Intensity and energy cost of weighted walking vs. running for men and women

JAMES F. MILLER AND BRYANT A. STAMFORD
Exercise Physiology Laboratory, Division of Allied Health, School of Medicine, University of Louisville, Louisville, Kentucky 40292

Miller, James F., and Bryant A. Stamford. Intensity and energy cost of weighted walking vs. running for men and women. J. Appl. Physiol. 62(4): 1497-1501, 1987.—The energy cost and intensity of exercise performed at 0% grade were determined for walking at 2, 3, and 4 mph, running at 5, 6, and 7 mph, and walking at 2, 3, and 4 mph with ankle and/or hand weights. Subjects were young moderately trained males (4) and females (3). The energy cost per kilogram of body weight was similar between sexes, and data were combined for among-treatment comparisons. Intensity of effort and energy cost per minute and per mile were increased when weight was added during walking and were increased more with hand weights compared with ankle weights regardless of speed. The average increase in O2 uptake (ml·kg⁻¹·min⁻¹·100 g⁻¹ of added wt) was 0.8% for ankle, 1.3% for hand, and 0.9% for ankle and hand weights. Gross energy cost per mile during weighted walking (120-158 kcal/mile) was comparable to and in some cases exceeded that of running which was independent of speed (120-130 kcal/mile). During nonweighted walking, the energy cost (kcal/mile) was significantly greater at 4 mph compared with 2 and 3 mph which did not differ. The intensity of walking at 4 mph with ankle and hand weights was comparable to running at 5 mph.

PREVIOUS INVESTIGATIONS pertinent to weighted walking have examined the intensity of effort and metabolic cost of load carriage from the military ergonomics point of view; i.e., relatively heavy loads have been distributed over the body to determine the most efficient means of transport (7, 13, 20). Weight added to the ankles has been shown to increase the energy cost of walking more than weight added to the torso or carried in the hands (13, 20). A 90° bend at the elbows combined with the natural arm movements associated with walking may increase the energy cost of hand loading to levels comparable to or exceeding ankle loading. This proposition was tested in the present investigation. Weights were carried in the hands and/or ankle weights; indirect calorimetry, body composition

MATERIALS AND METHODS

Seven (four male, three female) healthy, nonsmoking college students signed informed consent documents approved by the Human Subjects Committee of the School of Medicine, University of Louisville and volunteered as subjects. All regularly participated in recreational sports such as raquetball, softball, weight training, and five of the seven jogged at least twice weekly. Maximal O2 (V̇O₂ max) was above average for both males and females but well below levels associated with endurance athletes. The average age of males was 23 ± 4.5 yr and females 24.6 ± 4.3 yr. The average height and weight was 184.5 ± 7.9 cm and 79.9 ± 18.6 kg, respectively, for males and 163.2 ± 1.6 cm and 62.7 ± 4.2 kg, respectively, for females. Percent body fat was 8.5 ± 7.3% for males and 17.8 ± 7.5% for females. V̇O₂ max (expressed in ml·kg⁻¹·min⁻¹) was 51 ± 10 for males and 41 ± 9 for females, and maximal heart rate was 194 ± 14 beats/min for males and 190 ± 5 beats/min for females. Each subject participated in two preliminary sessions designed to acquaint them with walking and running on a motorized treadmill at a variety of speeds and the use of hand and/or ankle weights while walking. In a third session, percent body fat was determined via the hydrostatic weighing technique. During the fourth session, each subject performed an intermittent treadmill test, 7 mph running against a progressively increasing grade, for determination of V̇O₂ max (21). A plateau in O2 consumption despite further increases in treadmill elevation served as documentation for V̇O₂ max. The test was repeated if necessary to achieve a plateau. The highest heart rate recorded during the V̇O₂ max test was considered the HR max.

The remaining five sessions were randomly assigned and entailed walking speeds of 2 mph (0.89 m/s), 3 mph (1.34 m/s), or 4 mph (1.79 m/s) and running speeds of 5 mph (2.24 m/s), 6 mph (2.68 m/s), or 7 mph (3.13 m/s). Four sessions entailed 1) walking at 2, 3, or 4 mph; 2) walking at 2, 3, or 4 mph with ankle weights; 3) walking at 2, 3, or 4 mph carrying hand weights; and 4) walking
at 2, 3, or 4 mph with both ankle and hand weights. The fifth session required running at 5, 6, or 7 mph. All sessions were performed at 0% grade. Exercise was performed in 10-min bouts followed by a minimal 10-min rest period with subjects seated. Less demanding exercise always preceded more demanding exercise to minimize carryover effects. The laboratory environment was thermoneutral (21-23°C, 40-50% humidity) and subjects wore only gym shorts (and tank tops for females). A fan blowing directly on subjects during exercise and rest between bouts enhanced convective cooling.

Commercially available Heavy Hands weighing 2.25 kg each were carried with a 90° bend at the elbow. Subjects were instructed to swing the arms from the shoulder in synchrony (counterbalance) with hip movements as would normally occur, and the hand weights moved in an arc from approximately the umbilicus to the sternoclavicular joint. Straightening the arms briefly was permitted each minute to relax arm muscles and reduce localized fatigue. Commercially available ankle weights weighing 2.25 kg each were snugly fastened at malleolus level with Velcro straps.

Expired gas was collected in meteorological balloons and the average O2 uptake (\(V_O^2\)) during the final 4 min was used when making comparisons among treatments. Standard open-circuit spirometry techniques were utilized and fraction of expired O2 was assessed by means of an Applied Electrochemistry S-3A O2 analyzer and fraction of expired CO2 was assessed by means of a Beckman LB-2 CO2 analyzer. Analyzers were calibrated before each exercise bout with gas mixtures prepared in our laboratory (±0.03%) which were verified at regular intervals using gravimetric standards (±0.001%). Gas volumes were measured in a Tissot gasometer and corrected to STPD. The respiratory exchange ratio was used to compute the caloric equivalent per liter of O2 consumed. Heart rate was monitored continuously from an electrocardiograph. Body composition was measured with the hydrostatic weighing technique (12), and residual volume was determined according to the method of Wilmore (22).

Data pertinent to the energy cost per unit body weight (kcal·kg\(^{-1} \cdot \text{min}^{-1}\)) and \(V_O^2\) were statistically analyzed with a two-way repeated measures analysis of variance (sex, treatment). Because there were no differences between sexes per kilogram of body weight, data were combined for subsequent analyses. A two-way (speed, load) repeated measures analysis of variance was applied to each variable associated with walking. To determine statistical differences among all treatments for each variable, a one-way repeated measures analysis of variance was employed. When significant differences were found, post hoc comparisons were assessed with the Newman-Keuls procedure. In all cases, differences were considered statistically significant if \(P < 0.05\).

RESULTS

The caloric cost for males vs. females (expressed as kcal·kg\(^{-1} \cdot \text{min}^{-1}\)) is presented in Fig. 1. The caloric cost was similar for both sexes across all treatments and data were combined for subsequent analyses.

![FIG. 1. Energy cost for males (squares) and females (circles) during nonweighted and weighted [ankle (A) and/or hand (H)] walking at 2, 3, and 4 mph and running at 5, 6, and 7 mph.](image)

In Fig. 2 the gross caloric cost is reported as kilocalories per minute. As expected, the caloric cost was increased by increases in locomotor speed. When weights were added during walking at 2, 3, or 4 mph, imposing ankle and hand weights at the same time was significantly more costly than ankle or hand weights alone, and walking with hand weights was significantly more costly than walking with ankle weights. The caloric cost of walking with ankle and hand weights at the same time at 4 mph was similar to running at 5 mph without weights.

The addition of ankle weights increased the caloric cost above nonweighted walking to a similar degree regardless of speed (Fig. 3). The same was true when adding hand weights. However, when imposing both ankle and hand weights at the same time, there was a significant difference between the change in caloric costs at 2 and 4 mph.

Figure 4 contains gross kilocalories per mile data and reveals that the caloric cost for running at 5, 6, or 7 mph was significantly greater than walking at 2, 3, or 4 mph without weights. When walking without weights, the caloric cost per mile was significantly greater during
brisk walking at 4 mph compared with walking at 2 or 3 mph which did not differ. The caloric cost of walking at 2 or 4 mph with ankle and hand weights at the same time was significantly greater than the cost of running at speeds of 5, 6, or 7 mph. Because the difference in caloric cost per minute of walking with ankle and hand weights at the same time at 2 vs. 3 mph was not great, ~5.4 vs. 7.0 kcal/min, respectively, the extended time required to complete 1 mile at 2 mph (30 min) resulted in a greater (not significant) per mile caloric cost than that at 3 mph. This explains the seemingly unusual finding. The caloric cost of running per mile appeared to be independent of speed.

Figure 5 contains the heart rate (HR), \( \dot{V}O_2 \), and \%\( V_{O2\text{ max}} \) data for various speeds of walking with and without weights and running. The intensity of exercise during walking without weights is relatively low compared with jogging. In fact, there is a considerable gap in intensity between walking at 4 mph without weights and jogging at 5 mph. Adding ankle and hand weights at the same time during brisk walking at 4 mph increased the intensity of exercise to a level comparable to running at 5 mph.

In Table 1 the percent increase in \( \dot{V}O_2/100 \text{ g of wt added} \) during walking is averaged across speeds. The addition of a combined ankle weight of 4,500 g resulted in an average increase of 0.8%/100 g added. The addition of a combined hand weight of 4,500 g resulted in an average increase of 1.3%/100 g added. The addition of a combined ankle and hand weight of 9,000 g resulted in an average increase of 0.9%/100 g added.

**DISCUSSION**

Previous investigations provide conflicting results and indicate that the energy cost of walking is lower for women than men (1, 16), higher for women than men (2, 8), or there are no differences between sexes when energy cost is expressed per kilogram of body weight (5, 6). Our findings agree with the latter. It is possible that the discrepancy among reports could be due to the training, athletic status, and body composition of female participants. In the present study, female subjects were relatively well trained and athletic, and the mean percent body fatness (17.8%) for females was comparable to that for the males in many previous investigations.

When walking at 4 mph without weights, the energy cost was ~100 kcal/mile, whereas at 2 or 3 mph the cost was reduced to ~70–80 kcal/mile. This indicates that the speed of walking is an important consideration when attempting to estimate the caloric cost per mile. Running increased energy cost to ~120 130 kcal/mile and appeared to be independent of speed. This has been reported previously (14, 19).

The use of ankle weights during walking was not as demanding as the use of hand weights. In previous load carriage studies in which weights were carried by hand, the arms were extended and weights were carried closer...
to the center of gravity and there was little movement at the shoulders (13, 20). In the present study, arm movement was vigorous but not excessive. Subjects did not indicate unpleasantness or arm fatigue during walking with hand weights. The distance of the hand weights from the center of gravity, holding weights with a 90° bend at the elbow, and/or the length of the movement arc may be the key factors that contribute to increased energy expenditure.

The addition of ankle weights increased energy expenditure above that of nonweighted walking to the same degree regardless of the speed of walking at 2, 3, or 4 mph (Fig. 3). The same was true for hand weights. When both hand and ankle weights were imposed at the same time, the increase in cost was similar at 2 and 3 mph, but at 4 mph the increase was much greater. The increase during 4 mph (ankle and hand) was essentially the same as the combined individual increments associated with using ankle or hand weights separately while walking at 4 mph. At 2 or 3 mph the sum of the individual increments with ankle or hand loading imposed separately was greater than the cost of walking with both ankle and hand weights at the same time (Fig. 3). This suggests that at a brisk walking speed of 4 mph the full impact of simultaneous ankle and hand loading is realized, whereas at slower walking speeds compensations may occur which reduce the cost.

Previous studies concerning the energy cost of adding weight to the feet or ankles during walking and running indicate an average increase of 0.7–1.0% in \( V_O_2/100 \) g of wt added for men (4, 10, 15) and women (9). These studies entailed comparisons of the effects of shoes vs. boots which ranged in weight from \( \sim 520 \) to \( 1,371 \) g/pair. In the present study, ankle weights added \( 4,500 \) g. The percent increase in \( V_O_2/100 \) g added wt of \( 0.8\% \) (Table 1) agrees very well with these previous studies and indicates that the degree of increase in \( V_O_2/\)unit of wt added to the feet or ankles is consistent over a wide range.

The addition of hand weights (4,500 g) resulted in a higher percent increase in \( V_O_2/100 \) g added wt of 1.3% (Table 1). This is possibly due to vigorous movements at the shoulder joint and the static forces required to sustain a 90° bend at the elbow. When both ankle and hand weights were added (9,000 g), the percent increase per 100 g was 0.9%, which agrees very well with previous studies (4, 9, 10, 15). It is possible that the movement arc of the arms during walking with both ankle and hand weights at the same time was reduced somewhat compared with carrying hand weights alone. The investigators closely monitored the 90° bend at the elbow, and the weights were not permitted to fall below the umbilicus. However, the peak height of the arc, the sternoclavicular joint, was not as closely monitored and therefore subjects could have reduced the length of the arc as a means to conserve energy. Future studies need to more closely standardize arm movements. There is also the need to examine the influence of altering the length of the movement arc with respect to energy cost.

Discussions of the relative benefits of walking vs. running as daily exercise often focus on the energy costs per mile. On the one hand, it has been suggested that because a given mass is moved a given distance, the caloric expenditure should be the same. This assumes an identical mechanical and physiological efficiency associated with walking and running. In the present study, running expended significantly more calories per mile than nonweighted walking, and brisk walking at 4 mph was significantly more costly than walking at 2 or 3 mph. Adding weights (ankle and hand) during walking increased the energy cost per mile to levels which exceeded running. This could be important to weight watchers because even a mild walk at 2 mph with hand and ankle weights employed at the same time could result in a caloric expenditure of more than 300 kcal/h. At 3 mph the cost is increased to 420 kcal/h, and at 4 mph the cost is 640 kcal/h.

The risk of leg injury during weighted walking compared with running may be less because there is no airborne phase in walking. However, an increased risk of elbow tendinitis (tennis elbow) is likely when using hand weights. Weighted walking must be investigated further in longitudinal training studies before it is touted as a positive alternative to running.

To improve cardiorespiratory fitness there is the need to elevate HR to at least 60% of the heart rate reserve (HRmax - rest x 60% + HR rest) (11). In the present investigation 60% of the heart rate reserve equated to \( \sim 144 \) beats/min. This HR (144 beats/min) also equated to 75% HRmax. Running at 5, 6, or 7 mph easily exceeded this threshold (Fig. 5). Walking with hand weights at 4 mph and walking at 4 mph with both ankle and hand weights at the same time exceeded the threshold as well. This suggests that weighted walking may provide sufficient intensity to increase cardiorespiratory fitness in some populations and particularly in the poorly fit. This must be submitted to testing before conclusions are drawn. There is, however, some evidence in the literature which suggests that in poorly fit adults, prolonged mild walking with ankle weights modestly increased cardiorespiratory fitness (3, 17). Also, the classic study of Pollock et al. (18) reported that a program of brisk walking increased cardiovascular function in middle-aged men.

In summary, the energy cost of walking, weighted walking, or running at various speeds was similar for males and females when reported per kilogram of body weight. Nonweighted walking at 4 mph was significantly more costly (kcal/mile) than walking at 2 or 3 mph, whereas the caloric cost of running (kcal/mile) was independent of speed. The degree of increase in \( V_O_2/100 \) g of added wt to the ankles appears to be consistent over a wide range of weights up to and including 4,500 g. Carrying hand weights increased the energy cost and intensity of effort to a greater degree during walking than wearing ankle weights. The gross energy cost per mile of weighted walking compared favorably with the energy cost of running.

This study was supported in part by the Graduate Research Council of the University of Louisville and Contract 1984-1 from the City of Louisville, Civil Service Board.

Received 17 March 1986; accepted in final form 11 November 1986.
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