Measuring Energy Expenditure in Habitually Active and Sedentary Pregnant Women

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ABSTRACT

STEIN, A. D., J. M. RIVERA, and J. M. PIVARNIK. Measuring Energy Expenditure in Habitually Active and Sedentary Pregnant Women. Med. Sci. Sports Exerc., Vol. 35, No. 8, pp. 1441-1446, 2003. Purpose: To describe patterns of energy expenditure (EE) during pregnancy and to assess the convergent validity of three methods of estimating EE. Methods: We administered heart rate (HR) telemetry, accelerometry, and a physical activity record (PAR) over two consecutive days at weeks 20 and 32 of pregnancy and 12 wk postpartum to 28 habitually active and 28 habitually sedentary women. Results: Mean daily waking-time EE at 20 wk by HR telemetry was 1514 (SD 443) kcal in active women and 1738 (448) kcal in sedentary women (P > 0.50), and did not change over the period of study (for active women P = 0.46; for sedentary women P > 0.70). Compared with HR telemetry, accelerometry underestimated EE by ~400 kcal·d⁻¹, and the PAR overestimated EE by a similar amount, at all time periods in both active and sedentary women. EE, expressed per unit body weight, was consistently higher for active than for sedentary women during pregnancy. Pairwise correlations between methods ranged from 0.37 to 0.90 across time periods in both active and sedentary women. Correlations were lower (range 0.07–0.81) when adjusted for the length of the recording day. Conclusions: All methods were sensitive to variation in both the rate of EE and the duration over which activity was monitored. Accelerometry and PAR are useful methods for categorizing EE in epidemiologic studies among pregnant women but absolute estimates are biased relative to HR. Key Words: ACCELEROMETRY, CONVERGENT VALIDITY, HEART RATE TELEMETRY, PHYSICAL ACTIVITY RECORD, PREGNANCY

The role of physical activity in affecting pregnancy outcome has been studied, with conflicting results (5,18,25). Some, but not all, studies have shown job-related physical activity to be related to unfavorable birth outcomes, including premature delivery and low birth weight (2,13,15,17,19,23,27,30). However, in these studies, actual physical activity was not well quantified throughout gestation and was usually inferred from job titles. Also, other unknown stressors related to the job may have either confounded or modified the physiologic effects of physical activity. Results of the relationship between leisure-time physical activity and pregnancy outcome also appear to be mixed (6,7,10,11,14,27,28). One potential reason for the discrepant results is the lack of consistency in the method of assessing physical activity.

Heart rate (HR) monitors, motion sensors (such as the Caltrac®), and physical activity recall or record (PAR) instruments are reliable and valid ways to measure physical activity in nonpregnant individuals (4,8,9,12,16,20–22,29). However, these methods have not been validated among pregnant women. Additionally, a woman’s physiological status and perceptions both change throughout gestation (3). This may influence her ability to report physical activity, and more specifically the intensity of the activity, accurately. In one study (24), women’s HR during exercise were significantly higher than predicted from the Borg rating of perceived exertion scale (3). The extent of the discrepancy between expected and actual HR differed between the second and third trimesters. Thus, any method of measuring energy expenditure (EE) needs to be validated across trimesters of pregnancy. We therefore conducted a study of estimates of EE derived from three commonly used methods (HR telemetry, a motion sensor, and a PAR), obtained on two consecutive days at 20 and 32 wk of gestation and 12 wk postpartum, in healthy habitually active or sedentary women.

MATERIALS AND METHODS

Study Design

Study participants were recruited from obstetrical care clinics located in the mid-Michigan area. Local health care providers were informed of the study aims to ensure that their patients had no contraindications to participation. To maximize variance in likely EE, we recruited two groups of women: those who exercised regularly and planned to continue during pregnancy, and those whose lifestyles were primarily sedentary. We identified these two groups based on self-report questionnaires and physical activity monitors.
on responses to a screening interview administered by telephone. Women who were involved in regular exercise (average at least 3 d wk⁻¹, 30 min d⁻¹) for the previous 6 months; or whose primary occupation was rated at greater than or equal to a 4-MET level based on the Compendium of Physical Activities (1) and included a significant amount of walking, lifting, stair climbing, etc., were considered to be habitual exercisers. Women who had not exercised regularly for the past 6 months and whose primary occupation was rated at less than a 4-MET level and did not include significant amounts of walking, lifting, stair climbing, etc., were eligible for the sedentary group. Moderate exercisers were not studied.

Recruitment

Women were recruited into the study at ~15 wk of pregnancy. At this time, each woman and her physician provided written informed consent. All procedures were explained to the subject by the investigative team, and any questions (both hers and her physician's) were answered. Both the woman and her health care provider were informed that we planned to collect information on birth weight and Apgar scores at the time of delivery. The informed consent process and all study protocols were approved by the Michigan State University Committee for Research Involving Human Subjects.

Procedures

All women were studied at three time points: twice during pregnancy (~20 and ~32 wk) and once ~12 wk postpartum. We made no attempt to sample days at random or to ensure that the women were studied on the same days at each time point. Appointments were made with the women seven days per week, at the woman’s convenience. At each time point each woman underwent a similar protocol involving visits to the Human Energy Research Laboratory at Michigan State University on three consecutive days. The women were asked to try not to eat or eat only a light meal at least 2 h before coming to the laboratory on the first day; the time and type of any meal eaten was documented.

On the first day of each time point, anthropometric measures were obtained. Height (without shoes) was measured to the nearest 0.1 cm using a stadiometer that had been calibrated with a steel tape measure of known length. Body weight was measured to the nearest 0.1 kg on a beam balance that had been calibrated with known weights certified by the Bureau of Standards. Women were weighed in a bathrobe of known weight so an accurate nude weight could be obtained. Also on the first day of each time point a woman- and pregnancy-stage-specific HR/VO₂ regression line was developed, using an approach described more fully elsewhere (26). After the exercise bout, the study coordinator instructed each subject in how to use the three instruments (described below).

Instruments

Heart rate monitor. We used the Polar Vantage XL (Polar CIC Inc., Fort Washington, NY). Women were instructed to remove the HR monitor only when sleeping or bathing.

Motion sensor. The Caltrac (Hemokinetics, Madison, WI) is a single-plane motion sensor that provides a digital readout of EE. It uses a piezoelectric transducer to measure an individual’s movement and acceleration. A Caltrac motion sensor was worn on the left hip, clipped to the waistband. Height, weight, age, and gender were programmed at each study point. The separate bike and weightlifting modes were discussed with each subject, who was instructed to use these when appropriate. Because it is not water resistant, women were instructed to remove the Caltrac if they planned to swim or bathe. Women were asked to record the cumulative EE each hour and were reminded to do so by setting the HR monitor timer to sound every hour.

Physical activity record. Women were asked to record their activity on an hourly basis during all waking hours. Specifically, they were asked to write down the amount of activity spent during the previous hour in light, moderate, hard, or very hard activity when the HR monitor timer sounded or as soon as possible afterward. Moderate activity was defined as any activity intensity equivalent the exertion felt during a brisk walk. Hard activity was defined as activity intensity that felt as if it was between walking briskly and running. Very hard activity was defined as any activity intensity that felt equivalent to the level of exertion the women felt when running. All other minutes of recorded activity were considered light, and all remaining waking minutes were considered sedentary. No examples of types of activities were provided for the subject to ensure that the subjects determined the categories based on their perceived exertion.

Each woman practiced operating the HR monitor and Caltrac until they became comfortable operating the instruments. Each woman was also provided written reminder instructions. All times and reasons for removal were to be documented. Women were also asked not to deviate from their normal activities of daily living.

Follow-up

The women returned to the laboratory approximately 24 h after their first visit. Data from the HR monitor were downloaded into the computer. Caltrac values were recorded and the instruments were reset. Activity recorded on the PAR was reviewed by the study coordinator and ambiguities resolved. The second day of data collection by HR telemetry, Caltrac and PAR followed a protocol identical to the previous day. A different HR monitor was provided for PA measurement during the second day. The women returned to the lab approximately 24 h later to turn in the equipment, when data from all three instruments were reviewed again.
Data Reduction

Heart rate monitoring. HR monitors are susceptible to external interference, resulting in spiking of readings or invariant readings for various periods of time as well as unreasonably low values. We excluded from analysis any values less than 20 beats·min⁻¹ below the woman's resting HR or in excess of 180 beats·min⁻¹ not associated with documented exercise. These minutes were coded as the average of the values immediately before and after the excluded readings. We also excluded any period of recording in which 80% of all minutes average values were in one or more repeat sequences (defined as a series of three or more min of constant value). If the 2-d record for a woman included >30% repeated values the whole record was excluded from analysis. The 20-wk record for one woman and the postpartum record for a second woman (both exercisers) were excluded based on this criterion.

The main drawback to using HR as an index of exercise intensity is that it can be unreliable during very brief bursts of activity or at low exercise intensities. Investigators have addressed these potential problems by recording average HR on a minute-by-minute basis and by determining a “flex” HR for each individual. The “flex” HR is chosen as a point just above typical resting values but just below values seen during low-intensity, steady-state exercise (21). Accuracy of HR telemetry can be further improved by developing individual HR/VO₂ regression equations for each participant, rather than assuming the same line for all (21). This may be particularly important during pregnancy where resting HR and VO₂ both increase with advancing gestation and the relationship between HR and caloric expenditure during physical activity may change (24). We therefore calculated each woman’s flex HR at each period by averaging the steady-state HR values during standing rest and at the lowest exercise intensity (2 mph, 0% grade) and used the slope and y-intercept values from the individual HR/VO₂ regression lines to determine a VO₂ value for most recorded HR (26). Because the HR/VO₂ relationship is not as accurate for low-intensity activities, the average resting VO₂ value, defined as the average VO₂ value from the last 5 min of each period during the resting measurement, was used for all HR below the flex HR. Then, each VO₂ value was converted to kcal using a conversion of 4.86 kcal·L⁻¹ of O₂.

Motion sensor. Output from the Caltrac is provided directly in kilocalories. As the Caltrac is not waterproof, we estimated EE from swimming as light (4 METs; 1 habitually active woman who was playing with her child, no swimming), moderate (6 METs: 1 active, 1 sedentary), or hard swimming (8 METs: 2 active, 1 sedentary). Extra caloric expenditure attributable to swimming was calculated as kcal = S(min×MET×kg×IMET×0.00485), where min = minutes spent at activity level i; MET = assigned MET value for activity level i; kg = woman’s body weight in kilogramme; and IMET = woman’s individual MET value, expressed as mL O₂·kg⁻¹ body weight per minute at rest.

### Table 1

<table>
<thead>
<tr>
<th></th>
<th>Active</th>
<th>Sedentary</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age at 20 wk gestation (yr)</td>
<td>30.6 (4.70)</td>
<td>27.9 (5.35)</td>
<td>0.052</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>165.4 (7.40)</td>
<td>164.3 (7.37)</td>
<td>0.34</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>66.7 (10.12)</td>
<td>72.0 (9.67)</td>
<td>0.050</td>
</tr>
<tr>
<td>23 wk</td>
<td>71.8 (12.0)</td>
<td>78.7 (9.80)</td>
<td>0.031</td>
</tr>
<tr>
<td>32 wk</td>
<td>65.2 (10.0)</td>
<td>70.5 (10.94)</td>
<td>0.073</td>
</tr>
<tr>
<td>12 wk postpartum</td>
<td>804 (90)</td>
<td>759 (130)</td>
<td>0.14</td>
</tr>
<tr>
<td>Duration of monitoring by HR monitor (min)</td>
<td>781 (100)</td>
<td>768 (107)</td>
<td>0.48</td>
</tr>
<tr>
<td>12 wk postpartum</td>
<td>773 (117)</td>
<td>765 (106)</td>
<td>0.75</td>
</tr>
</tbody>
</table>

Physical activity record. Light activity was defined as 2 METs, moderate activity was defined as 4 METs, hard activity was defined as 6 METs, and very hard activity was defined as the MET value assigned for the given activity in the Compendium of Physical Activities (1). Time and intensity values were converted to METs, then to kilocalories, using the conversion equation described previously for swimming.

### Statistical Analysis

We computed the mean of the 2 days’ records. All analyses were conducted separately for habitually active and sedentary women. We considered the HR monitor to be the reference method, as this method is the least susceptible to user error, and relies on individual HR/VO₂ prediction equations developed in our laboratory. Differences in group mean estimates of waking-time EE were assessed using the paired-sample t-test for pairwise comparisons. To estimate individual-level rank-order consistency, we computed Pearson correlation coefficients between pairs of the three methods at each stage of pregnancy within the active and sedentary groups separately. As the periods of observation were sometimes inconsistent (and in the case of HR, some of the data had to be excluded for technical reasons), we repeated the analysis after expressing the data as EE per standardized 14-h d. To assess whether changes in weight might be associated with variation in convergence of estimates across methods, we computed a measure of weight-adjusted energy by dividing daily EE by weight (kg) at the time of the laboratory visit. Analyses were implemented in SPSS version 10 (SPSS Inc., Chicago, IL).

### RESULTS

Fifty-six women completed at least the 20-wk examination. Selected characteristics of the 56 study participants are provided in Table 1. Eighty percent of the women were white; the remainder were Native American (1), African American (2), Hispanic (5), or other (3). Of the 56 women, 28 were habitually active and 28 were habitually sedentary. All the active women were employed; five were designated as active because of a combination of their occupation and their reported activity levels. Eighteen sedentary women were employed, all in low-energy intensity occupations.

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TABLE 2. Energy expenditure (mean of waking periods over two consecutive days) assessed by three methods among 28 habitually active and 28 habitually sedentary pregnant women, Michigan 1987–88.

<table>
<thead>
<tr>
<th></th>
<th>Unadjusted (kcal)</th>
<th>Standardized to 14-hr period (kcal)</th>
<th>Adjusted for body weight (kcal·kg⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Heart Rate</td>
<td>Caltrac Motion Sensor</td>
<td>Physical Activity Record</td>
</tr>
<tr>
<td></td>
<td>Monitor</td>
<td>Sensor</td>
<td>Record</td>
</tr>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>Active women</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 wk (N = 28)</td>
<td>1814 (443)</td>
<td>1436 (239)</td>
<td>225 (413)</td>
</tr>
<tr>
<td>32 wk (N = 27)</td>
<td>1568 (385)</td>
<td>1389 (267)</td>
<td>2420 (393)</td>
</tr>
<tr>
<td>12 wk postpartum (N = 27)</td>
<td>1804 (735)</td>
<td>1365 (358)</td>
<td>2016 (410)**</td>
</tr>
<tr>
<td>P for change over time within method</td>
<td>0.47 (0.2)</td>
<td>0.67 (0.2)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Sedentary women</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 wk (N = 28)</td>
<td>1738 (448)</td>
<td>1292 (295)</td>
<td>2065 (384)</td>
</tr>
<tr>
<td>32 wk (N = 25)</td>
<td>1681 (380)</td>
<td>1361 (236)</td>
<td>2430 (469)</td>
</tr>
<tr>
<td>12 wk postpartum (N = 27)</td>
<td>1759 (450)</td>
<td>1297 (301)</td>
<td>1914 (337)*</td>
</tr>
<tr>
<td>P for change over time within method</td>
<td>0.72 (0.4)</td>
<td>0.44 (0.1)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Within each time period and method of adjustment, all CT and PAR values differ from the HR estimate at P < 0.01 except where noted.
** 0.001 < P < 0.05; * 0.05 < P < 0.10 by paired t-test.

Within the unadjusted method, week 32 of pregnancy differs from both week 20 and week 12 postpartum at P < 0.05 when estimated by PAR among both active and sedentary women.

Within the 14-hr day method, all three periods differ from each other (P < 0.05) when estimated by PAR for both active and sedentary women. Among sedentary women, the PAR estimate at week 32 differs at P < 0.05 from the 12-week postpartum estimate. Pairwise comparisons only performed where the overall analysis of variance had P < 0.05.

Within the weight-adjusted method, all comparisons between active and sedentary women were statistically significant at P < 0.05 across the three methods and the three time points, except for HR at week 20 (P > 0.07), HR at week 12 postpartum (P > 0.25), and Caltrac at week 12 postpartum (P < 0.06), by unpaired t-test.

Complete data from all three time periods were available from 25 active and 24 sedentary women. One woman in the active group delivered before 32 wk, and two women in the sedentary group were on bed rest for premature contractions at the time of the 32-wk visit. All three women completed the postpartum visit. Two additional women in the active group did not respond to repeated requests for postpartum appointments. The active women did not differ from the sedentary women on height but were lighter at all three periods and tended to be older (Table 1).

Although there was considerable variation across women in the data monitoring period, from a low of 397 min to a high of 1055 min within any 24-h period, the mean period of monitoring (approximately 780 min, or 13 hr⁻¹) did not differ markedly by time period, assessment method, or between active and sedentary women (all pairwise tests P > 0.05). Mean daily waking-time EE as estimated by the three methods at each time period are provided in Table 2. Although unadjusted EE did not differ between active and sedentary women, once the lower weight of the active women was accounted for, their EE per unit body weight was consistently greater than that of sedentary women (P < 0.05 for six of nine tests, P < 0.10 for two tests, and P > 0.1 for one test).

When estimated by either HR or Caltrac, unadjusted EE did not vary across periods of pregnancy regardless of the method of adjustment of EE (P > 0.20 for each test). When estimated by PAR, EE was highest at 32 wk and lowest at 12 wk postpartum (overall analysis of variance P < 0.05 for time period within each method and each group of women; pairwise differences all P < 0.05). After adjustment for body weight, these differences were attenuated, although 12-wk postpartum EE still tended to be lower. Among the sedentary women, the 12-wk postpartum estimate was lower (P < 0.05) than the 32-wk estimate.

Estimated EE in both active and sedentary women was lowest from the Caltrac and highest for the PAR. Across time periods and activity groups, estimates from Caltrac were 378–578 kcal·d⁻¹ lower than HR (all P < 0.001), whereas estimates from PAR were 155–600 higher than from HR (all P < 0.001 except for the difference between HR and PAR at 12-wk postpartum among active (P < 0.05) and sedentary (P < 0.10) women). This pattern was consistent across method of adjustment of EE.

At the individual level, unadjusted EE estimates were at least moderately correlated (range 0.37–0.90) across the three periods and two activity groups (Table 3). The lowest observed pairwise correlation for unadjusted EE was 0.37 (PAR and HR monitor among sedentary women at the 32-wk visit). Other than this instance, all correlations were statistically significant at P < 0.05. In general, correlations between the Caltrac and the PAR were higher than the other pairwise correlations. All three pairwise correlations were highest among active women at the postpartum visit. When we repeated the analysis with all estimates of expenditure expressed in terms of expenditure over a 14-h day, the correlations among individual values were reduced considerably, although the overall pattern was maintained. Adjustment for body weight resulted in correlation coefficients that were equal to or stronger than the unadjusted coefficients.

**DISCUSSION**

We tested two common approaches to estimation of EE, a Caltrac motion sensor and a PAR, against the more complex (and presumably more valid) reference method of HR monitoring using woman- and period-specific HR/VO₂ calibration equations, in pregnant and postpartum women, purposefully sampled to include habitually active and sedentary individuals. Our data suggest that absolute EE as estimated...
by the three methods are not highly convergent in this sample of women. Compared with the HR monitor, the PAR overestimated, and the Caltrac underestimated, EE. Although the methods were at least moderately correlated, much of this covariance was attributable to variation in the period of observation—when day length was standardized, the correlations were reduced. Our data appear to be coherent, insofar as weight-adjusted estimates of EE were higher for active compared with sedentary women at all time periods and across all methods. Active women were lighter than sedentary women, so that unadjusted estimates of EE did not differ between the two groups.

Although probably typical of healthy pregnant and postpartum women, our sample should not be considered fully representative of pregnant women. We purposively sampled to recruit women who were either habitual exercisers or who were sedentary before pregnancy and intended to continue this lifestyle, excluding moderate or intermittent exercisers. Furthermore, the demands placed upon the women resulted in a motivated sample who presumably differ from other women in ways that we are unable to estimate. Our sample was overwhelmingly Caucasian, and the small sample size precludes us from testing for differences among the various ethnic groups, or among women of different age, with respect to the extent of bias in estimating EE. Larger studies in more diverse populations would be required to address these issues.

Part of the reason that the estimates of EE differ across methods may result from the inherent limitations of the methods. The Caltrac measures only linear motion, and not all physical activity is captured in this plane. Newer versions of motion sensors, which measure movement in three dimensions, may not suffer from this problem. However, the one-dimensional Caltrac is still the most widely used. Furthermore, the instrument may be sensitive to the specific placement on the waist, and this sensitivity may increase during pregnancy as body proportions alter.

The PAR, on the other hand, may overestimate expenditure as it uses self-determination of effort and standard estimates of MET equivalents for reported activities. Especially at the lower end of the activity intensity spectrum, EE may be overestimated, and the extent of this overestimation likely varies as pregnancy progresses. We used the recommended 2.0 METs as an estimate of energy output for "light-intensity" activity. Use of lower estimates (e.g., 1.5 METs) would make the PAR data more comparable to data obtained by HR telemetry, but choice of the specific values to be assigned is inherently arbitrary unless participant-specific estimates are used, which negates the whole advantage of PAR methods. Additionally, our methodology, which required the women to record each hour what they had done the previous hour, may have resulted in higher reports of activity than retrospective recall approaches in which women are queried about their experiences one or more days before the interview. We observed a trend toward lower EE in the postpartum period across methods—we assume that this reflects lower levels of sustained physical activity due to the increased time demands of caring for the newborn.

Nevertheless, our data suggest that EE in pregnancy can be estimated with reasonable precision for epidemiologic studies. In such studies, absolute quantification of EE may be less critical than the ability to rank-order the population. In our study, the three methods had fairly high Pearson correlations, suggesting that rank-order might be assigned without substantial misclassification even using a method with a relatively low respondent burden, such as a PAR. If absolute expenditures are of interest, we recommend that a calibration study be conducted. Such a study, in which the study method is compared to a reference method (such as direct observation) in a subset of the study population, provides a population-specific estimate of the bias resulting from use of the less intensive method.

We conclude that EE in pregnancy can be measured, but that approaches more suitable to large-scale epidemiological studies are biased relative to a direct measure of HR. We stress that estimates of EE that derive from different methods of assessment cannot be directly compared.

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REFERENCES


