Effects of obesity and sex on the energetic cost and preferred speed of walking

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Browning, Raymond C., Emily A. Baker, Jessica A. Herron, and Rodger Kram. Effects of obesity and sex on the energetic cost and preferred speed of walking. J Appl Physiol 100: 390–398, 2006. First published October 6, 2005; doi:10.1152/japplphysiol.00767.2005.—The metabolic energy cost of walking is determined, to a large degree, by body mass, but it is not clear how body composition and mass distribution influence this cost. We tested the hypothesis that walking would be more expensive for obese women compared with obese men and normal-weight women and men. Furthermore, we hypothesized that for all groups, preferred walking speed would correspond to the speed that minimized the gross energy cost per distance. We measured body composition, maximal oxygen consumption, and preferred walking speed of 39 (19 class II obese, 20 normal weight) women and men. We also measured oxygen consumption and carbon dioxide production while the subjects walked on a level treadmill at six speeds (0.50–1.75 m/s). Both obesity and sex affected the net metabolic rate (W/kg) of walking. Net metabolic rates of obese subjects were only ~10% greater (per kg) than for normal-weight subjects, and net metabolic rates for women were ~10% greater than for men. The increase in net metabolic rate at faster walking speeds was greatest in obese women compared with the other groups. Preferred walking speed was not different across groups (1.42 m/s) and was near the speed that minimized gross energy cost per distance. Surprisingly, mass distribution (thigh mass/body mass) was not related to net metabolic rate, but body composition (% fat) was ($r^2 = 0.43$). Detailed biomechanical studies of walking are needed to investigate whether obese individuals adopt novel energy saving mechanisms during walking.

Walking is a popular and convenient form of exercise that can play an important role in weight management (24, 26). Effective weight management requires an accurate knowledge of how much metabolic energy is expended during exercise. Obese individuals expend much more metabolic energy during walking than normal-weight individuals (3, 16, 18, 31, 32). However, the energy expended across walking speeds has only recently been established for obese female adults (6, 31, 32), and it is not well understood for obese men. One might predict that walking would be more expensive for obese women because women carry more of their body fat in the hips and thighs (gynoid adiposity) than men (android adiposity) (4). However, it is not known whether the energy expenditure during walking is different for obese women vs. obese men and whether any difference is due to the distribution of adipose tissue. It seems logical to expect that the net metabolic cost of walking is affected by the distribution of adipose tissue. Experiments on normal-weight individuals show that walking is more expensive when mass is placed on the thighs or lower legs compared with waist loads (41). This increase in net metabolic rate is partly due to the increase in mechanical work required to swing legs that have a greater mass and moment of inertia (38). Women may have relatively heavier legs (thigh mass/body mass) than men due to differences in the distribution of body fat (4), which might result in a greater net metabolic rate. Dual-energy X-ray absorptiometry (DEXA) provides a means of accurately determining leg segment masses and moments of inertia (13), but no leg mass or moment of inertia data have been reported for obese individuals.

Even among normal-weight individuals, sex may affect the net metabolic rate measured during walking. Normal-weight women and men have similar gross energy expenditures during walking (41). However, normal-weight women have smaller standing metabolic rates (per kg body weight) than normal-weight men (37) because of their smaller lean body mass (greater body fat percent) (7). The similar gross and smaller standing metabolic rates of normal-weight women would presumably result in a greater net metabolic rate than normal-weight men during walking.

In normal-weight adults, the gross energy consumed per unit distance vs. walking speed relationship is U-shaped (30, 35). The minimum energy cost required to walk a given distance occurs at ~1.4 m/s (~5 km/h or 3 miles/h) (30, 34, 43), which is also the preferred walking speed of normal-weight adults (37). Class II obese adults prefer to walk more slowly than...
normal-weight adults (1.2 vs. 1.4 m/s) in some studies (31, 32),
but our recent study found no difference between young class
II obese and normal-weight women (6). Although we reported
that young obese women walked slightly faster (1.4 m/s) than
the speed that minimized gross energy cost/distance (1.25 m/s),
it is important to note that the difference in energy cost
between the preferred and energetic minimum speed was small
(~3%). Our study suggests that obese adults prefer a walking
speed that approximately minimizes the energy cost per
distance and that moderate obesity does not affect the gross
energy cost per distance metabolic rate vs. walking speed
relationship (6, 37). Therefore, we would expect that preferred
walking speeds would be similar between class II obese and
normal-weight women and men.

The primary purpose of this study was to compare the
metabolic rates, energy cost per distance of walking vs. speed
relationships, and the preferred walking speed for class II
obese vs. normal-weight women and men. A secondary pur-
pose of this study was to determine the effects of adipose tissue
distribution on the metabolic cost of walking.

We hypothesized the following. 1) The net metabolic cost of
walking is greatest (per kg total body mass) for obese women,
less for obese men and normal-weight women, and least for
normal-weight men. 2) The greater net metabolic cost of
walking for the obese women is due, in part, to the greater
relative mass and moment of inertia of their legs compared
with the obese men and normal-weight women and men. 3) Preferred walking speed corresponds to the speed that mini-
mizes the gross energy cost per distance for obese and normal-
weight adults of both sexes.

METHODS

The experimental protocol as well as the methods used to deter-
mine metabolic rate and preferred walking speed have been described
in detail in Browning and Kram (6) and will be described only briefly
here.

Subjects

Four groups of young adults volunteered for this study: class II
obese women (n = 9), class II obese men (n = 10), normal-weight
women (n = 10), and normal-weight men (n = 10). BMI was used to
classify the participants; obese subjects had BMI values of 30–40
kg/m², and normal-weight subjects had BMI values of <25 kg/m².
The female subjects were part of an earlier study (6). All subjects were
in good health, not taking medications known to influence metabo-
lism, sedentary to moderately physically active (27). More
than 90 min of moderate or vigorous activity per week was an
exclusion criterion.

Table 1. Physical characteristics of obese and normal-weight women and men

<table>
<thead>
<tr>
<th>Physical Characteristic</th>
<th>Women</th>
<th></th>
<th></th>
<th>Men</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Obese (n = 9)</td>
<td>Normal (n = 10)</td>
<td>Obese (n = 10)</td>
<td>Normal (n = 10)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>33.8 (3.3)</td>
<td>20.4 (2.1)</td>
<td>33.5 (2.1)</td>
<td>22.3 (1.9)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Body mass, kg</td>
<td>94.8 (15.7)</td>
<td>58.7 (9.5)</td>
<td>104.7 (10.2)</td>
<td>74.7 (7.1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height, m</td>
<td>1.67 (0.07)</td>
<td>1.68 (0.06)</td>
<td>1.76 (0.08)</td>
<td>1.82 (0.03)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age, yr</td>
<td>25.3 (7.3)</td>
<td>26.6 (5.5)</td>
<td>25.6 (7.0)</td>
<td>20.6 (1.3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Waist-to-hip ratio</td>
<td>0.82 (0.08)*</td>
<td>0.73 (0.04)</td>
<td>0.95 (0.06)*</td>
<td>0.80 (0.04)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percent body fat, %</td>
<td>45.5 (2.3)*</td>
<td>27.8 (6.2)</td>
<td>34.5 (4.1)*</td>
<td>16.2 (4.2)*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lean body mass, kg</td>
<td>51.6 (8.5)*</td>
<td>42.1 (5.9)</td>
<td>67.5 (6.4)*</td>
<td>62.6 (6.1)*</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Values are means (SD); n, no. of subjects. *P < 0.05, obese vs. normal-weight of that sex. †P < 0.05, women vs. men of that group (obese or normal weight). BMI, body mass index.

Subjects gave written, informed consent to this study that followed the
guidelines of the University of Colorado Human Research Committee.

The physical characteristics of the groups were significantly dif-
ferent and are shown in Table 1. The obese groups had a greater body
mass, waist-to-hip ratios, BMI, and percent body fat than the normal-
weight groups. In addition to differences in fat mass, lean body mass
was greater in the obese women compared with normal-weight
women, but the difference in lean body mass between the male groups
was not significant. The men were taller and had a smaller percent
body fat than their female counterparts.

Experimental Protocol

Each subject completed three test sessions. In the first session,
12-h-fasted subjects underwent a physical examination, blood draw
and analysis, and body composition measurement. The second session
included treadmill familiarization (Track Master 425, Newton, KS)
and a maximal oxygen uptake (VO2 max) test. In the third session, we
measured each subject’s preferred overground walking speed and then
their metabolic cost during six level treadmill walking trials. The trials
began after 5 min of quiet standing on the treadmill, and speeds were
0.50, 0.75, 1.00, 1.25, 1.50, and 1.75 m/s, with 5 min of rest between
trials. Trial order progressed from the slowest to the fastest speed.

Assessments

Physical health and activity. Each subject’s health and physical
activity level were assessed by physical examination and interview.
Resting heart rate and blood pressure were recorded, and resting levels
of glucose, thyroid-stimulating hormone, and blood cell counts and
profiles were determined and confirmed to be within normal ranges.
Subjects completed a physical activity-level questionnaire (27). More
than 90 min of moderate or vigorous activity per week was an
exclusion criterion.

Body and segment measurements and composition. Measuring each
subject’s waist circumference at the level of the umbilicus and hip
circumference at the widest point between the hips and buttocks
yielded the waist-to-hip ratio (4). We measured each subject’s body
composition using a whole body DEXA scanner (DPX-IQ, Lunar,
Madison, WI). The DEXA scan measured fat mass, lean tissue mass,
and bone mineral content of the total body and of the trunk, arm, and
leg regions. The DEXA software allowed us to identify and digitize
the thigh and shank segments lengths and cross-sectional areas using
the DEXA software (Fig. 1). The thigh segment proximal and distal
end points were the superior border of the greater trochanter and a
transverse plane running between the femoral condyles and the tibial
plateau, respectively. The shank segment proximal end point was the
same as the distal end point of the thigh, and the distal end point was
the lateral malleolus. Polygons defined the thigh and shank cross-
sectional area. After segment cross-sectional areas were defined, the
DEXA software calculated segment mass and composition. To deter-
mine thigh and shank radius of gyration, we used the regression

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Finally, dividing gross metabolic rate (W/kg total body mass) by anabolic rate from the walking gross metabolic rate yielded net metabolic plane values to represent the sagittal plane moments of inertia. Differences between frontal and sagittal plane segment parameters have been shown to be small (8), so we used the frontal gyration. Differences between frontal and sagittal plane segment moments of inertia could be explained by differences in the percentage of body fat, but the metabolic cost of walking was not related to distribution of body mass.

### Energetics

While standing, obese subjects consumed ~20% less metabolic energy per kilogram body mass than normal-weight subjects. However, when standing V\(\dot{O}_2\) was normalized to lean body mass, there were no differences among the groups. Moreover, obese and normal-weight subjects of each sex achieved similar absolute V\(\dot{O}_2\) max (l/min) values (Table 2). When normalized to mass, V\(\dot{O}_2\) max values were lower in the obese subjects. Specifically, the obese women had a 33% lower mass-specific V\(\dot{O}_2\) max compared with the normal-weight women, whereas the obese men had a 28% lower mass-specific V\(\dot{O}_2\) max compared with the normal-weight men.

The gross V\(\dot{O}_2\) vs. walking speed relationships was curvilinear for all groups. Differences between the groups were dependent on the normalization method used. Gross V\(\dot{O}_2\) (l/min) was greater for the obese vs. normal-weight groups (Fig. 2A). The difference in gross V\(\dot{O}_2\) between the obese and normal-weight groups increased with walking speed. Gross V\(\dot{O}_2\) was 53 and 70% greater for obese vs. normal-weight women at 0.5 and 1.75 m/s, respectively. For the men, the differences in gross V\(\dot{O}_2\) were 29 and 47% at those speeds. There were no differences between the groups when V\(\dot{O}_2\) was normalized to total body mass (ml·kg\(^{-1}\)·min\(^{-1}\)) (Fig. 2B). Normalizing
**Table 2. Standing and maximal metabolic rates for obese and normal-weight men and women**

<table>
<thead>
<tr>
<th>Metabolic Rate</th>
<th>Women (n = 9)</th>
<th>Normal (n = 10)</th>
<th>Men (n = 10)</th>
<th>Normal (n = 10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>V\textsubscript{O2} Stand, mL·kg\textsuperscript{-1}·min\textsuperscript{-1}</td>
<td>3.07 (0.36)*</td>
<td>3.84 (0.50)</td>
<td>3.44 (0.29)*</td>
<td>4.01 (0.49)</td>
</tr>
<tr>
<td>V\textsubscript{O2} Stand, mL·kg\textsubscript{lean}·min\textsuperscript{-1}</td>
<td>5.64 (0.55)</td>
<td>5.32 (0.54)</td>
<td>5.28 (0.44)</td>
<td>4.78 (0.48)</td>
</tr>
<tr>
<td>Standing metabolic rate, W/kg</td>
<td>1.06 (0.12)*</td>
<td>1.32 (0.17)</td>
<td>1.19 (0.11)*</td>
<td>1.40 (0.17)</td>
</tr>
<tr>
<td>V\textsubscript{O2} max, L/min</td>
<td>2.44 (0.40)</td>
<td>2.27 (0.47)</td>
<td>3.58 (0.63)†</td>
<td>3.64 (0.50)†</td>
</tr>
<tr>
<td>V\textsubscript{O2} max, mL·kg\textsuperscript{-1}·min\textsuperscript{-1}</td>
<td>25.9 (3.3)*</td>
<td>38.6 (4.4)</td>
<td>35.1 (7.5)†</td>
<td>48.6 (4.4)†</td>
</tr>
</tbody>
</table>

Values are means (±SD); n, no. of subjects. V\textsubscript{O2} Stand: standing oxygen consumption; kg\textsubscript{lean}, lean body mass; V\textsubscript{O2} max, maximal oxygen consumption. *P < 0.05, obese vs. normal weight of that sex. †P < 0.05, women vs. men of that group (obese or normal weight).

\(\text{V}_2\text{max}\) to lean body mass (L·kg\textsuperscript{-1}·min\textsuperscript{-1}) resulted in obese women having the greatest metabolic rate (Fig. 2C), due to their smaller relative lean tissue mass (greater percent body fat).

The net metabolic rate (i.e., the cost of the walking movement per kg body mass) was ~10% greater for the obese groups compared with their normal-weight counterparts averaged across all speeds (Fig. 3). ANOVA revealed that there were significant speed \(\times\) obesity (\(P = 0.006\)) and speed \(\times\) sex (\(P = 0.020\)) interactions, but there was no significant interaction between speed, sex and obesity (\(P = 0.158\)). In addition, there were significant between group (obese vs. normal weight) and sex main effects (\(P < 0.01\), but the interaction between group and sex was not significant (\(P = 0.928\)). ANCOVA revealed that neither height, mass, or percent body fat was responsible for the group or sex differences in the net metabolic rate vs. walking speed relationship. The net metabolic rates (W/kg) for walking were significantly greater for the obese vs. normal-weight women at 1.50 and 1.75 m/s and significantly greater for the obese vs. normal-weight men at 1.00, 1.25, 1.50, and 1.75 m/s. Stride lengths were not different between the groups at any walking speed.

**Body Mass Distribution and Net Metabolic Rate**

Thigh and shank mass and I\textsubscript{com} were dramatically different between the obese and normal-weight groups (Table 3). The obese groups had greater thigh mass, thigh I\textsubscript{com}, and shank mass than the normal-weight groups. The ratio of thigh mass to total body mass was greater in the obese women compared with the other groups, as was the composition of the thigh and shank (\% fat). Interestingly, the absolute thigh mass, thigh I\textsubscript{com}, shank mass, and shank I\textsubscript{com} did not differ between normal-weight women and men. Also, thigh and shank composition were similar between the obese men and normal-weight women.

Multiple linear regressions of the pooled subject data revealed that body mass distribution (i.e., thigh mass/body mass) did not explain the variance in net metabolic rate (\(r^2 = 0.04\), \(P = 0.54\) at 1.5 m/s, similar values at other speeds). In addition, normalized thigh I\textsubscript{com} did not explain the variance in net metabolic rate (\(r^2 = 0.004\), \(P = 0.69\) at 1.5 m/s, similar values at other speeds). However, overall body composition (\% body fat) did explain a significant portion of the variance in net metabolic rate, as shown in Fig. 4 (\(r^2 = 0.43\), \(P < 0.001\) at 1.5 m/s). At slower speeds, body composition explained less of the variance in net metabolic rate. For example, at 0.75 m/s body composition explained only 15% of the variance in net metabolic rate (\(r^2 = 0.15\), \(P = 0.01\)).

**Gross Energy Cost per Distance and Preferred Walking Speed**

Subjects in all groups consumed a similar amount of gross energy per distance traveled (J·kg\textsuperscript{-1}·m\textsuperscript{-1}) at all speeds. Although net metabolic cost was greater in the obese subjects, their lower standing metabolic rates led to similar gross costs (Fig. 5). All groups exhibited similar U-shaped relationships between cost per distance and walking speed. The calculated speeds (from second-order least squares regression) that corresponded to the minimum energy cost per distance were slightly slower for the obese women compared with the other groups (Table 4). Minimum energy cost per distance was 2.95, 2.89, 3.01 and 2.81 J·kg\textsuperscript{-1}·m\textsuperscript{-1} for obese women, obese men, normal-weight women, and normal-weight men, respectively.

Neither obesity nor sex affected the preferred walking speed (Table 4). The obese women walked slightly slower (1.41 m/s) than the normal-weight women (1.47 m/s), but the difference was not statistically significant (\(P = 0.28\)). By interpolating the energy cost per distance vs. walking speed relationship to their preferred walking speeds, we found that the gross energy cost per distance was 3.04, 2.92, 3.06, and 2.81 J·kg\textsuperscript{-1}·m\textsuperscript{-1} for obese women, obese men, normal-weight women, and normal-weight men, respectively. Thus the difference in the energy cost per distance at the preferred speed and at the minimum energy cost per distance speed was small, ~3% for the women and <1% for the men.

**DISCUSSION**

**Energetics**

We accept our hypothesis that the net metabolic rate of walking would be greatest for obese women and least for normal-weight men. The ~10% greater mass-specific net metabolic rate of obese vs. normal-weight adults reported here is similar to values reported by Mattsson et al. (31) and Melanson et al. (32), but it is lower than values reported by others. Bloom and Marshall (3) reported that the net metabolic rate of walking at speeds ranging from 0.7 to 1.4 m/s was ~45% greater in obese men and women compared with normal-weight adults, but their data are difficult to interpret because mean data for all subjects are not presented. The study of Foster et al. (16) reported net metabolic rates of slight uphill walking for adults with class II obesity (BMI = 39 kg/m\textsuperscript{2}) that were ~45% greater than the net metabolic rate of normal-weight subjects during level walking. Walking on a slight incline increases net metabolic rate by ~15% (33), so the difference in net metabolic rate between the Foster et al. study and ours is 20%. It
may be that walking up a slight incline increases the metabolic rate disproportionately for obese subjects.

It is intriguing to compare the effects of obesity and external loading on the net metabolic rate of walking. Griffin et al. (22) found that when normal-weight individuals walked with an external load of 30% of body mass carried around the waist, net metabolic rate increased by 47%, whereas lower extremity kinematics were unchanged. Hence, net metabolic rate increased by ~15% when normalized by total mass (body + load). When we account for differences in lean body mass, our obese subjects were carrying ~30% of their “normal” mass (assuming same percent body fat as normal-weight subjects) as extra adipose tissue and net metabolic rate increased by 10%. Thus our net metabolic rate data suggest that external loading and adipose tissue have similar effects on the energetic cost of walking.

However, the situation may not be so simple. Stride lengths were similar between all of the groups, but other biomechanical variables may affect metabolic cost. Although we did not measure step width and leg swing circumduction in our subjects, Spyropoulos et al. (40) report that obese persons walk with a step width that is twice that of normal-weight persons and a midswing hip abduction angle of 19° vs. 9° in obese vs. normal-weight individuals, respectively. In normal-weight adults, doubling step width increases the metabolic cost of walking by 25% (10), and increasing leg swing circumduction increases the metabolic cost of walking by up to 30% (39). These increases are much larger than the 10% differences observed in this study and suggest that obese individuals may be able to walk in a way that minimizes the metabolic penalty associated with their step width and leg swing circumduction.

Supporting body weight and performing work on the center of mass are two important determinants of the net metabolic cost of walking (20). Obese individuals may reduce the cost of supporting body weight by walking with a straighter leg and more erect posture (9). This adaptation would reduce the muscles forces required to support the body (2). Obese individuals may reduce the work performed on the center of mass by a more effective use of the body as an inverted pendulum. An improved “recovery” of mechanical energy has been implicated in mitigating some of the increase in metabolic rate associated with carrying loads (23). In addition, obese individuals may somehow use wider steps to their advantage by utilizing lateral motion to improve the recovery of mechanical energy, a phenomenon that has been observed in penguins (21).
Contrary to our hypothesis, the greater net metabolic cost of walking for obese women was not due to body mass distribution. The use of DEXA allowed the determination of a thigh mass-to-body mass ratio and the Icom of the thigh. The obese women had a 62% greater body mass and their thigh mass was 70% greater than the normal-weight women. The obese men had a 40% greater body mass, and their thigh mass was 41% greater than the normal-weight men. As a result, the thigh mass-to-body mass ratio was slightly greater for the obese women (14%) vs. the other groups (13%), indicating that they have relatively heavier legs. In addition, the Icom of the thigh was greater in the obese women. The greater mechanical work required to swing the relatively heavier legs of obese women may increase the metabolic cost of walking (38), especially at faster walking speeds. However, recent evidence suggests that in normal-weight adults leg swing only accounts for 10% of the total metabolic cost of walking (19). On the basis of this finding, to account for the 10% increase in net metabolic rate in obese vs. normal-weight women, the cost of leg swing would have to increase by 100%. Therefore, the relatively small difference in the thigh mass-to-body mass ratio between obese women and obese men does not seem to be sufficient to elicit a measurable influence on net metabolic rate.

Our segment mass and Icom data highlights the importance of individual subject anthropometric data. We compared our shank segment masses obtained via the DEXA software with values obtained using the regression equations developed by Durkin and Dowling (12). Differences between measured and calculated shank mass were relatively large (root-mean-square error of 19.9, 9.5, 11.7, and 8.4% for the obese women, obese men, normal-weight women, and normal-weight men, respectively), despite similar segmentation. One possible explanation for this difference is that although Durkin and Dowling’s study included obese individuals, their regressions were based on groups with a wide range of individual adiposity. The development of regression equations to calculate anthropometric parameters for obese individuals is clearly needed, especially for biomechanical studies.

We found that the percent of body fat explains ~45% of the variance in the net metabolic rate of walking. Obese men and normal-weight women had similar body composition and also had similar net metabolic rates. The thigh and shank fat percents were even more similar between the obese men and normal-weight women, but these measures were strongly correlated to body fat percent, and including them in the multiple regressions did not improve the correlation between body fat

<table>
<thead>
<tr>
<th>Segment Characteristic</th>
<th>Women</th>
<th>Men</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Obese (n = 9)</td>
<td>Normal (n = 10)</td>
</tr>
<tr>
<td>Thigh mass, kg</td>
<td>13.5 (2.7)*</td>
<td>7.9 (1.7)</td>
</tr>
<tr>
<td>Mv/Mb ratio</td>
<td>0.142 (0.009)</td>
<td>0.134 (0.01)</td>
</tr>
<tr>
<td>Thigh fat, %</td>
<td>55.4 (2.8)*</td>
<td>43.3 (5.4)</td>
</tr>
<tr>
<td>Icom thigh, kg-m²</td>
<td>0.242 (0.081)*</td>
<td>0.145 (0.040)</td>
</tr>
<tr>
<td>Shank mass, kg</td>
<td>3.9 (0.82)*</td>
<td>2.6 (0.37)</td>
</tr>
<tr>
<td>Shank fat, %</td>
<td>44.5 (3.4)*</td>
<td>32.6 (6.3)</td>
</tr>
<tr>
<td>Icom shank, kg-m²</td>
<td>0.040 (0.014)</td>
<td>0.028 (0.007)</td>
</tr>
</tbody>
</table>

Values are means (±SD); n, no. of subjects. Mv/Mb ratio, ratio of thigh mass to body mass; Icom, frontal plane moment of inertia. *P < .05, obese vs. normal weight of that sex. †P < .05, women vs. men of that group (obese or normal weight).
and mean net metabolic rate. The fact that body fat is related to
the net metabolic cost of walking is not surprising given how
increasing body fat reduces standing metabolic rate (36) but
does not change the gross metabolic cost of walking.

**Preferred Walking Speed and Gross Energy Cost per Distance**

As we hypothesized, preferred walking speeds were not
different between the groups and were near the speed that
minimized gross energy cost per distance. Our measured pre-
ferred speeds were faster than previous reports for obese
adults. Mattsson et al. (31) and Melanson et al. (32) measured
preferred speeds of 1.18 and 1.19 m/s, respectively, for class II
obese adults. Although the differences in preferred speed
appear large (1.4 vs. 1.2 m/s), they are in the region where the
energy cost per distance vs. walking speed relationship is
relatively flat (i.e., the bottom of the U-shaped curve) and may
not reflect different strategies for selecting preferred walking
speed. Preferred speed has been shown to be slower in older
adults (>65 yr old) (29), but the subjects in the studies of
Mattsson et al. (31) and Melanson et al. (32) were younger
(mean age ~45 yr old). Thus differences in age are not likely
to account for the differences observed in preferred speed.

**Relevance for Exercise Prescription**

Our results also show that equations that predict mass-
specific VO\(_2\) (ml·kg\(^{-1}\)·min\(^{-1}\)) during walking based on tread-
mill speed provide reasonable estimates for obese adults. For
example, the mean mass-specific gross VO\(_2\) of obese groups in
our study during level walking at 1.5 m/s was ~13.5
ml·kg\(^{-1}\)·min\(^{-1}\), similar to predicted values of 12.5 and 14.5
ml·kg\(^{-1}\)·min\(^{-1}\) using the equations provided by Franklin et al.
(17) and Pandolf et al. (33), respectively. However, these
relatively small differences between the measured and pre-
dicted values of energy expenditure may be important given
that a small positive energy balance (<100 kcal/day) has been
associated with the development of obesity (25).

Although our emphasis has been on the similarity of the
metabolic energy expended per kilogram of body mass, the
total metabolic cost may be more important for exercise pre-
scription. For example, if an obese person (150 kg) and a
normal-weight person (75 kg) seek to counteract an excess
intake of 400 kJ (100 kcal) of energy, the obese person only
needs to walk half as far. Or, perhaps more optimistically, the

![Fig. 6. Relative aerobic effort (% maximal VO\(_2\) (%Vo2max)) for obese and normal-weight women and men. The relative aerobic effort was significantly greater for the obese vs. normal weight at all speeds (P < 0.001) and was greater for women compared with men (P < 0.001). Solid vertical line indicates preferred walking speed (1.42 m/s). Values are means ± SE.](http://jap.physiology.org/)

![Fig. 7. Net metabolic rate vs. walking speed (A) and energy cost/distance vs. walking speed (B) for class III obese compared with obese women and normal-weight men. For clarity, metabolic rate and energy cost/distance for obese men and normal-weight men are not shown. Net metabolic rate for class III obese subjects was similar to obese men and normal-weight men. Speed that corresponded to the minimum energy cost/distance was slower in the class III obese (1.21 m/s), as was preferred speed (1.32 m/s). Minimum energy cost/distance was 2.82 J·kg\(^{-1}\)·m\(^{-1}\) for the class III obese subjects, which was similar to normal-weight men (2.81 J·kg\(^{-1}\)·m\(^{-1}\)).](http://jap.physiology.org/)
obese person would expend slightly more than twice as many total kilocalories by walking the same distance.

The relative aerobic effort required to walk at the preferred speed was greater in the obese than normal-weight groups (Fig. 6). Walking at the preferred speed required 50, 40, 36, and 25% of mass-specific VO\(_2\)max for the obese women, obese men, normal-weight women, and normal-weight men, respectively. At preferred walking speed, the obese adults were at a moderate-intensity effort (40–55% VO\(_2\)max/kg). Although walking faster than their preferred speed will provide an increase in energy expenditure, it may also increase the risk of musculoskeletal injury. Obese adults have a much greater risk of developing knee osteoarthritis (14) than normal-weight adults. In normal-weight subjects, faster walking speeds result in increased biomechanical loads on the lower extremities (28), which may increase the risk of chronic injuries and osteoarthritis. A strategy of walking slower for a defined distance may effectively maintain or even increase energy expenditure (J·kg\(^{-1}·m^{-1}\)), while reducing the risk of lower extremity injury.

Class III Obesity Data

The degree of obesity may affect the net metabolic rate of walking. The data of Freyschuss and Melchener (18) suggest that net metabolic rate was ~60% greater in class III (BMI = ~49 kg/m\(^2\)) obese men and women compared with normal-weight controls walking at 1.0 m/s across a range of inclines. To begin to address the question of the effects of increasing adiposity on net metabolic rate, we have collected metabolic data on five class III obese subjects (3 men, 2 women, mass = 153 kg, BMI = 47.1 kg/m\(^2\)) while they walked on the level at 0.50–1.5 m/s. Surprisingly, the net metabolic rate (W/kg) vs. speed relationship was similar compared with the class II obese subjects (Fig. 7A). The similarity in net metabolic rate of class II and class III obese subjects is likely due to the fact that as BMI increases above the class II obesity standard, the slope of the percent body fat vs. BMI relationship decreases (15). As a result, our class III obese subjects may have had body fat percents that were similar to our class II subjects, although we could not determine body composition due to weight limitations of the DEXA device. This idea is supported by our finding that standing metabolic rates (1.14 W/kg) of the class III obese subjects were also similar to the class II obese subjects, despite having a 50% greater body mass. Class III obese have been shown to walk with a shorter stride length (9). The shorter stride length may reduce the metabolic cost of walking by reducing the mechanical work associated with redirecting the center of mass during the double-support phase (11).

The preferred speed of our class III obese subjects was 1.32 m/s and was near the speed that minimized the gross energy cost per distance (1.24 m/s) (Fig. 7B). The energy cost per distance curve for the class III obese was shifted slightly, toward slower speeds. This shift is a result of the steeper slope of the metabolic rate vs. speed relationship. These data suggest that increasing levels of adiposity do not alter the strategy of selecting preferred speed based on minimizing energy cost per distance. Other factors may cause preferred speed to slow (e.g., joint pain), but our subjects were young and asymptomatic for pain during walking.

In conclusion, we found that the mass-specific net metabolic rate of walking was greater in obese adults and that sex also affects the metabolic cost of walking. Obese women had a 10% greater net metabolic rate than obese men and normal-weight women and a 20% greater net metabolic rate compared with normal-weight men. Body mass distribution did not explain the differences in net metabolic rate between the groups. Preferred walking speeds were similar for all the groups and were near the speed that minimized the energy cost per distance. Future studies on the effects of obesity on the biomechanics of walking are needed to investigate whether obese individuals adopt novel energy-saving mechanisms during walking.

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