high speed or at a leisurely pace (19), whereas research on humans (7,13,15,18) has shown that humans tend to expend more energy running than walking.

The American College of Sports Medicine (ACSM) guidelines (1) provide formulas to calculate energy expenditure for both running and walking speeds when caloric expenditure is calculated based on oxygen consumption. For example, according to this formula, an individual weighing 80 kg and walking on level grade at 1.41 $m \cdot s^{-1}$ should burn 88 kcal, and, when running at 2.82 $m \cdot s^{-1}$, should burn 137 kcal for 1600 m. However, in other tables provided (22), this same individual would burn 118 kcal walking at 1.41 $m \cdot s^{-1}$, and approximately 145 kcal running at 2.82 $m \cdot s^{-1}$, respectively, for 1600 m (22). The inconsistency between these values and ACSM prediction formulas causes concern about the accuracy of these equations and how they compare with actual energy expenditures (1,12,20,22,27,33). Moreover, these estimations do not consider the potential differences in energy expenditure during track and treadmill exercise. These inconsistencies in calculation of energy expenditure create potential problems when prescribing exercise for weight loss.

The primary purpose of this study was to establish how well the published prediction equations for the energy expenditure of walking and running compare with the measured values. To accomplish this we reexamined whether differences exist in the energy expenditure of walking versus running 1600 m, and whether energy expenditure differences occur due to being on the track or treadmill, which could confound the estimation of energy expenditure. It was hypothesized that running 1600 m would result in a greater energy expenditure than walking, and a large discrepancy would be found between the measured value and values obtained from the prediction equations. We anticipated that the ACSM equation would be the best estimate of energy expenditure compared with the other tables or equations we found in the literature.

METHODS

Subjects. Male and female subjects (age range 18–30 yr) were recruited from the Syracuse University campus and the surrounding community. Before participation, all sub-

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jects signed an informed consent approved by the Syracuse University Institutional Review Board. All subjects were recreationally active with no orthopedic limitations, disease free, taking no medications affecting metabolism, and nonsmokers. Most importantly, all subjects had to be able to run and walk 1600 m on both the track and treadmill.

Experimental design and protocol. Each subject had a total of five visits. The first visit entailed an orientation of the study, informed consent acquisition, collection of initial demographics (i.e., height and weight), and the measurement of peak aerobic power ($\dot{V}O_{2peak}$). Visits 2–5 were randomized and included walking at 1.41 $m \cdot s^{-1}$ and running at 2.82 $m \cdot s^{-1}$ on both a treadmill and indoor track. These measurements were made on separate days.

$\dot{V}O_{2peak}$ testing. The $\dot{V}_{peak}$ test began with the subject walking at 1.41 $m \cdot s^{-1}$ at 0% grade. In 2-min stages, the speed of the treadmill was increased by 0.47 $m \cdot s^{-1}$ increments until 2.82 $m \cdot s^{-1}$ was achieved. Thereafter, the speed of 2.82 $m \cdot s^{-1}$ was held constant while the grade was increased in 2.5% increments every 2 min until volitional fatigue. Heart rate (HR) and Borg scale rating of perceived exertion (RPE) values were recorded during the last 20 s of each stage and at the very end of the test, when the subject reached exhaustion. $\dot{V}O_2$ values were recorded continuously via breath-by-breath sampling during the test using the Cosmed Quark b^2 metabolic cart (Rome, Italy). A $\dot{V}O_{2peak}$ test was accepted when at least three of the following criteria were satisfied: the RPE was greater than 17, the respiratory quotient (R-value) was greater than 1.10, HR approached age-predicted max and $\dot{V}O_2$ did not increase more than 150 mL with an increase in work load (1,22).

Study day. On a subsequent day, all subjects were instructed to refrain from eating for at least 3 h and refrain from caffeine at least 6 h before testing. The subjects were instructed to wear the same footwear each day, as well as shorts and T-shirts during testing. Although energy would be dissipated in the shoe cushioning, wearing the same sneakers should have limited the variability in energy expenditure lost in the dissipating substratum (14). All visits had a minimum of 24 h between visits to omit carry over effects on energy expenditure between protocols and the possible influence of fatigue.

For measurements on the track, an indoor 200-m track was utilized for walking and running. Before the test, the track was measured using a meter wheel to ensure the length of the track was exactly 200 m. An indoor track was selected to control for wind resistance changes (24,29,30) and to control the thermal environment (26). On the track, the aid of a stopwatch and track markings permitted regulation of running and walking speeds. Four cones divided the track into 50-m quarters. The time required to run or walk 50 m was calculated. Walking on the indoor track was at 1.41 $m \cdot s^{-1}$ (02:30 min per lap for 23 min; a 3-min warm-up followed by the 1600-m walk), while running on the track was at 2.82 $m \cdot s^{-1}$ (01:15 min per lap for 13 min; 3 min warm up followed by the 1600-m run). Verbal feedback to the subject to increase or decrease speed was employed to monitor speed at every track marking. Every effort was made to minimize pace variation.

For the treadmill exercise, a Quinton Instruments Treadmill (Q65 Series 90, Seattle, Washington) was selected for the 1600-m walk/run. The hard running surface of the treadmill aided in limiting energy dissipation (14,21). To induce convectional cooling as experienced during running or walking in track environments, a fan was placed to blow a minimum breeze on the subject during all treadmill testing. The treadmill was calibrated before each use to ensure the proper speed was maintained. According to pace calculation, 1.41 $m \cdot s^{-1}$ would require the duration of 20 min to complete 1600 m; and 2.82 $m \cdot s^{-1}$ would require the duration of 10 min to complete 1600 m. An additional 3 min were included to permit the subject to reach steady state before metabolic measurements.

Energy expenditure was measured by indirect calorimetry utilizing open circuit spirometry of the Cosmed K4 b^2 metabolic analyzer (Rome, Italy). The K4 b^2 analyzer has been validated in previous studies (16,23,28). The Cosmed system was calibrated using known gas concentrations for the gas analyzers. A calibration syringe (3 L) was used to calibrate the turbine, which is flow-rate independent. Before running or walking on the track or treadmill, the subjects rested quietly for 5 min without any measurements and then energy expenditure was measured for 3 min while the subject sat quietly in a chair. The day to day test-retest reliability for $\dot{V}O_{2max}$ and submaximal exercise testing in our lab is 0.96 and 0.90, respectively.

Body composition. Each subject underwent body composition analysis by air displacement plethysmography (BodPod, Concord, California). Subjects were asked to wear a bathing suit, a swim cap, and a nose clip. Procedures followed were according to the manufacturer's guidelines. Percent body fat and fat-free mass were calculated from body density using the subject's body weight divided by the volume of air displacement minus the measured anatomical lung volume. The day to day reliability for our system was 0.980 and the BodPod has been validated previously in the literature (34).

Data analysis. Energy expenditure was determined by converting the $\dot{V}O_2$ to kilojoules by assuming 1 mL of oxygen consumed produces 20.1 J of energy (7,13,19,20,31). Whole body oxygen consumption was measured using breath-by-breath $\dot{V}O_2$ and $\dot{V}CO_2$ and the respiratory exchange ratio was calculated from these values. Using this data, the Cosmed software calculates energy expenditure using the equations in Elia and Livesey (11). Total energy expenditure for 1600 m was the sum of the 1-min energy expenditure values for the duration of the exercise. In addition for comparison with a previous study (13), it was assumed that $\dot{V}O_2$ during exercise above resting values (sitting) was used for locomotion. The cost of locomotion was also calculated by subtracting the preexercise resting values multiplied by the total minutes of the exercise from the total energy expenditure. Energy expenditure was also calculated from the end of the 3-min window that was permitted for the subject to reach steady state to the end of the 1600-m walk/run.

Statistical analysis of the data. Descriptive statistics were used to analyze potential differences between gender using SPSS 10.0 for Windows. Differences in energy expenditure for 1600 m between intensities (walking or running) and mediums (treadmill or track) were performed for both genders using a two (intensity) by two (mode) by two (gender) analysis of variance (ANOVA) repeated measures design where significance was accepted at a preset $\alpha \leq 0.05$. In addition, fat-free mass was used as a covariate in the ANOVA model to adjust for gender differences. Only steady state data for the 1600-m run/walk were used in the analysis and are reported as means ± standard error. Pearson's bivariate correlations were applied to identify if a relationship existed between $\dot{V}O_2$ and anthropometric measures. A modified Bland–Altman plot (2) was performed to compare the measured results with those calculated from the prediction formula. We used a modified Bland–Altman plot because we had the actual energy expenditure measurement and were able to compare it with estimations of energy expenditure to determine their agreement. Power calculations were performed to determine the probability that a statistical difference was missed when no statistical difference was found. Values are presented as means ± SE.

Numerous equations have been used in the literature for the prediction of energy expenditure. We selected the following tables and equations because they were frequently cited in the literature. The ACSM equation was used because most exercise physiologists are familiar with the ACSM guidelines handbook (1). The McArdle tables for walking and running were employed because they are found in a commonly used teaching textbook (22) and they are frequently used by researchers in the field for estimation of energy expenditure. The other equations were selected because they had been cited in the literature and they provided additional estimates of both walking and running. The prediction formulas that were used are listed below:

ACSM (1):

Running. $\dot{V}O_2$ (mL·kg^{-1}·min^{-1}) = 0.2 (m·s^{-1}) + 0.9 (m·s^{-1}) (fractional grade) + 3.5

Walking. $\dot{V}O_2$ (mL·kg^{-1}·min^{-1}) = 0.1 (m·s^{-1}) + 1.8 (m·s^{-1}) (fractional grade) + 3.5

McArdle (22):

McArdle's tables are available in the referenced text.

Van der Walt (33):

Walking.

$\dot{V}O_2$ (L·min^{-1}) = 0.00599 M + 0.000366 MV^2

Running.

$\dot{V}O_2$ (L·min^{-1}) = −0.419 + 0.03257 M + 0.000117 MV^2

Pandolf (27):

W (J·s^{-1}) = 1.5 M + 2.0 (M + L)(L/M)^2 + n(M + L)[1.5V^2 + 0.35VG]

M = body mass (kg), L = load carried, V = velocity (m·s^{-1}), G = grade, and n is the terrain factor. For unloaded, level walking on a track or treadmill, the following formula is used: W (1 J·s^{-1}) = 1.5 W + 1.5V^{2}W

Léger (21):

$\dot{V}O_2$ (mL·kg^{-1}·min^{-1}) = 2.209 + 3.1633 (running speed in km·h^{-1})

Epstein (12):

Mr = Mw − 0.5 (1-0.01L) (Mw − 15L-850)

Mr = metabolic cost of running, Mw = metabolic cost of walking, L = clothing weight

In all equations, $\dot{V}O_2$ predictions were expressed in kilojoules (kJ).

RESULTS

Twenty-eight subjects (15 males and 13 females) were recruited for this investigation, with only 24 subjects (12 males and 12 females) meeting all the inclusion criteria. Subjects were excluded if their RER was above 1.0 while running 1600 m on the track or treadmill. The mean age of the women and men was 21.4 ± 1.1 yr and 23.2 ± 1.0 yr, respectively. The women were a mean height and weight of 1.69 ± 0.02 m and 63.9 ± 3.1 kg, and the men were 1.80 ± 0.02 m and 76.6 ± 3.0 kg, respectively. The women had a significantly higher percent body fat (23.7 ± 2.2%) and had a smaller fat-free mass (48.0 ± 1.5 kg) than was found in the men (11.6 ± 1.9% and 67.4 ± 2.3 kg, respectively, $P < 0.05$). The $\dot{V}O_{2peak}$ was significantly lower in the women (48.0 ± 1.5 mL·kg^{-1}·min^{-1}) than was observed in the men (53.0 ± 1.6 mL·kg^{-1}·min^{-1}, $P < 0.05$). The subjects ranged in BMI from 20.0 to 27.4 kg·m^{-2}.

Energy expenditure. Running elicited a significantly greater total energy expenditure than walking on both the treadmill and the track ($P < 0.001$) for both genders (Fig. 1a). On the treadmill, the males expended 520.6 ± 27.6 kJ for 1600 m; this was significantly higher ($P < 0.05$) than the energy expenditure by the females (441.1 ± 25.6 kJ). For the walk, the males expended 370.4 ± 17.7 kJ, and the females expended 309.6 ± 17.2 kJ for 1600 m ($P < 0.05$ between genders). When energy expenditure was adjusted for fat-free mass, the gender effect disappeared, but running

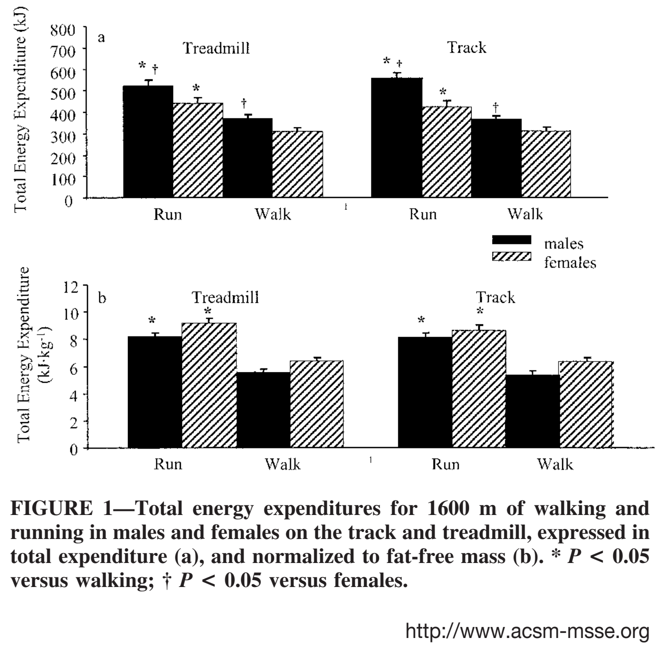

FIGURE 1—Total energy expenditures for 1600 m of walking and running in males and females on the track and treadmill, expressed in total expenditure (a), and normalized to fat-free mass (b). * $P < 0.05$ versus walking; † $P < 0.05$ versus females.

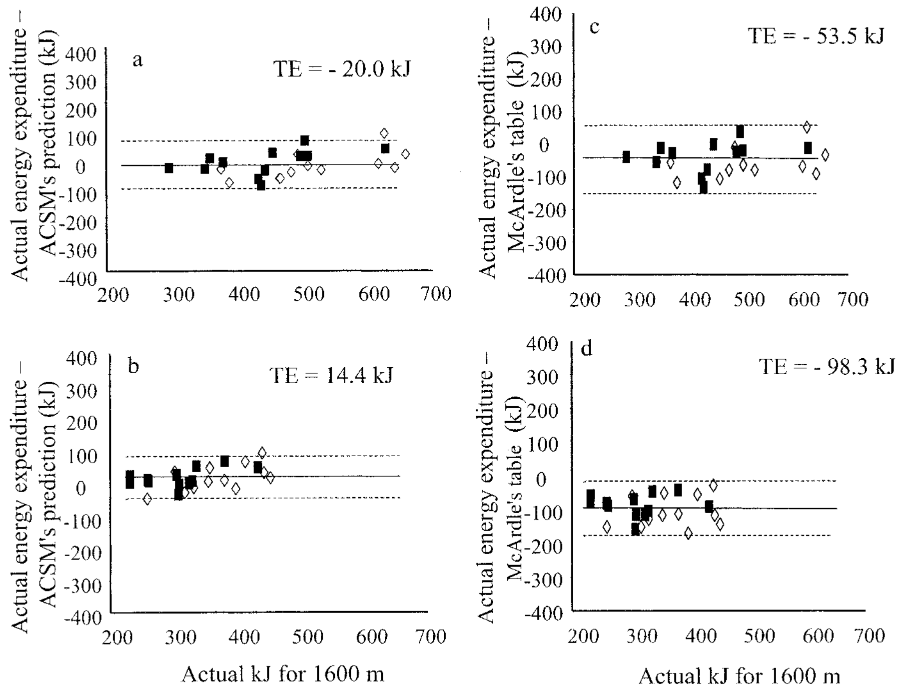

FIGURE 3—Comparison of difference between measured energy expenditure (kJ) and ACSM's prediction for energy expenditure for running (a) and walking (b) and McArdle's table for energy expenditure for running (c) and walking (d) 1600 m using the modified Bland–Altman technique. Males represented by open diamonds, and females by solid squares. Solid line is total error (TE) from zero, with ±2 SD (dashed lines). Figures 4 and 5 follow the same format.

exercise still required more energy than walking ($P < 0.01$; Fig. 1b).

In the previous literature, sitting metabolic rate was subtracted from the total energy expenditure to acquire energy expenditures for locomotion. Sitting energy expenditure was 8.5 ± 0.4 and 7.8 ± 0.4 kJ for men and women, respectively. After subtracting sitting energy expenditure from the total energy expenditure, running energy expenditure was still significantly greater than walking energy expenditure ($P < 0.001$) in both the men and women (treadmill: running males 437 ± 27 kJ, females 378 ± 23 kJ; walking males 216 ± 14 kJ, females 177 ± 10 kJ; track: running males 469 ± 24 kJ, females 347 ± 28 kJ; walking males 196 ± 20 kJ, females 164 ± 14 kJ).

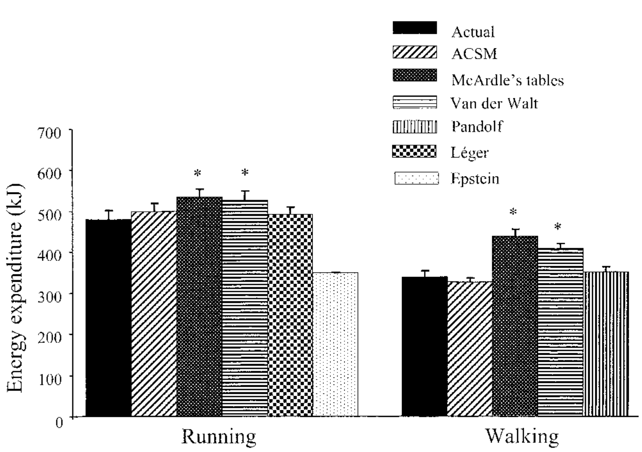

FIGURE 2—Actual total energy expenditure (solid) compared with energy expenditure predictions by ACSM (diagonal lines), McArdle (M) (dotted), van der Walt (horizontal lines), Léger (checkered), and Pandolf (vertical lines) for 1600 m. Values reported in means ± SE. * $P < 0.05$ between actual expenditures and predicted.

Of the 24 subjects, a subgroup of 17 subjects (10 females and 7 males) performed the run and walk on the track. Total energy expenditure during steady-state track running was significantly greater than track walking ($P < 0.05$), but no significant differences were found between the track and treadmill total energy expenditure. Adjusting energy expenditure for the sitting energy expenditure did not alter these findings. Gender differences occurred on the track as well as on the treadmill; these differences disappeared after adjusting for fat-free mass.

The predictions using the ACSM or Léger equations for running did not differ significantly from actual energy expenditures (Fig. 2). For walking, the actual energy expenditure was not significantly different than the ACSM or Pandolf prediction. However, both McArdle's table and van der Walt's prediction significantly overestimated ($P < 0.001$) energy expenditures for running and walking 1600 m for both genders (Fig. 2), whereas the Epstein equation underestimated the metabolic cost of running ($P < 0.01$). To ensure that we did not make a Type II error, power calculations comparing actual energy expenditures and the prediction equations were performed. When we found significant differences, the power approached 1.0. Where there were no significant differences, the power ranged from 0.11–0.35, indicating that considerably more subjects would have been required to produce a significant difference between actual and predicted energy expenditures. Hence, we are confident that the differences that we found are real.

Figures 3–5 show the modified Bland–Altman plots for the actual energy expenditure versus prediction models available in the literature. The mean (solid line) ± 2 SD ranges (dashed lines) for the entire group are shown in each figure. When the ACSM's prediction model was compared

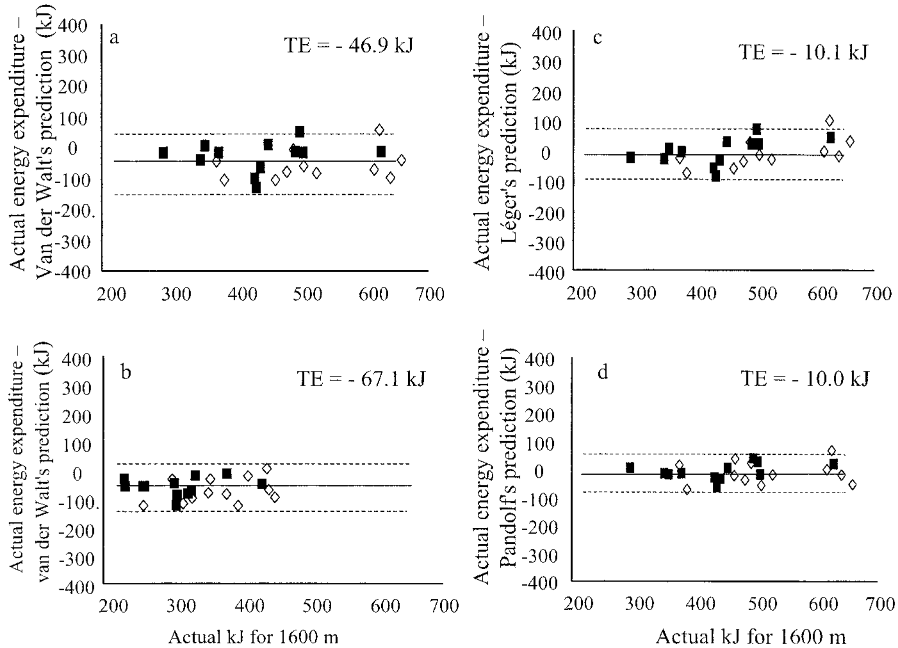

FIGURE 4—Comparison of difference between measured energy expenditures (kJ) and van der Walt's energy expenditure prediction for running (a) and walking (b) and Léger's energy expenditure prediction for running 1600 m (c) and Pandolf's energy expenditure prediction for walking 1600 m (d) using the modified Bland–Altman technique.

with the measured value (Fig. 3a), a TE of −20.0 kJ was observed with 95% confidence intervals (±2 SD) of ±92.1 kJ for running, and a TE of 14.4 kJ was observed with 95% confidence intervals of ±68.7 kJ while walking (Fig. 3b). The McArdle tables, compared with actual energy expenditure for running and walking, had a TE of −53.5 kJ with 95% confidence intervals of ±95.3 kJ for running (Fig. 3c) and a TE of −98.3 kJ with 95% confidence intervals of ±81.1 kJ for walking (Fig. 3d). When comparing actual energy expenditures against van der Walt's prediction model, a TE of −46.9 kJ with 95% confidence intervals of ±100.4 kJ was observed for running (Fig. 4a), and a TE of −67.1 kJ with 95% confidence intervals of ±74.5 kJ was found for walking (Fig. 4b). In Figure 4c, the comparison with Léger's prediction for running energy expenditures resulted in a TE of −10.1 kJ with 95% confidence intervals at ±92.1 kJ. Pandolf's prediction model for walking energy expenditures noted a TE of −10.0 kJ with a ±69.3 kJ 95% confidence interval (Fig. 4d). Lastly, when the Epstein prediction model was compared with the measured value (Fig. 5), a TE of 135.5 kJ was observed with 95% confidence intervals of ±167 kJ for running.

A significant ($P < 0.001$) inverse relationship between $\dot{V}O_{2peak}$ and percent fat was observed (r = −0.75), as well as between $\dot{V}O_{2peak}$ and total energy expenditures adjusted for fat-free mass ($P < 0.01$) for running and walking (track: r = −0.65, r = −0.64; treadmill: r = −0.57, r = −0.69, respectively). Thus, the more fit individuals used less energy per unit of fat-free mass for 1600 m than the less fit. Moderately strong correlations ranging from 0.71 to 0.83 ($P < 0.01$) were found between percent body fat and energy expenditures normalized for body weight for both the track and treadmill.

DISCUSSION

In the development of exercise prescription, knowing the actual energy expenditure of the prescribed activity is essential, particularly in weight loss programs. The ACSM guidelines (1), as well as numerous well-published equations, exist. These guidelines and equations allow for the prediction of walking or running, but how they compare with actual measures has seldom been analyzed. Our findings show that the total energy expenditure for running 1600 m was ~30% higher than walking the same distance, regardless of gender. When resting energy expenditure was subtracted from the total energy expenditure, as has been done in earlier studies (21), the cost of locomotion was ~55% lower for males during walking than running, and ~52% lower for females. Similarly Farley et al. (13) observed greater energy expenditures for running compared with walking, and this occurred whether they were in normal or reduced gravity conditions. Our findings disagree with those of Kram et al. (19), who reported that running

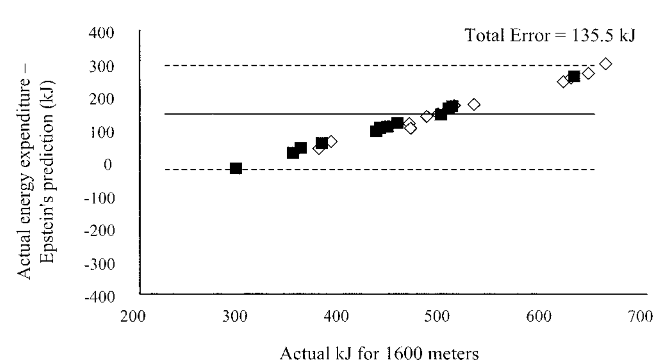

FIGURE 5—Comparison of difference between measured energy expenditures (kJ) and Epstein's energy expenditure prediction for running 1600 m using the modified Bland–Altman technique.

and walking 1600 m require the same amount of energy; such a finding would agree with the theoretical physics calculations.

Frequently, it is observed that women have a greater difficulty than men in losing weight when in a walking or running program. This difficulty could possibly be due to the lower energy expenditure for walking and running than we observed in women. In this study, the gender differences observed between walking and running 1600 m were attributed to the significantly larger metabolically active tissue (fat-free mass) found in the male population. By adjusting for metabolically active tissue, gender differences disappeared, and the energy cost of running was 8.4 kJ per unit of fat-free mass, and for walking was 5.9 kJ per unit of fat-free mass for both genders.

We also hypothesized that an energy expenditure difference between the track and treadmill when walking or running would not be observed when factors such as wind influence were controlled. Our findings agree with this hypothesis; as we noted, there was no difference between the energy expenditure on the track and the treadmill. This is consistent with McMiken et al. (24), who noted that submaximal exercise on the track and treadmill elicited the same physiological responses when running at low to moderate speeds. Although we found no difference at 2.82 $m \cdot s^{-1}$, their research indicates that running at higher speeds might potentially cause wind resistance to influence energy expenditures (24). Pugh et al. (29,30) have reported that running at speeds above 4.0 $m \cdot s^{-1}$ (8.44 $miles \cdot h^{-1}$) can result in an increase in energy expenditure up to 16% because of the energy cost of overcoming wind resistance. In the present study we specifically chose a speed below 4.0 $m \cdot s^{-1}$ to minimize or eliminate potential influences of wind resistance. Furthermore, this is one of the first studies comparing track and treadmill exercise at submaximal intensities using the portable unit (Cosmed K4 b^2), and not the more cumbersome Douglas bags (24,29,30). More recent work (8) has used the portable K4 b^2, investigating maximal physiological responses on the track and treadmill, and reporting no significant differences between the two surfaces. We have now also demonstrated that no differences occur between track and treadmill measurements during submaximal exercise.

One of the primary purposes of this study was to compare the actual energy expenditures of walking and running with the energy expenditure calculated through predictions equations. In many research and clinical settings, actual energy expenditure methods cannot be utilized, resulting in reliance on prediction equations. To address this issue, we compared our actual measures against formulas or tables frequently cited in the literature or used in clinical practice (the ACSM prediction formula (1), McArdle tables (22), van der Walt prediction formula (33), Epstein (12) and Léger (20) prediction models for running, and Pandolf prediction formula for walking (27)). We observed that the ACSM formula overestimated the average energy expenditure in steady-state running of 1600 m by only 4.3% (21kJ), and underestimated energy expenditure by only 3.8% (13 kJ) for 1600 m. The total error of this overestimation was −20.0 kJ for running energy expenditures, and there was a 14.4-kJ underestimation of walking energy expenditures. Similarly, the equation by Léger overestimated by 2% (−10.1 kJ), and Pandolf overestimated by 2.8% (−10.0 kJ); these differences were minimal.

Unlike the above equations, the McArdle tables revealed an 11% overestimation (−54.5 kJ) for running and a 30% overestimation (−98.3 kJ) for walking. Similarly, van der Walt's prediction model overestimated running energy expenditures by 10.4% (−46.9 kJ) and 19.7% (−67.1 kJ) for walking. Again, this overestimation was evenly distributed across the ranges of energy expenditures for both genders for the tables and prediction model. The Epstein equation was the only equation that substantially underestimated the energy expenditure of running, and did so by the largest margin of error. In fact, this underestimation occurred in a linear fashion, such that at higher energy expenditures, a greater underestimation occurred. The reason for the larger discrepancy with this equation is unclear to us. Thus, caution is recommended when using these tables and prediction models to estimate walking and running energy expenditure. The error may not seem substantial for a single exercise bout, but if these equations were used as part of a weight loss program, this error would be magnified with daily exercise, such that weekly energy expenditure values would be significantly in error.

Closer examination of the Bland–Altman plots reveals that there are larger limits of agreement for running than for walking. Although total errors vary considerably between prediction models, during running it is much more difficult to predict energy expenditures for a 1600-m run than a 1600-m walk.

It was initially hypothesized that a significant inverse correlation between $\dot{V}O_{2peak}$ and the total energy expenditure difference between walking and running 1600 m would be found. Our results did not support this hypothesis; however, the finding of a significant Pearson correlation between $\dot{V}O_{2peak}$ and energy expenditures normalized to fat-free mass may have two separate explanations. First, it can be hypothesized that the more fit individuals are simply more economical than unfit individuals. This would be consistent with previous studies suggesting that trained individuals optimize locomotion to minimize energy expenditure from the biochemistry of muscle tissue to gait economy (4–6,9,10,25). Second, the metabolically active tissue working during the run/walk has to carry nonmetabolically active tissue (i.e., adipose tissue). Hence, the individual with a lower percent body fat is carrying less excess weight, and therefore consumes less energy per unit of fat-free mass; thus, they are more economical. When expressing this finding in terms of carrying external workloads, the addition of weight to walking or running has been shown to increase energy expenditure in the literature (13,27). From this, one could propose that body composition might help explain why males have been found to have better economies than females (10,17). When normalized to fat-free mass, the gender difference disappeared. Hence, the less economical running energy expenditures found in females might be explained by the fact that females are traditionally less lean than males, and must carry more adipose tissue than males.

Although theoretically walking and running a mile should require the same work (5), running required more energy than walking for 1600 m, regardless of whether the subject was on the track or the treadmill. Comparison of the actual energy expenditure with prediction equations reveals that the ACSM and Léger's prediction model for horizontal running are more accurate in a young healthy population. For horizontal walking, ACSM and Pandolf's prediction models also appear more accurate than the other equations evaluated.

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